

ENERGY EFFICIENCY IN WASTEWATER TREATMENT -FINAL REPORT-



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1 Introduction

1.1 Background

Turkey aims to join the European Union in a foreseeable future. To this aim, the country has to adopt and implement the European Union's legislature, including the environmental legislation. To comply with the requirements of the EU UWWT Directive, Turkey will have to realize an important number of wastewater treatment facilities, small and large, all over the country.

According to the highest cost scenario on the harmonization of Urban Wastewater Treatment Directive that considers all waters of the country as sensitive, advanced wastewater treatment is deemed necessary in all agglomerations with more than 10000 p.e. Moreover, installation of appropriate treatment facilities for agglomerations between 2000 - 10000 p.e will be required.

The investment needs in the wastewater sector in Turkey are considerable. As shown in Chapter 2.2.1, the greater portion of the requirements are clustered around agglomerations with less than 50.000 p.e. In view of the required number of WWTPs to be realised in the coming decades of more than 3,000 facilities of different sizes, the development of a guideline for energy efficiency will certainly contribute to realising important energy savings in this sector.

The challenge for Turkey is to establish wastewater treatment plants which are as energy efficient as possible. Turkey has no important indigenous energy resources (except for hydropower and some coal) and thus depends heavily on imports of fuels (Energy Efficiency Strategy for Turkey, MVV Consultants on behalf of The General Directorate of Electrical Power Survey and Development Administration (EIE)). Energy conservation in all sectors will contribute to reducing the dependence on foreign fuel supply. In addition, energy efficient installations will reduce the operating costs of facilities, especially when energy conservation measures are implemented at the design stage. As Turkey will still design quite a number of small, medium sized and large wastewater treatment installations, energy efficiency can be taken into account at least costs. The main problems and challenges can be summarised as follows:

- Create awareness among decision makers on the benefits and opportunities of energy efficiency in waste water treatment;
- Ensure effective operation of wastewater treatment plants taking energy efficiency into account (training of operators);
- Establish sufficient knowledge in Turkey among design and engineering companies in the field of wastewater treatment to allow inclusion of energy efficiency opportunities in future projects.

1.2 This Guideline on Energy Efficiency in Wastewater Treatment

This guideline on Energy Efficiency in Wastewater treatment for Turkey aims at providing background information on how energy efficiency in wastewater treatment plants can be improved. The guideline for Turkey on energy efficiency in the waste water treatment sector is aiming at a fossil carbon (CO₂) neutral urban waste water treatment sector in Turkey. The guideline contains best technological practices and design and operation criteria for UWWT's energy consumption and suggestions for municipalities to enforce energy efficiency and reduce CO₂ emissions. Banks can use the guideline to facilitate the standardization of sustainable investments in energy efficient UWWT systems.

This guideline is based on the Dutch experience in this sector. In the Netherlands since several years, a program aimed at reducing energy consumption in a range of sectors (industrial sec-

tors; waste management; water and wastewater) has been developed and is still being implemented. This long term approach is explained in more detail in Chapter 5. One of the outcomes of this process for the sewage treatment sector was a wide overview of detailed energy efficiency measures for wastewater treatment plants and a manual. These products have been at the basis of the development of this guideline.

Important element of implementing energy efficiency measures in the wastewater sector is co-operation among the main stakeholders. It is essential that all stakeholders are committed to realising a significant reduction of energy consumption. The legal background must be in place and should not restrict the implementation of energy efficiency measures.

The current legal and institutional background in Turkey is explained in more detail in Chapter 2. The main stakeholders involved are:

- The municipalities who are responsible for realising new WWTPs and for the operation and maintenance (including renovation) of existing WWTPs;
- The Provincial Directorates of the Ministry of Environment & Forestry as the competent authorities for WWTPs;
- İller Bank as the organisation that assists in the development and realisation of WWTPs. In general, İller Bank develops and implements projects for local administrations to meet their urban requirements on the basis of international standards, İller Bank provides loans and also provides consulting services and technical assistance.
- The Water and Sewerage Administrations of the Greater Municipalities (ASKI, BUSKI, ISKI, ISZU etc.) prepare, realise and operate/maintain the larger WWTPs in Turkey.
- The Turkish Municipalities Union (TMU) coordinates different activities for the municipalities of Turkey. TMU is now preparing a 10 year training program, in cooperation with universities and MoEF.

To effectively implement energy efficiency measures, the approach and this guideline must be adopted by these institutions and should be promoted by all of these parties.

Main target group of this Guideline are the organisations and companies active in designing and realising WWTP facilities and the operators of wastewater treatment plants in Turkey.

This guideline has been prepared within the framework of the Dutch funded project “Energy Efficiency in the WasteWater Treatment Sector in Turkey”, a G2G-project funded by NL-EVD International (former EVD), and NL Energy and Climate Change (part of NL Agency, the former SenterNovem), which was implemented in close cooperation with the project ‘Develop Appropriate Methodology for Wastewater Treatment in Small and Medium Sized Municipalities in Turkey’ which is executed by a consortium under project management of Ameco. Elements of this guideline e.g. Chapter 2 and some other sections, have been prepared by this Ameco-project. Within the Energy Efficiency project, Grontmij Nederland participated as the expert responsible for preparing this guideline.

This guideline has the following sections:

- Chapter 2 presents the legal and institutional background;
- Chapter 3 gives a brief introduction on wastewater treatment in general and the process steps in which energy efficiency measures can be introduced;
- Chapter 4 gives a summary of the Long Term Agreement on Energy Efficiency in the Netherlands and the activities towards the wastewater treatment sector;
- Chapter 5 presents a wide and detailed overview of energy efficiency measures in the wastewater treatment sector; supported by a process scheme (decision tree) to facilitate the selection of measures ;
- Chapter 6, finally, gives an overview of our conclusions and recommendations on how this guideline and the measures can best be adopted and implemented in Turkey. (to be prepared).

2 Institutional and legal status

2.1 Legal Framework

Turkey has already harmonised important elements of the EU Directives in the field of water. The two Turkish regulations that regulate UWWT discharges, based on the UWWTD Council Directive 91/271/EEC of 21 May 1991 (UWWTD), are the Regulation on UWWT, in which the collection, treatment and discharge of urban wastewater on UWWTPs is arranged, and the Regulation on Control of Water Pollution, whose aim is to regulate the water pollution of all discharges of households and industries on surface water. A relevant law for this energy efficiency guideline is the Turkish energy efficiency law 5627, from 2007. The purpose of this law is to increase efficiency in using energy sources, avoid waste of energy and ease the burden of energy costs on the economy and protect the environment.

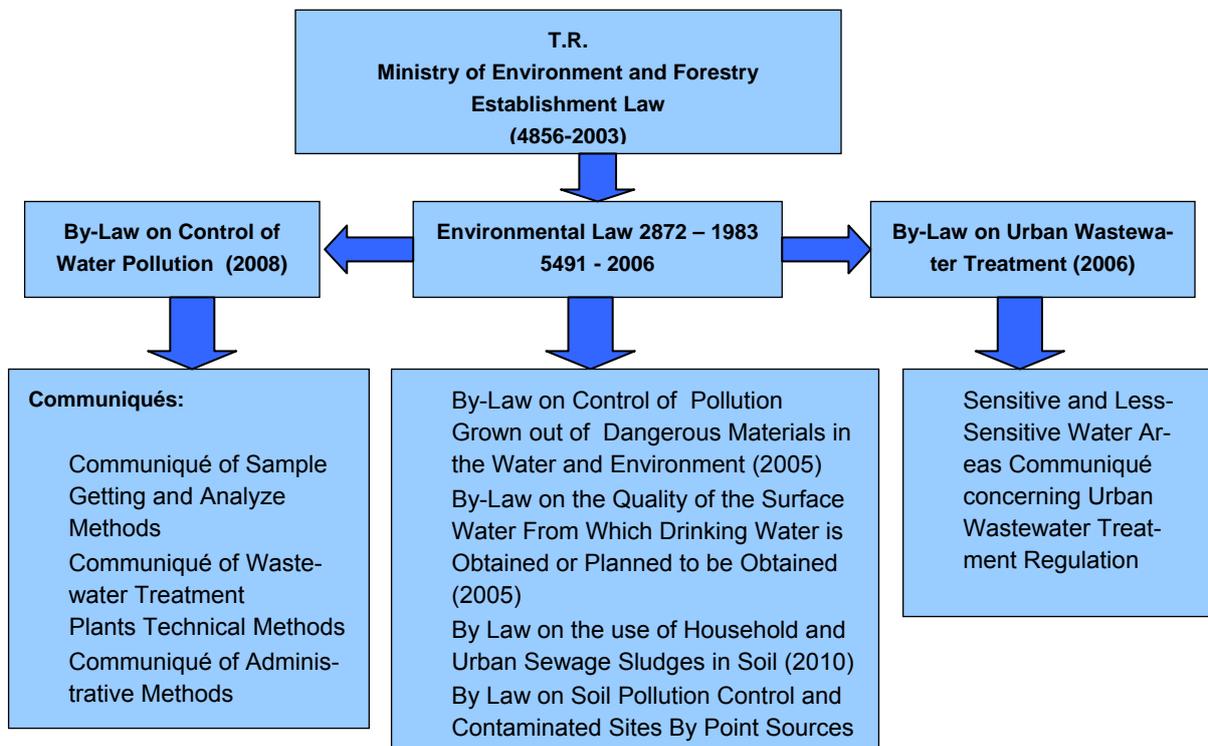


Figure 1: overview of relevant wastewater legislation
(Source: Baseline Assessment: Ministry of Environment and Forestry, 2009)

Regarding the establishment of wastewater treatment plants, the following regulations are relevant from specific points of view:

- Regulation on Urban Waste Water Treatment

This Regulation (Article 6a) sets out the procedures and principles to be followed in the design, construction and maintenance of the urban wastewater treatment plants, taking into account seasonal changes in organic and hydraulic loads and adequate performance under normal local climate conditions. It also sets out procedures and rules regarding discharges of agglomerations of

different size (2.000 – 10,000 p.e. and > 10,000 p.e). Other topics that are dealt with in this regulation relate to treatment of sewage sludge, requirements for discharges to fresh water, estuaries and coastal waters and monitoring the discharges of urban wastewater and receiving environments.

- Regulation on Control of Water Pollution

The Regulation on Control of Water Pollution regulates all waste water discharges including UWW. This regulation aims to protect surface water and groundwater from water pollution from household and industrial discharges. It also sets out rules for pretreated industrial discharges to the sewage system, and periodic analysis by the administrations of the wastewater infrastructure authorities of samples from the wastewater treatment discharges.

- Sensitive and Less-Sensitive Water Areas Communiqué concerning Urban Wastewater Treatment Regulation

This communiqué defines the sensitive and less sensitive areas and also sets out the rules for urban waste water discharges.

A more detailed scheme of the relevant Turkish legislation and related permitting of UWWT facilities is presented in Section 2.1.2.

2.1.1 Progress to date

The UWWT Directive has been transposed to the Turkish legislation by the Regulation on UWWT, which was published in the Official Gazette No. 26047 on 8 January 2006. In accordance with the Provisional Article 2 of the Regulation on UWWT, sensitive areas were determined in June 2009. A technical study is currently being conducted for the determination of the sensitive areas and the agglomeration to these sensitive areas. According to the official data of Turkish Statistical Institute (2008), number of UWWTPs and ratio of connection to UWWTPs by population groups can be classified as follows:

Table 1: Overview of waste water statistics in Turkey

<i>Population Groups</i>	<i>Number of Municipalities</i>	<i>The Ratio of Population Served with UWWTP</i>	<i>Number of WWTPs (Biological+Advanced)</i>
≥100.000	152	81,3%	76
50.000-99.999	96	29,9%	18
10.000-49.999	317	21,5%	46
2.000-9.999	1455	8,2%	62

(Source: Ministry of Environment and Forestry, 2009 and TÜİK, 2008)

In Turkey there are still quite a number of facilities will have to be developed and constructed, which means that information on energy efficiency measures can be applied in a large number of new installations allowing for an important potential reduction of the energy consumption of new waste water treatment plants.

The statistical data that belong to the municipalities can be classified as below:

- The ratio of population connected to sewerage to total population of municipality is 88%.

- 2421 of 3225¹ municipalities are served by a sewerage system.
- Out of 3.26 billion m³ of wastewater discharged through sewerage systems, 2.25 billion m³ was treated in WWTP's. Of this treated wastewater, 38,3% was biologically treated, 32,7% had physical treatment and 28,8% had advanced treatment (P and N removal) and 0,3% had wetlands.
- In 2002, the ratio of the population served by wastewater treatment plants to total population of municipalities was 34%, while in 2009 this ratio has reached to 68% according to the recent data by MoEF.
- At the end of the 2009, 242 municipal WWTP's, serving 342 municipalities.

In comparison with the earlier information, the number of WWTP's has increased significantly. The connection ratio could not be compared but will have improved a lot as well. However, it remains clear that the number of municipalities that require the construction of a WWTP is still high, looking at the number of municipalities with more than 10,000 inhabitants, compared to the number of WWTP's in 2008.

Technical studies are currently being carried out to complete a list of agglomerations based on population equivalent (p.e.). Technical studies are also being carried out to determine the size and load of the agglomerations, as well as the monitoring of the amount of treatment sludge.

The performance of the UWWTPs is monitored individually by the municipalities to which they are connected. The compliance of discharge water from the UWWTP according to receive environmental discharge standards for relevant sectors as defined in the Regulation on Control of Water Pollution (Official Gazette: 31 December 2004, No. 25687) has been monitored.

Figure 2 shows a schematic diagram of the legislation of discharges on public UWWTPs and surface water. In each step the applicable articles of both regulations are provided. (Source: Baseline Assessment: Wastewater treatment in small and medium sized municipalities in Turkey, Ameco, November 2009).

In addition to the regulations and national requirements related to industrial discharges, the Water and Sewerage Administrations of the Greater Municipalities have their own regulations related to discharges to the sewer system. These regulations are not included in Figure 2. These regulations set specific requirements related to the local conditions.

¹ According to TÜİK-2010 results, the number of the municipalities in Turkey has decreased from 3225 to 2951 and some municipalities were converted into villages and small districts

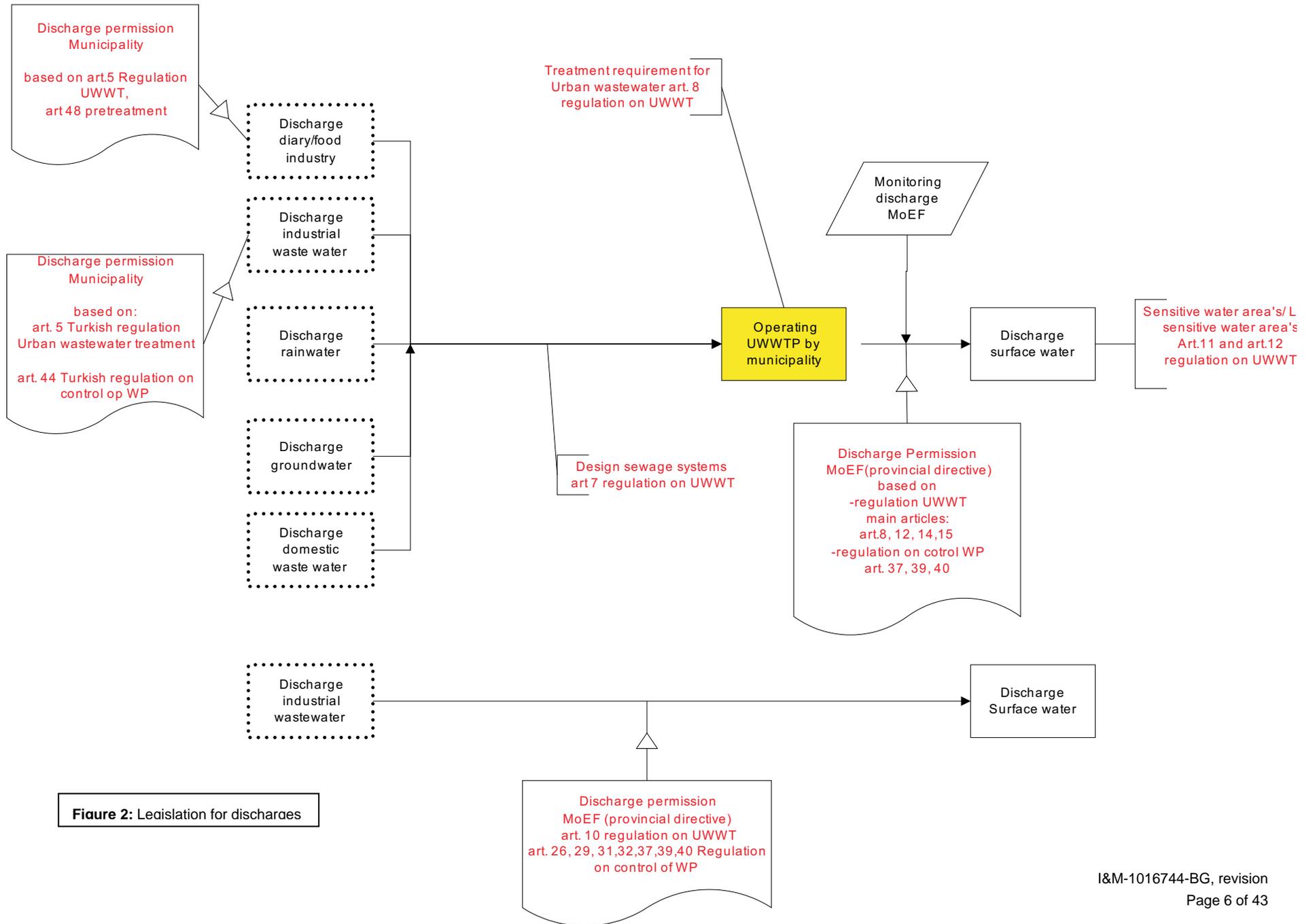


Figure 2: Legislation for discharges

2.2 Institutional context

General duties and responsibilities include:

- The MoEF is responsible for wastewater discharge principles, sectoral discharge standards, legal permissions related discharging to the receiving environment and sewage system, controlling and monitoring, approval of WWT projects.
- Iller Bank is responsible for WWTP project-design, tendering and construction, if requested by a municipality. Iller Bank also provides loans or grants to the municipality for WWTPs.
- The Metropolitan Municipality and other municipalities are responsible for establishment of sewage system and UWWTPs, maintenance, improvement and operation.

Duties and responsibilities of Municipalities related to industrial discharges on municipality sewerage systems include:

- Municipalities provide data of analysis of measurements of industrial discharges on sewerage systems.
- Municipalities check whether the wastewater conforms to the Regulation on Control of Water Pollution.
- Permission is given by the municipality to the company;
- Control regular intervals.
- Change permits when necessary.

2.3 General status of wastewater treatment

At a series of meetings and discussions with different stakeholders during the inception mission and during the inception workshop of the project “Energy Efficiency in the WasteWater Treatment Sector in Turkey” (source: *Inception report of the project, NL Energy and Climate Change, February 2010*), a number of findings and conclusions was formulated. These findings can be summarised as follows:

- Turkey has transposed the main EU directives in the field of water and wastewater, including the EU UWWT Directive. In the Turkish regulation all treatment requirements of wastewater are described. The duties and responsibilities on UWWT of organisations and institutions are addressed clearly
- The requirements of the UWWTD have been incorporated in Turkish laws and regulations; however it remains unclear as to what extent regulations are being executed as written. The general picture is that the staff at national, provincial and municipal level, need further capacity building to adequately implement these regulations.
- There is a lack of personnel that is properly educated in UWWT technology. Also staff responsible for the operation and maintenance of UWWT facilities need training and capacity building;
- Municipalities are responsible for issuing permits for industrial discharges into the municipal sewerage system but do not regularly check the quality of these discharges. There is a need for monitoring and analysis equipment and facilities together with training of staff (see also bullet point 2);
- The challenge to further develop both wastewater collection and UWWT is significant (see to Table 1). The potential for energy efficiency measures in wastewater treatment is therefore high.

The report: *Baseline Assessment: Wastewater treatment in Small and Medium sized Municipalities in Turkey, Ameco, November 2009*, provides a number of findings, conclusions and recommendations on the current status of wastewater treatment in Turkey which are in line with the above.

During the inception workshop the need for additional training of staff responsible for operating and maintaining UWWT facilities to keep knowledge up-to-date, was widely confirmed and supported:

The realisation of energy efficiency in the design AND operation of a wastewater treatment facility can only be effectively realised when WWTPs are well managed and operated in accordance with their design. Monitoring of WWTPs should be detailed and well-organised.

Operation of a WWTP should be conducted by well trained staff.

Implementation of energy-efficiency measures, explained in the next sections risks to result in sub-optimal operation of WWTPs in those cases where staff is not sufficiently trained and experienced and/or where monitoring should be further improved.

3 General description of a WWTP

3.1 Description of the WWTP

The typical waste water treatment plant (further: WWTP) is based on BOD/COD removal, P-removal (biological, chemical or combination of both) and biological N-removal through nitrification and denitrification. In the Netherlands 75% of the total P and 75% of the total N has to be removed from the influent. A typical sludge loading is 0,05 kg BOD/kg sludge-day. The typical WWTP consists of the following components:

- Coarse screens;
- Sand trap;
- pre-settlement;
- Anaerobic tank;
- Selector;
- Anoxic tank;
- Aerobic tank;
- Post settlement;
- Return sludge pumping station;
- Secondary sludge pumping station;
- Sludge thickening (primary + secondary sludge);
- Sludge digestion;
- Sludge dewatering;

Coarse screens

Coarse screens remove coarse materials as leaves, hair, paper etc. to prevent any component downstream from clogging.

Sand trap

The sand trap removes sand to prevent damaging of pumps and pipelines.

Pre-settlement tank

In the pre-settlement tank approximately 50% of the total dry solids and 30% of the organic load (COD, BOD) is removed from the incoming waste water and will settle as primary sludge. By installing a pre-settlement tank:

- the volume to be installed for the aeration tank can be smaller;
- primary sludge is produced which causes high gas production at sludge digestion;
- the denitrification can be more difficult because of less BOD available for denitrification.

So whether it is useful or not to install a pre-settlement tank strongly depends on local circumstances.

Anaerobic tank

The anaerobic tank, with strictly anaerobic circumstances, is necessary for selecting the Phosphate Accumulating bacteria (PAO's). One of the main characteristics of these bacteria is the luxury uptake of phosphate, meaning that they store more phosphate than strictly necessary for growth resulting in 3,5% P instead of 2% P related to dry solids. In order to select these bacteria they need alternating anaerobic and aerobic/anoxic circumstances. Under anaerobic circum-

stances phosphate is released to the water phase, under aerobic circumstances phosphate is absorbed by the bacteria from the water phase.

The anaerobic tank is fed with wastewater and a recirculation flow from the anoxic tank.

Selector

The selector is a relatively small and unaerated compartment, fed with the outflow of the anaerobic tank and (part of the) return sludge. The meaning of this section of the WWTP is to favour the growth of the flock forming bacteria above the growth of the filamentous bacteria. Filamentous bacteria are not or less capable of absorbing BOD under anoxic conditions, where flock forming bacteria are. So under the anoxic conditions of the selector most of the BOD is absorbed by the flock forming bacteria and is therefore no longer available for the filamentous bacteria under the aerobic conditions in the aerobic tank.

Anoxic tank

The anoxic tank is fed with the outflow of the selector and a nitrate containing recirculation flow from the end of the aerobic tank. In this sector of the WWTP heterotrophic bacteria oxidise COD/BOD using nitrate instead of dissolved oxygen. Nitrate is in this denitrification process reduced to nitrogen-gas.

Aerobic tank

Subsequently the outflow of the anoxic tank enters the aerobic tank where the rest of the COD/BOD is oxidised by means of the heterotrophic bacteria and dissolved oxygen is added by means of bubble aeration or surface aeration. Ammonium is oxidised via nitrite to nitrate by the autotrophic bacteria. The excess sludge, as a result of growth, is wasted as secondary sludge by means of the secondary sludge pumping station.

Post settlement tank

Effluent and sludge are separated in the post settlement tank. The settled sludge is returned as return sludge, by means of the return sludge pumping station, to the selector, the effluent is discharged to the surface water.

Sludge thickening

The primary sludge as well as the secondary sludge are thickened from 0,8 – 1,0% dry solids to 3,5 – 6,0% dry solids by means of a gravitational thickener or a mechanical thickener.

Sludge digestion

The thickened sludge is pumped into the sludge digester. At an temperature of ca. 33°C and anaerobic circumstances the organic dry solids content of the sludge will be decreased with approximately 35% - 50%. The organic material is converted to methane gas, CO₂-gas and water by means of anaerobic bacteria. The methane gas can be used in a co-generator producing electricity and heat. Heat is used for warming of the digestion and for warming of buildings on the plant. The electricity is used to operate the wwtp.

Sludge dewatering

The digested sludge is subsequently dewatered by means of a centrifuge or a belt press. The total solids concentration afterwards is 20 – 25%. The dewatered sludge is discharged to an incinerator.

3.2 Energy consumption of wastewater treatment facilities

The energy consumption of a WWTP facility will depend on size and type of WWTP. Also through effective operation and monitoring of the WWTP-process significant improvements in energy efficiency can be realised.

The energy consumption of wwtp's in the Netherlands is monitored. The results of the different waterboards are compared in a benchmark analysis. From these data general figures about energy consumption of wwtp's are known. The energy consumption of a wwtp is referring to the treatment of wastewater and sludge. Processing of sludge after the dewatering is not included in these data. Energy for transport refers to the transport systems from the Waterboards, the energy from the transport systems within the municipalities are not included.

Per removed population equivalent (PE-r) the energy consumption of wastewater treatment in the Netherlands is approx. 27 kWh/PE-r * year. From that amount on average 15 kWh/PE-r * year is used for aeration. Typical data for energy (electricity) consumption from the Netherlands are as follows:

	average	range	
Total wwtp	27	20-34	Kwh / PE-r.
Aeration	15	10-20	Kwh / PE-r.
Dewatering	0,13	0,04-0,27	Kwh / kg ds
Transport	0,016	0,0028-0,0333	Kwh/m ³ .km

The main part of the energy demand is electricity to run the processes at the wwtp. Methane gas consumption from the grid is negligible. Heat used for digestion is provided from the exhaust heat of the gas-engine for electricity production from biogas. When digestion and production of electricity and heat from biogas are present, the electricity produced is consumed by the wwtp. Additional electricity has to be taken from the grid. The heat produced by co-generation is sufficient to provide heat for digestion. In 2008 in the Netherlands 24% of the electricity demand of all municipal wastewater plants was generated in gas-engines from the biogas produced by digestion. Approx. 50% of the PE is digested in 85 out of 350 municipal wastewater treatment plants. Mainly large wwtp's are equipped with digestion. Above given numbers represent the consumption of electrical energy of wwtp's. However it should be noted that with the use of chemicals (e.g. dewatering, phosphate removal) indirectly (for the production and transport) additional energy is required. For a complete overview of the direct and indirect energy consumption of wwtp's, the energy associated with chemical consumption should be taken in to account. However this is outside the scope of this guideline.

3.3 Sludge end-processing

In the Netherlands the final stage of the processing of sludge from municipal wastewater treatment plants is incineration. This is regulated by law, it is not allowed to re-use the sludge in agriculture, mainly due to the heavy metal content. At the wwtp's the sludge is dewatered to a dry solids content of 20-25%. In this way cost for transport is saved, and the caloric value of the sludge is increased. For reasons of economy of scale, the dewatering is regionally centralised at larger wwtp's. Sludge from smaller wwtp's is thickened on site and transported to the central dewatering facilities. In the Netherlands 50% of the sludge is incinerated in two specific sludge incineration facilities. The rest of the sludge is co-incinerated in waste-incinerators or in coal based power plants. Typically the caloric value of the dewatered sludge is sufficient to be able to incinerate the sludge autothermic in the sludge incineration plants. These plants are not designed for energy recovery. To apply the sludge in co-incineration, the sludge is dried after dewatering to increase the caloric value and to full fill the specifications of the co-incineration plants. For the drying, two methods are used. Composting (or biological drying), or drying with drum filters. The energy for the drum filters is provided by methane from the grid, the energy

accompanied with this is partly recovered in the power plant where electricity is produced. The biological drying is more energy efficient.

To be able to assess the energy efficiency of a wastewater treatment plant in total, a complete analysis of the energy balance of the water line and the sludge line, including end-processing, has to be made. Several studies in this field are performed in the Netherlands. Although more optimal solutions are available, the present infrastructure for sludge incineration is a boundary condition which limits significant changes on short term.

In Turkey the dried matter content of sludge produced in wwtp's larger than 1 million PE should be increased to >90% dry solids by the year 2010. The choice of the type of drying is important for the energy efficiency of the total water and sludge line. A so called chain analysis on this aspect is recommended.

For smaller wastewater treatment plants in Turkey the use of sludge in agriculture is allowed at very specific conditions. Case by case this application of sludge has to be assessed and permits are required.) Whether dewatering of sludge is required depends on the economics related to transport costs. By using sludge in agriculture the energy content of sludge is not used, however re-use of nutrients (nitrogen, phosphorus) and minerals can be achieved. Local application of sludge in agriculture might save energy related to transport. For smaller wastewater treatment plants, the energy balance related to sludge is specific for local situations. Relevant Turkish laws are the Turkish Soil Pollution Control and the draft of the regulation on Stabilized Sludge Usage in Soil. Turkey transposed 86/278/EEC for agricultural usage of sludge.

3.4 Energy management at operational level

For successful implementation of energy efficiency measures, several aspects at operational level are of importance. At first monitoring of the energy consumption of different process components is essential to prioritise the measures. Secondly awareness of operators on energy efficiency and education of operators to apply operational aspects of energy measures are important. This guide line provides measures for process engineers. When these measures are applied in the field, it is essential that the role of operators is secured such that energy management at operational level is made possible.

4 Energy Efficiency in Wastewater Treatment in the Netherlands

4.1 The Longterm Agreement on Energy Efficiency in Wastewater Treatment

Mid 2008, the Dutch Union of Waterboards has signed the LongTerm Agreement on Energy Efficiency in Wastewater Treatment with the Ministry of Economic Affairs.

The overall objective of this LTA is to increase the energy efficiency of wastewater treatment in the Netherlands with 2% per year. In the period 2005 – 2020 this should result in a reduction of the energy consumption by wastewater treatment facilities of 30%. For more information visit the following websites: www.ltauptake.eu and www.senternovem.nl/lta/

The Waterboards, e.g. the operators of wastewater treatment facilities have taken up the following obligations:

- Prepare an Energy Efficiency Plan (EEP) for their WWTP facility, and report about progress made on a yearly basis;
- Include measures that are economically and technically feasible in their EEPs;
- Make efforts to include in the EEPs measures that are now uncertain or not feasible, as soon as these measures become feasible;
- Make efforts to include improvement of energy efficiency through cooperation with other organisations (chain-oriented measures);
- Provide the required data to the sector-organisation which are required to prepare a Long-term Energy Efficiency Plan.

The Waterboard will provide detailed motivations and arguments in case the realised energy efficiency improvement will be less than 2% per year for their facilities.

The sector-organisation e.g. the Union of Waterboards will stimulate its members to participate actively in this longterm agreement. The Union of Waterboards acts as the focal and contact point for the Dutch authorities e.g. the Ministries of Economic Affairs and of Environment.

The Ministries will provide support to the Union of Waterboards and its members to realise the above objectives. In addition, the Ministries will ensure that there will be no further energy efficiency regulations or requirements for this sector and the Ministry will develop and implement policy measures to facilitate the realisation of the LTA-goals.

To assist the Waterboards with the realisation of the LTA-objective of 30% energy efficiency improvement by 2020, NL-Agency (former SenterNovem), has developed a program to support the waterboards. The main components of this program are:

- All waterboards get expert-support to develop the EEPs and provides expert-support on the implementation of identified measures;
- Prepares knowledge transfer and capacity building activities on energy-efficiency, chain efficiency and sustainable energy;
- Prepares studies and roadmaps for the longer term measures;
- Monitoring of the LTA.

In this process the Waterboards and Agentschap NL make proper use of the Overview of Energy Efficiency Measures that has been prepared earlier. The main elements of this overview are presented in Chapter 5.

4.2 Organisation of the LTA process

The stakeholders involved in the LTA process on Energy Efficiency in Wastewater Treatment are:

- Union of Waterboards as the sector organisation for the operators of wastewater treatment facilities. The Union of Waterboards has taken up the ambition to realise the energy efficiency improvement for the sector as a whole. This means that not each specific WWTP-facility needs to achieve this objective;
- The individual Waterboards being the operators of the WWTP facilities and responsible for preparing roadmaps and EEPs, and for implementing the energy efficiency measures;
- NL-Agency (former SenterNovem) as the coordinating and executive body for the Ministry of Economic Affairs, responsible for monitoring the LTA-process for different sectors, including the wastewater treatment sector. AgentschapNL also organises and provides support to the Waterboards, and organises capacity building and knowledge transfer activities ;
- Municipalities/provinces as the competent authorities for the Waterboards and WWTP facilities. Municipalities/provinces have their own energy efficiency and climate change programs and favour the efforts of the waterboards as a contribution to realising their own goals. The Municipalities take the LTA into account in their licensing and inspection activities.
- Consulting & Engineering companies are supporting the Waterboards to implement energy efficiency measures, supported by the Ministry of Economic Affairs and the Dutch National Government.

5 Energy Efficiency Measures

5.1 Introduction

WWTP's differ in size, type and process configuration. The energy efficiency measures presented are meant as a general guide line. The guide line acts as a road map on which basis a first selection of suitable measures can be made. The target group for the use of the guide line is process engineers involved in design and optimisation of wwtp's. For each case and situation these general guidelines have to be worked out specifically. For this reason, ranges are presented for the effect on the energy consumption and for the payback time. In some cases these ranges can not be given due to a high dependency of the local situation. The guideline can be used to obtain ideas about energy efficiency measures in an existing situation and can be used as a checklist to asses whether energy efficiency measures are sufficiently incorporated in a design. This guideline does not give technical details and specifications for the different measures as these details depend on size, type and other parameters of the WWTP where the measure will be applied. The steps to take are as follows:

1. Select potential measures from the guide line
2. Detail the measure for the specific local situation
 - effect on energy efficiency
 - additional costs, cost/benefit analysis
3. Decide to apply the measure

The working area of the guide line is step 1, a gross list to be able to make a selection of interesting measures. For step 2 and 3, state of the art waste water treatment engineering capabilities have to be used.

The energy efficiency measures presented are based on a similar guide line made for and used by the Dutch Water boards. The guideline is focusing on biological municipal wastewater treatment as usually applied. This concerns aerobic treatment for COD removal. In Turkey however, in some regions for COD removal anaerobic (pre)treatment of municipal wastewater could be a viable option due to the higher temperature of the wastewater.

5.1.1 Effect of measures

For the effect of the measure on the energy consumption, the percentage of energy saving is presented in five ranges:

<1 %
1-5 %
5-10 %
10 -20 %
> 20 %

A measure can be taken for two situations:

1. An existing well functioning wwtp, for which energy efficiency measures are taken. The costs involved in this must be completely accounted to this measure.

2. An existing wwtp or new wwtp for which a choice has to be made for equipment, processes, etc. In case of an existing wwtp this could be a renovation, in case of a new wwtp this could be a design issue. In these cases an extra amount of money to be invested is relevant to realise energy efficiency. These additional costs are accounted to this measure.

For the guide line the second situation is applicable. The reason for this is that many measures will have a long payback time when implemented at a well functioning wwtp (as there is no technical need to replace equipment). It is more realistic to consider a choice for additional investment to achieve higher energy efficiency.

The numbers presented are based on a reference wwtp of 100.000 PE. For measures accompanied with digestion a size of 250.000 PE is applicable.

W2.

% Effect	Pay back time	Extra investment
10 – 20%	5 - 15	< 500.000 – 1.500.000 €

Bubble aerators (dish, tube, or plate aerators) have a superior oxygen transfer capacity

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	< 500.000 – 1.500.000 €

Centrifugal compressors can have a lower energy consumption compared.

5.1.2 Investments

For the additional investment costs the following categories are used (numbers in euro).

< 10. 000
< 50.000
< 100.000
< 250.000
< 0,5 million
0,5-1,0 million
> 1,5 million

The background for this choice is as follows. In the Netherlands the costs for wastewater treatment average at 35 euro per PE. For a wwtp of 100.000 PE this leads to 3,5 million euro's of yearly costs. An investment of 1,0 million euro leads approx. to 100.000 euro of capital costs yearly, a cost increase of 1 euro per PE. Compared to the 35 euro per PE of total cost, 1 euro additional costs are considered to be significant.

The amount of additional investment presented is based on Dutch prices. No translation is made between the investment figures for the Dutch situation to the Turkish situation. It is assumed that the ratio between additional investments and savings expressed as a payback time is comparable for the Dutch and Turkish situation.

5.1.3 Payback time

For the payback time three ranges are defined.

Short: < 5 years
Average: 5-15 years
Long: > 15 years

The payback time is defined as the investment divided by the annual saving. Measures with a short pay back time are financially interesting and can be applied immediately. In this case the payback time is shorter than the technical life time. Measures with an average payback time can be financially interesting when the payback time is in the range of the technical lifetime. The

measures with a long payback time are financially not interesting and will be realised when non-financial issues are in consideration or when e.g. a higher energy price is expected in the future.

5.2 Categories of measures

Energy efficiency measures at wastewater treatment plants can be divided in three main categories:

1. Water related, the treatment of the wastewater in the wwtp;
2. Sludge related, the treatment of sludge resulting from the treatment of the influent.
3. Air treatment related, the treatment of air coming from different parts of the wwtp to prevent odour.

5.2.1 Water related measures

Energy efficiency measures with respect to the wastewater treatment system are predominantly related to the aeration of the biomass. A subdivision can be made between hardware and process control measures. In addition several other measures can be mentioned which are not related to aeration. All measures for wastewater treatment are mentioned in Table 5-1.

Table 5-1: Energy measures for wastewater treatment (water related)

Number	Measure
W1	Disconnection of aeration and liquid propulsion.
W2	Bubble aeration instead of surface aeration.
W3	High efficiency surface aerators.
W4	Remove covers for spray prevention at surface aerators.
W5	Adjust water head at surface aerators.
W6	Plate aeration instead of tube or dish aeration.
W7	Centrifugal compressors instead of displacement or roots compressors.
W8	Optimise tank depth.
W9	Intermittent aeration control.
W10	Reduce oxygen concentration setpoint.
W11	Process operation on the basis of sludge age.
W12	Improve alpha-factor.
W13	Alarm report in case of unexpected high aeration rate.
W14	Optimise configuration.
W15	Upflow Sludge Blanket Filtration (USBF).
W16	Sequencing Batch Reactor (SBR).
W17	Treatment at source.
W18	Thermal energy exchange.
W19	Avoid frequent switching off and on of hardware.
W20	Avoid unfavourable ranges for hardware.
W21	Manage scraper operation in clarifiers.
W22	Advanced pre-treatment (sieves).
W23	High efficiency mixers for propulsion and mixing.
W24	Periodical adjustments in the propulsion propeller operation.
W25	Type and positioning of propellers for propulsion in combination with bubble aeration.
W26	Exchange between compartments in direction of flow.
W27	Mix by aeration instead of propellers.
W28	Switch off propulsion propellers during aeration.
W29	Gravity transport.
W30	Disconnection of rain water.
W31	Avoid infiltration water.
W32	Optimise transport system.
W33	Nutrient removal

W34	Creation of additional anoxic volume.
W35	Choose the energetically most favourable design.
W36	Managing return sludge flow rate.
W37	Regulate nitrate recirculation to the anoxic zone.
W38	Couple aeration rate to process parameters.
W39	Optimise position and number of sensors.
W40	Regular calibration of the sensors.
W41	Optimise phosphorous removal.
W42	De-ammonification
W43	Aerobic granular sludge (Nereda).

5.2.2 Sludge related measures

Energy efficiency measures in the sludge line can be subdivided in thickening, dewatering, digestion, biogas utilisation and other measures. The measures are given in Table 5-2.

Table 5-2: Energy measures for sludge treatment (sludge related)

Number	Measure
S1	Worm bloom.
S2	Timing of sludge transport.
S3	Cannibal.
S4	Sludge digestion and cogeneration.
S5	Thermophilic multiple stage digestion.
S6	Utilise existing digestion capacity.
S7	Insulation of (old) digesters.
S8	Sand removal prior to sludge treatment.
S9	Direct operation compressor/blower by gas motor.
S10	Energy production in small gas turbines or gas engines.
S11	Add small gas turbine or extra biogas buffer.
S12	High efficiency heat power coupling.
S13	Optimise heat power coupling.
S14	Gas conditioning prior to heat power coupling.
S15	Fuel cells for higher efficiency.
S16	Utilisation of the heat buffering capacity of the digester.
S17	Blend biogas with natural gas.
S18	Transport biogas to third parties.
S19	Convert biogas into methane and supply it (back) to the gas network.
S20	Installation of (additional) gas storage buffer.
S21	High efficiency primary settling.
S22	Sludge disintegration techniques prior to digestion: ultrasonic/hydrodynamic.
S23	Sludge disintegration techniques prior to digestion: high pressure, thermal, hydrolysis, cambi.
S24	Constant feeding of the digester.
S25	Proper mixing in the digester.
S26	Mixing in the digester with a mixer instead of blowing gas to the digester.
S27	One-time removal of sand from the digester.
S28	Maintenance removal of sand from the digester
S29	Use waste heat from surroundings.
S30	Supply waste heat to third parties.
S31	PE dosing.
S32	Mechanical thickening instead of gravitational thickening of sludge.
S33	Treatment of return liquors with SHARON.
S34	Chemical nitrogen precipitation to struvite.
S35	Anaerobic de-ammonification.
S36	Two-stage Sharon-Anammox process with 2 reactors.
S37	Reuse of low value heat
S38	Reuse of heat from gas engine exhaust gases.
S39	Feasibility of dewatering
S40	Belt press instead of centrifuge after thickening.
S41	Cascade line-up and belt press for direct sludge dewatering.
S42	Belt press for sludge dewatering after digestion.
S43	Dry matter content in the dewatering installation.
S44	Drainage of water from the activated sludge storage.
S45	Back drive operation on centrifuges
S46	Control system for operation of the centrifuges.
S47	Well mixed sludge to the dewatering installation.

5.2.3 Air treatment related measures

Energy measures for air treatment can be divided into measures for exhaust air treatment and air extraction. The measures are given in Table 5-3

Table 5-3: Energy measures for air treatment

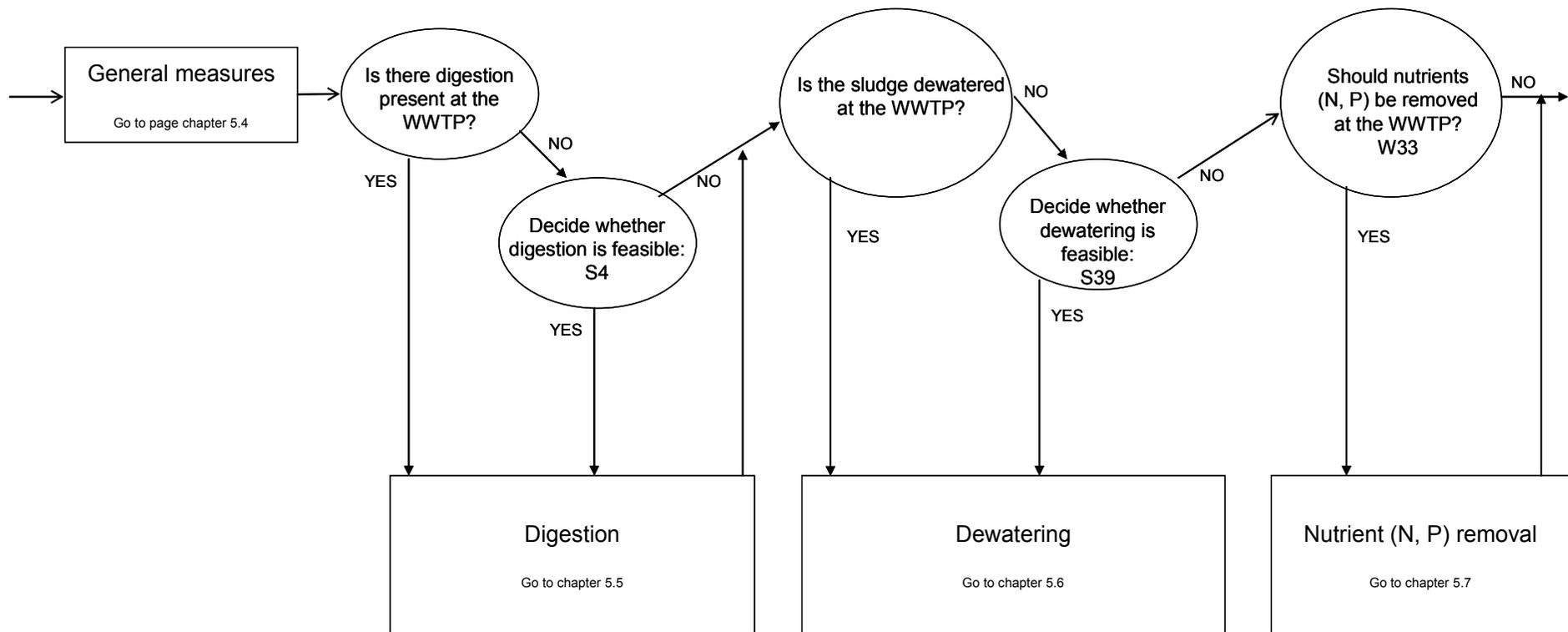
Number	Measure
A1	Send exhaust air from the treatment process to the aeration tank.
A2	Replace compost filters by lava filters.
A3	Breathing filter.
A4	Optimise air extraction.
A5	Reduction of the extracted air volume.
A6	Regulate air extraction on the basis of H ₂ S measurements.
A7	Increase ventilation flow rate above the aeration tank.

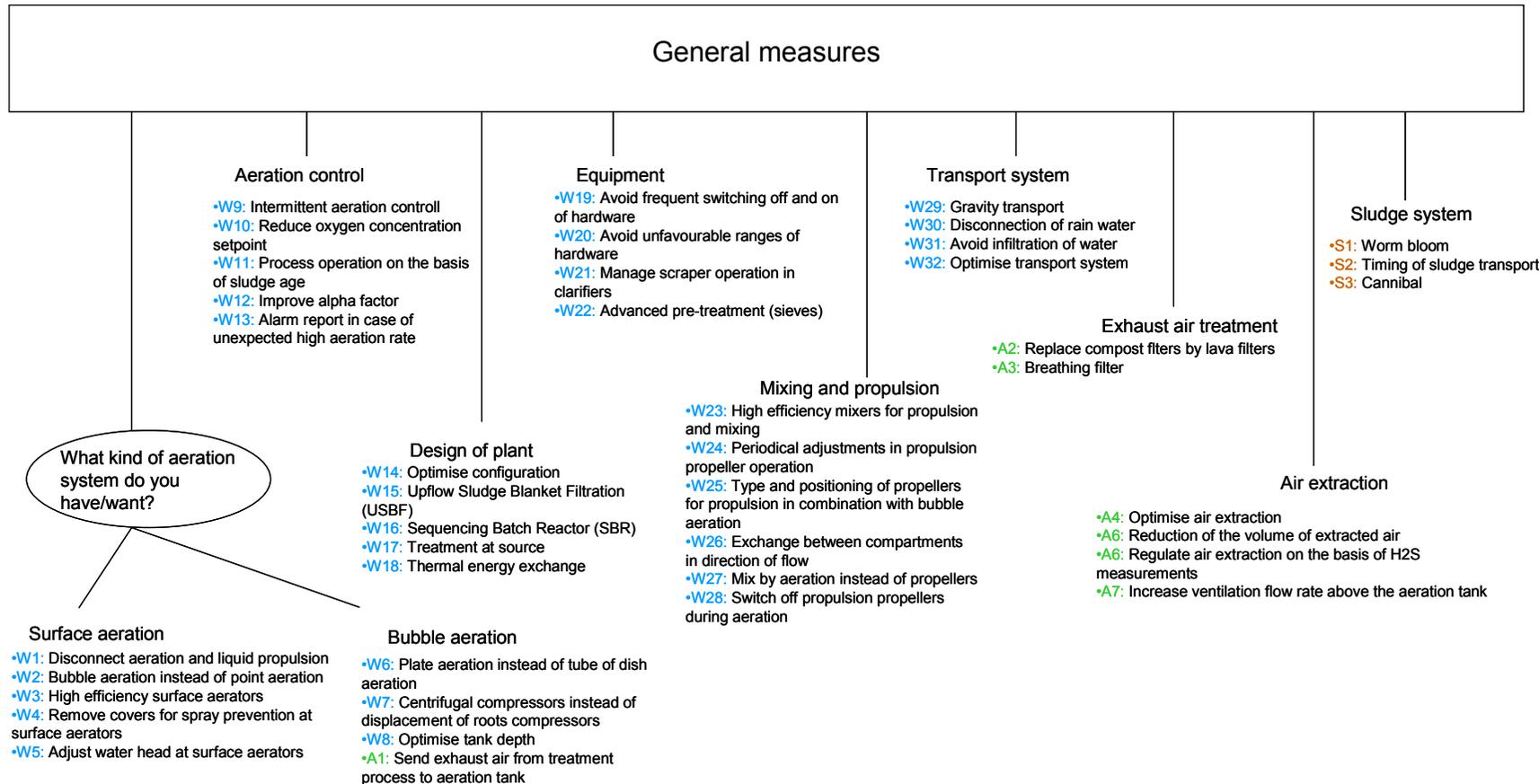
5.3 Decision tool

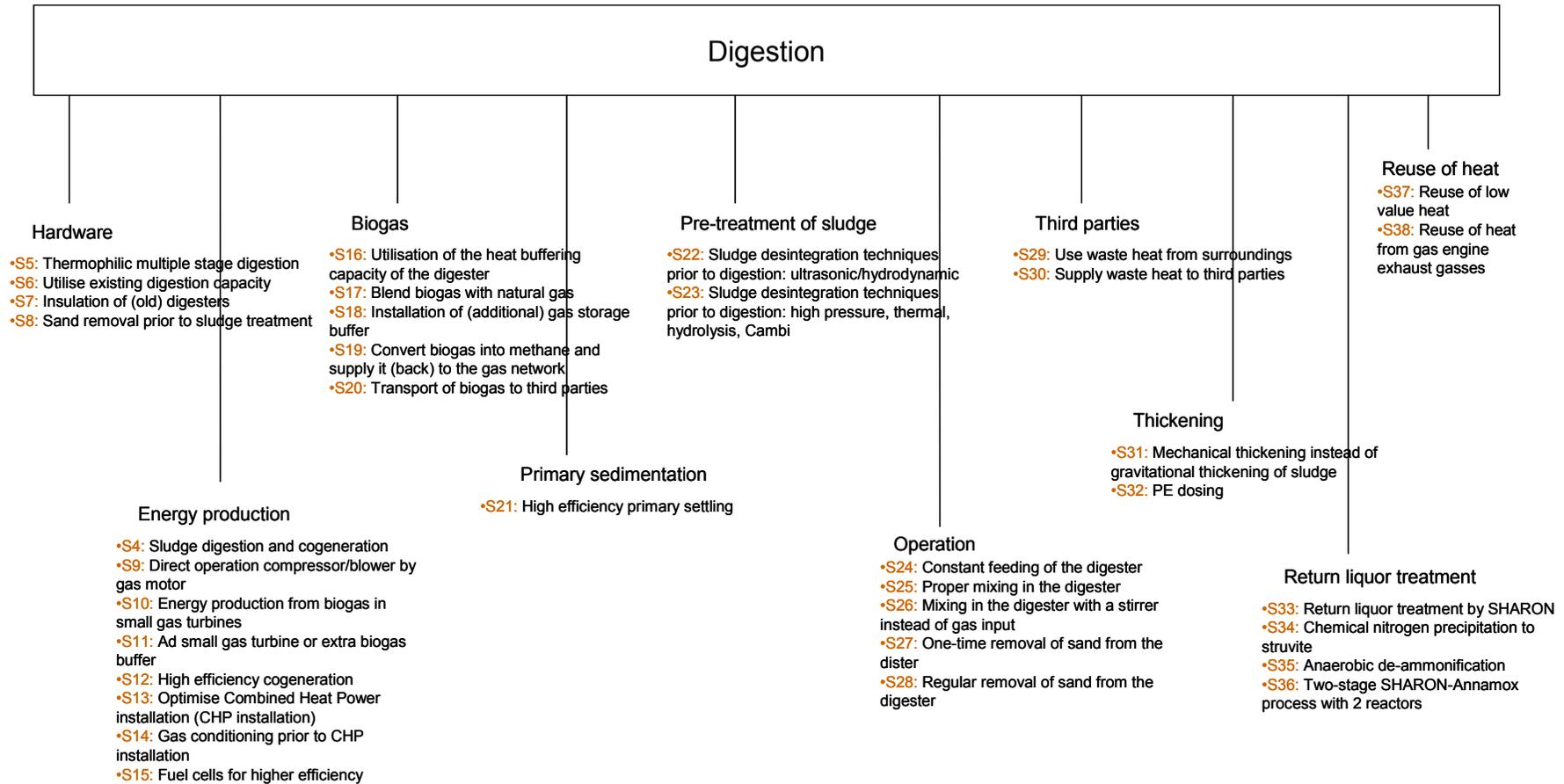
To assist on the choice of measures on energy efficiency for municipal wastewater treatment, a decision tree is provided. Based on the structure of the decision tree, the measures of tables 5-1, 5-2 and 5-3 are subdivided into main categories:

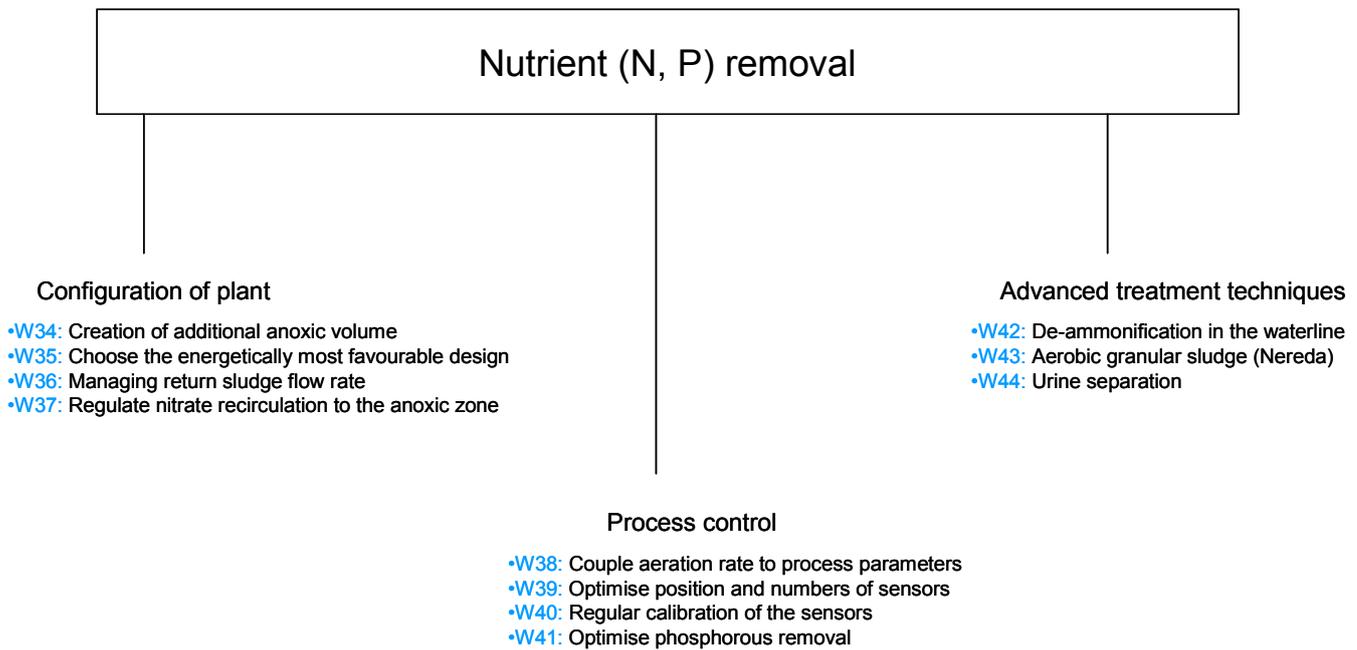
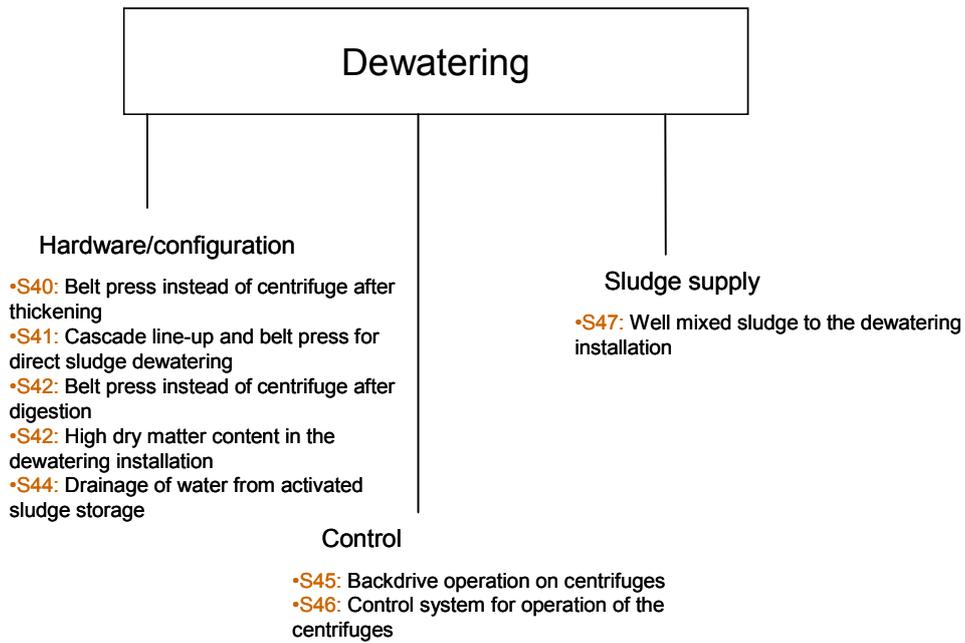
- General, applicable for all wwtp's
- Digestion
- Sludge dewatering
- Nutrient removal
- Air treatment

The decision tree is presented in the following figures. Subsequently the measures are presented in more detail comprising a short description of the measure and a summary of the effect of measures on energy saving, additional investment costs involved and the payback time (as explained in 5.1). The measures are numbered, the ranking and numbering is not related to the importance of the measure.

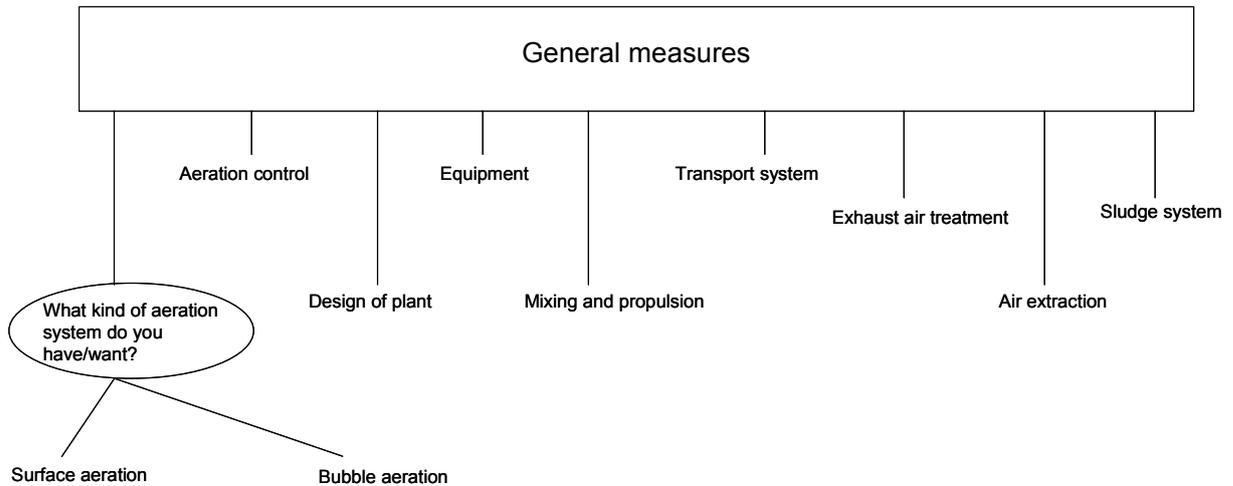








5.4 General Measures



In this chapter general measures for energy efficiency at a WWTP are described. These measures can be taken irrespective the configuration of the WWTP. In the first paragraph measures for the aeration system are describes, divided by the kind of aeration system. After that measures for aeration control, design of plant, equipment, mixing and propulsion, transport system, exhaust air treatment, ventilation and the sludge system are described.

5.4.1 Type of aeration system

5.4.1.1 Surface aeration

W1. Disconnection of aeration and liquid propulsion.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

By decoupling the liquid propulsion from the aeration the aerators can be employed exclusively for oxygen input. As a result the aerators do not have to operate at a fixed capacity to create a sufficient liquid flow rate in the system.

W2. Bubble aeration instead of surface aeration.

% Effect	Pay back time	Extra investment
10 – 20%	5 – 15	< 500.000 – 1.500.000 €

Bubble aerators (dish, tube, or plate aerators) have a superior oxygen transfer capacity compared to surface aerators (rotors or surface aerators), enabling a lower energy input for aeration. Note that additional liquid propulsion hardware might be required, implying extra energy consumption. But overall energy will be saved. Water depth of tanks is an important parameter in this respect.

W3. High efficiency surface aerators.

% Effect	Pay back time	Extra investment
5 – 10%	5 -15	< 250.000 €

By replacing conventional surface aerators by modern high efficiency surface aerators the oxygen transfer efficiency can be improved and the energy consumption for aeration can be forced back. Water depth of tanks is an important parameter in this respect.

W4. Remove covers for spray prevention at surface aerators.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 50.000 €

Covers above surface aerators hamper the oxygen input. On the other hand removing them promotes the diffusion of aerosols.

W5. Adjust water head at surface aerators.

% Effect	Pay back time	Extra investment
1 – 10%	> 15	< 50.000 €

Applying a baffle behind the surface aerator or elevating the overflow height increases the immersed water depth and provides more efficient oxygen transfer efficiency. On the other hand a baffle leads to additional resistance and requires more energy for liquid propulsion. Elevating the overflow height is the more conventional measure.

5.4.1.2 Bubble aeration**W6. Plate aeration instead of tube or dish aeration.**

% Effect	Pay back time	Extra investment
5 – 10%	> 15	< 500.000 – 1.500.000 €

Plate aeration provides higher oxygen transfer efficiency compared to tube or dish aeration. The loading on plates is lower, resulting in a higher efficiency. Similar efficiency can be reached by installing more tube or dish aerators operating at a lower loading rate.

W7. Centrifugal compressors instead of displacement or roots compressors.

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	< 500.000 – 1.500.000 €

Centrifugal compressors can have a lower energy consumption compared to displacement or roots compressors. The energy gain is strongly depending on the specific situation, especially on the required control range for the oxygen input. Centrifugal compressors are only feasible in case of high aeration rates and relatively large WWTPs.

W8. Optimise tank depth.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

The oxygen transfer efficiency is more efficient when the air travels a longer distance (i.e. when the tank is deeper). On the other hand compressors have to operate at higher capacity to overcome additional pressure due the increased water level. Design should be based on the maximum energy efficiency and oxygen transfer efficiency.

A1. Send exhaust air from the treatment process to the aeration tank.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

The exhaust air can be transported to the aeration tank through an air blower instead of being treated by a lava filter or compost filter. This measure is only applicable for (partly) continuous aeration operation.

5.4.2 Aeration control**W9. Intermittent aeration control.**

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 250.000 €

Application of intermittent or non-step-wise aeration control increases the control range and makes it possible to adjust the aeration input more accurately (0-100%) to the actual oxygen need of the system.

W10. Reduce oxygen concentration setpoint.

% Effect	Pay back time	Extra investment
1 – 10%	No investments required	None

The aeration rate can be reduced by decreasing the dissolved oxygen concentration setpoint of the system. Note that reduction of the aeration rate does not cause a disadvantageous effect on the oxygen transfer rate in the system or leads to other undesirable situations (such as bulking sludge). As a rule of thumb for completely aerated and well mixed tanks a mini-

imum of approx. 0,8 mg/l and a maximum oxygen concentration of approx 2,0-2,5 mg/l can be applied.

W11. Process operation on the basis of sludge age.

% Effect	Pay back time	Extra investment
1 – 10%	No investments required	None

The oxygen requirement of the system can be reduced by decreasing the sludge concentration. In summer time the sludge concentration (MLSS) might be decreased even further. This will result in a higher sludge loading (F/M ratio), higher sludge production and lower sludge age. Note that the treatment efficiency has to comply with the permit requirements. Because the sludge production and thereby the energy consumption in the sludge line increases, attention should be paid to the total energy balance.

W12. Improve alpha-factor.

% Effect	Pay back time	Extra investment
1 – 10%	No investments required	None

The alpha factor is important for the oxygen transfer efficiency. High sludge concentration in the aeration tank usually results in a deterioration of the alpha-factor above a certain critical value (about 6 to 8 g/L). In addition several other factors affect the alpha-factor, such as shear rate and stress on the biomass. Low alpha-factors can also occur at standard sludge concentrations, thereby requiring a higher aeration rate to reach the same treatment efficiency. It is advisable to measure the alpha-factor.

W13. Alarm report in case of unexpected high aeration rate.

% Effect	Pay back time	Extra investment
1 – 5%	< 5	< 10.000 €

When the aeration rate is much higher than expected something might be wrong with the aeration system, for instance a leakage. Excessive aeration might be prevented by tracing this.

5.4.3 Design of plant

W14. Optimise configuration.

% Effect	Pay back time	Extra investment
5 – 10%	Dependent on situation	Dependent on situation

When designing a WWTP (newly built or renovation) minimisation of the water head elevation and the return and recirculation flows should be incorporated. By choosing a smart configuration the hydraulic energy losses (minimise flow resistance and water heads) can be minimised.

W15. Upflow Sludge Blanket Filtration (USBF).

% Effect	Pay back time	Extra investment
1 – 5%	Dependent on situation	Dependent on situation

The USBF process is a sludge/water separation technique with a V-shaped construction. In this configuration no scraper is required and the return sludge pump requires a lower head of discharge compared to conventional clarifiers. Both differences allow lower energy consumption, but a thorough comparison with conventional clarification has to be made.

W16. Sequencing Batch Reactor (SBR).

% Effect	Pay back time	Extra investment
1 – 10%	Dependent on situation	Dependent on situation

By applying batch wise treatment of wastewater, energy can be saved with respect to recirculation. This operation mode is only applicable for Dry Weather Flow systems or for systems with a very low Rain Weather Flow to Dry Weather Flow ratio. SBR systems can be build modularly, for larger wwtp's more SBR units are required.

W17. Treatment at source.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	> 1.500.000 €

In case of a concentrated discharge (for example from a hospital, or a large residential or office complex) wastewater can be treated locally, thereby decreasing the loading rate on the WWTP. Especially for problematic micropollutants, such as medicines, decentralised treatment might be interesting because degradation from a concentrated flow is easier than from a diluted flow. The energy profit is highly dependent on the current and the reference situation.

W18. Thermal energy exchange.

% Effect	Pay back time	Extra investment
< 1%	> 15	> 1.500.000 €

The temperature of groundwater is reasonably constant throughout the year. This water can be used to heat or cool down office buildings or the water in WWTPs. For WWTPs levelling of the influent temperature can be achieved. The effect of temperature levelling of the influent on the energy consumption is dependent on the specific circumstances at the WWTP. Detailed research is required and thermal energy exchange has not been applied yet in practice at wwtp's.

5.4.4 Equipment

W19. Avoid frequent switching off and on of hardware.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	< 100.000 €

By implementing small adjustments in the process operation, frequent switching of hardware with high energy consumption during the start-up phase can be prevented. Examples are compressors and surface aerators.

W20. Avoid unfavourable ranges for hardware.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 100.000 €

Energy is needlessly consumed when (big) installations (pumps, blowers) operate in unfavourable ranges. In this case the process operation should be adjusted.

W21. Manage scraper operation in clarifiers.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 50.000 €

Energy can be saved by managing the scrapers in clarifiers (primary or secondary) on the basis of the influent flow rate and the return sludge flow rate or in combination with the suspended solids concentration in the aeration tank or of the return sludge, instead of on the basis of a fixed flow rate (usually Rain Weather Flow). To this aim scrapers should have an adjustable speed and adjustments in the operating system (process control) are required.

W22. Advanced pre-treatment (sieves).

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By application of fine sieves/filters instead of primary clarification more BOD can be removed from the wastewater and converted into biogas through digestion. Note that sufficient BOD has to be available in the water to comply with the requirements for nitrogen removal. By improving the digestion process an increase in the nitrogen load in the rejection water can be encountered; in this case advanced side stream rejection water treatment can be applied.

5.4.5 Mixing and propulsion

W23. High efficiency mixers for propulsion and mixing.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 250.000 €

The application of high efficiency stirrers is preferred over conventional mixers due to lower energy consumption. A selection out of different suppliers should be made.

W24. Periodical adjustments in the propulsion propeller operation.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	< 10.000 €

Energy can be saved by optimising the propeller operation on the basis of the measured liquid flow velocity in the tank. Continuous measurements are not feasible due to the difficulty in measuring the velocity profile over the tank. The velocities can be measured periodically and the operation of the propellers can be adjusted. To this aim the propellers require variable frequency drive operation, high/low speed operation or blade operation and adjustments in the operating system are required.

W25. Type and positioning of propellers for propulsion in combination with bubble aeration.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

The choice of type of propellers determines the distance between the propeller and the aerated zone. The aerated zone can be disturbed when the propeller is located too nearby and additional energy is required to realise the desired liquid flow velocity. Positioning the propellers in a bend of the tanks is also not advisable.

W26. Exchange between compartments in direction of flow.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

Between compartments in a wwtp, often liquid flow is exchanged. By realising the direction of the exchanged flow in an angle of the main flow (rather than perpendicular to it), the energy required for liquid propulsion can be reduced.

W27. Mix by aeration instead of propellers.

% Effect	Pay back time	Extra investment
1 – 5%	No investments required	None

By applying bump aeration (intensive aeration during a very short time) during non-aerated periods almost no oxygen is transferred, but the sludge is still mixed. As a consequence propellers might become redundant, thereby reducing the energy consumption.

W28. Switch off propulsion propellers during aeration.

% Effect	Pay back time	Extra investment
1 – 5%	No investments required	None

By switching off the propellers in fully aerated tanks during aeration, energy can be saved with respect to liquid propulsion.

5.4.6 Transport system*W29. Gravity transport.*

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

For newly built WWTPs the construction should aim to utilise gravity transport as much as possible. This reduces the energy consumption for pumping stations. Depending on the specific situation a (partly) underground construction is an option, to optimise the height of the waterline. The higher costs (including the pumping of groundwater during construction) have to be considered in relation to lower energy costs for utilities over a longer period of usage.

W30. Disconnection of rain water.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By disconnection of the rain weather flow from wastewater less water has to be transported to the WWTP. For the WWTP this implies that various devices and tanks can be implemented with smaller dimensions and that various devices are less frequently or intensively in use. Drawback is that in case of "strict" effluent discharge regulations (for example $N_{tot} = 10$

mg/L) the treatment efficiency of the WWTP has to be improved (as rain water has a diluting effect). This requires a higher energy consumption, especially for aeration. The preferable extent of disconnection depends on the specific situation, especially with respect to the influence of the Rain Weather Flow on the treatment process.

W31. Avoid infiltration water.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Infiltration of e.g. (ground)water in sewage systems should be avoided. Sewer infiltration water results in a higher flow rate to be treated by both the sewer and the WWTP. This implies higher energy consumption than necessary for both systems. By avoiding the infiltration of (ground) water less water has to be transported to the WWTP. As a result the installations and tanks can be designed on smaller and various devices are less frequently or intensively in use. Drawback is that because of the lower flow rate the concentrations in the wastewater increase and that in case of "strict" effluent discharge regulations (for example $N_{tot} = 10$ mg/L) the treatment efficiency of the WWTP has to be improved. This implies higher energy consumption, especially for aeration.

W32. Optimise transport system.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By optimising the process control over the pumping stations in the transport system, for example by Real Time Control, the supply of wastewater to the WWTP can be distributed more evenly. This has a positive effect on the energy consumption in the total treatment process.

5.4.7 Exhaust air treatment

A2. Replace compost filters by lava filters.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

The filter type affects the energy consumption of the ventilators by the pressure loss over the filter. For lava filters the pressure difference is more constant in time. Lava filters have superior odour removal efficiency. For newly built exhaust air treatment filters lava filters are preferred.

A3. Breathing filter.

% Effect	Pay back time	Extra investment
< 1%	Dependent on situation	Dependent on situation

If part of the exhaust air contains a low H_2S concentration it might be possible to disconnect this part and install a breathing filter. A breathing filter is connected with the open air and is used without a ventilator. Natural ventilation induces the air flow through the filter. As a consequence less air has to be transported to the (lava) filter and its efficiency will improve. On the other hand the extra investments and exploitation costs for a breathing filter have to be considered.

5.4.8 Air extraction

A4. Optimise air extraction.

% Effect	Pay back time	Extra investment
< 1%	5 - 15	Dependent on situation

By reconsideration of the design principles the possibility of reducing the volume of exhaust air can be assessed. Reduction of the electricity consumption can be realised by technical adjustments such as the installation of smaller ventilators, application of variable frequency drive or the use of time switches.

A5. Reduction of the extracted air volume.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

By reducing the volume of space to be ventilated, the volume of exhaust air can be reduced. Pay attention to minimal requirement.

A6. Regulate air extraction on the basis of H_2S measurements.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	Dependent on situation

By regulating the air extraction on basis of the measured H_2S concentrations the air flow can be reduced.

A7. Increase ventilation flow rate above the aeration tank.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

This measure is only applicable in case of point/surface aeration. When aeration tanks are covered the exhaust air might contain less oxygen than the open air. As a consequence more intensive or prolonged aeration is required. Increasing the ventilation rate above the aeration tank can lead to an increase in the oxygen concentration in the air, resulting in a decrease in the energy consumption for aeration. However, this measure has to counteract with the extra energy consumption by the blowers supplying the air to improve the ventilation rate.

5.4.9 Sludge system

S1. Worm bloom.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Worms reduce the sludge volume in a WWTP, which effects the energy consumption in the sludge line, the transport and the final processing of the sludge. Research into energy profits for the specific location is required.

S2. Timing of sludge transport.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

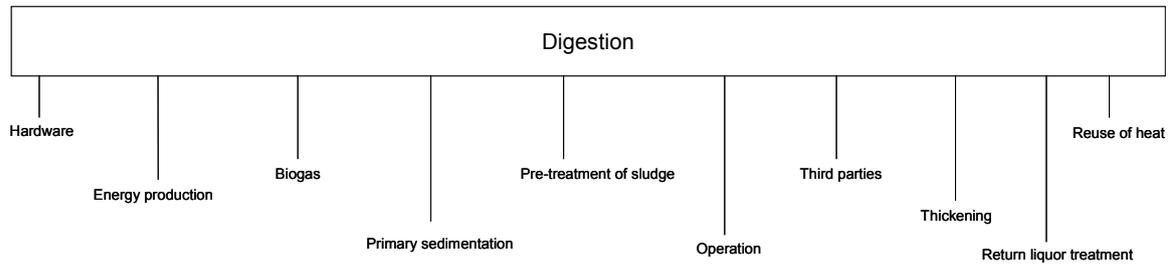
By smartly choosing the moments of (excess) sludge transport fuel can be saved, for example by avoiding traffic jams.

S3. Cannibal.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	> 1.500.000 €

In the Cannibal process the activated sludge is “starved” for a certain period in a separate tank. The sludge will “eat itself” with less net sludge mass as a consequence. This affects the energy consumption in the sludge line, the transport and the final sludge processing of the sludge. This requires additional aeration, however. Research into the energy benefit for the total water chain for each specific situation is required.

5.5 Digestion



In this chapter the energy measures for with respect to digestion are described. The first question is whether it is feasible to digest the sludge at the WWTP and after that measures for hardware, energy production, biogas, primary sedimentation, pre-treatment of sludge, operation of the digester, co-operation with third parties, thickening of the sludge, return liquor treatment and reuse of heat are given.

S4: *Sludge digestion and cogeneration.*

% Effect	Pay back time	Extra investment
>20%	> 15	> 1.500.000 €

In case of the absence of digestion at the WWTP, a digester can be constructed. In addition a combined heat and power installation (CHP-installation) needs to be constructed to generate heat and electricity. Or other equipment capable of converting the biogas into useful energy (like heaters, or transfer of biogas to the natural gas network) can be considered. The choice whether a digestion is feasible depends on the criteria (costs and/or energy) and specific local conditions. Sludge digestion reduces the amount of sludge and the costs related with the transport and removal of it. Secondly biogas is produced which can provide savings on purchasing electricity. The economic feasibility depends on the investment, and savings on operational costs and on the financial criteria for return on investments. Economy of scale is important for the economic feasibility of digestion. For that reason, digesters mainly are realised at larger wwtp's. However, transport of sludge from different smaller wwtp's to a larger digestion facility at a wwtp can provide an increase of scale also.

5.5.1 Hardware

S5. *Thermophilic or multiple stage digestion.*

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By operating the digestion process at a higher temperature (thermophilic) or operate a multiple stage digester the conversion efficiency in the process can be increased. Stability of the process is a point of attention. Application depends on sludge characteristics, specific point of attention is inhibition by ammonia.

S6. *Utilise existing digestion capacity.*

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In case of excess digestion capacity this can be complemented with sludge from other wwtp's or organic waste suitable for digestion (from third parties). This can have a positive effect on the degradation of the sludge, resulting in a higher biogas production. The possibilities are strongly dependent on the specific situation (and the permit).

S7. *Insulation of (old) digesters.*

% Effect	Pay back time	Extra investment
< 1%	5 – 15	< 100.000 €

By insulation measures the temperature in the digester remains higher and the conversion process is improved. This results in a higher biogas production. In addition less heat is re-

quired for maintaining the required temperature in the digester. This is of importance for useful application of the biogas. This measure is in particular applicable for older digestion tanks.

S8. Sand removal prior to sludge treatment.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In the course of time sand accumulates in the digester. To prevent this, measures can be taken to remove sand in the sludge- or waterline before it ends up in the digester. When this can not be prevented, the degree of sand accumulation is strongly depending on the measures for removal of sand in the water and sludge line, the mixing in the digester and the volume of sand that is supplied with the wastewater. The sand in the digester causes a reduction of the effective residence time in the tank and thereby results in a lower conversion efficiency of the sludge. This also results in a lower biogas production.

To prevent sand entering in the digestion, sand can be removed prior to the sludge treatment by e.g. sand cyclones.

5.5.2 Energy production

S9. Direct operation compressor/blower by gas motor.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Direct operation (instead of electricity) of the compressor/blower with produced biogas by a gas motor can often be applied in combination with a conventional Combined Heat Power installation (CHP installation) to utilise the gas in case of a low aeration demand. The CHP installation produces electricity which can be used at the WWTP, or can be supplied to the network.

S10. Energy production in small gas turbines or gas engines.

% Effect	Pay back time	Extra investment
Dependent on situation	> 15	Dependent on situation

Energy production in several small gas turbines rather than one big one, thereby coping more flexible with variations in the biogas supply. Point of attention is that bigger gas turbines have a higher efficiency.

S11. Add small gas turbine or extra biogas buffer.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In case of a temporary gas surplus a small gas turbine can be added, thereby increasing the biogas usage for energy production at the WWTP. In addition fluctuations in the biogas supply can be handled more flexible. Additional buffering capacity for the biogas is also possible. The advantage is that flaring or storing of biogas is less or not required. Additional maintenance is required, however.

S12. High efficiency heat power coupling.

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	< 250.000 €

In case of a newly built WWTP application of a high efficiency combined heat and power (CHP-) installation can be a good investment. Electric efficiency of 38-42% can be achieved. Applying ORC (Organic Rankine Cycle) technology additional to a heat and power installation can increase the electric efficiency to 45%. ORC technology is based on evaporation and condensation of organic solvents. For cost efficient use, relatively large (> 1 MW electricity) heat and power installations are required.

S13. Optimise heat power coupling.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Be alert for maintaining maximum efficiency of the CHP-installation by adequate maintenance. Compare performance with specifications from supplier.

S14. Gas conditioning prior to heat power coupling.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By improving the gas quality (less polluted) the efficiency of the CHP-installation can be improved. Check specifications of supplier for specific components.

S15. Fuel cells for higher efficiency.

% Effect	Pay back time	Extra investment
10 – 20%	> 15	> 1.500.000 €

WWTPs with a digester and gas turbines/cogenerators usually have a surplus of heat energy and a considerable lack of electricity. Application of fuel cells can produce considerably more energy than gas engines or gas turbines; in addition the total efficiency (heat and electricity) on the biogas utilisation increases. Fuel cells based on biogas are available, but still developing. Efficiency amounts to 45%.

5.5.3 Biogas

S16. Utilisation of the heat buffering capacity of the digester.

% Effect	Pay back time	Extra investment
1 – 5%	No investments required	None

The temperature in the tank is usually maintained at 33 ± 2 °C. In case of a heat surplus an increase of the temperature to 36 °C does not cause a provable disadvantageous effect, but a higher biogas production on the contrary. Additional heating in periods that the temperature is not reached are required less frequently.

S17. Blend biogas with natural gas.

% Effect	Pay back time	Extra investment
>20%	> 15	Dependent on situation

When the supply of biogas is lower in certain periods and the capacity of the gas engine is not fully utilised, blending with natural gas allows for continuous running of the gas engine ensuring an acceptable efficiency.

S18. Transport biogas to third parties.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

After minor post-treatment the biogas can be transported by pipeline to a location that has better possibilities for supplying surplus heat or electricity generation at a higher efficiency. In case of electricity generation at the WWTP from biogas, alternative electricity supply provisions are required. Transport distance is an important cost factor. Complete energy balance should be calculated for best option.

S19. Convert biogas into methane and supply it (back) to the gas network.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Biogas can be upgraded to natural gas. The natural gas can be supplied to the network. Part of the biogas can be used for heat production for the digester. When in the previous situation electricity was produced at the WWTP from biogas an additional electricity supply is required. A complete review on the energy production and energy consumption is necessary to determine whether electricity (primary energy) is conserved.

S20. Installation of (additional) gas storage buffer.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Supplementary buffering capacity can yield an improved annual average biogas utilisation. This requires regular surplus biogas production and a useful application of the gas.

5.5.4 Primary settling

S21. High efficiency primary settling.

% Effect	Pay back time	Extra investment
5 – 20%	< 5	< 100.000 €

By dosing a polymer (PE) or a metal salt the production of primary sludge in the primary clarifier can be increased. Primary sludge has more favourable digestion properties than secondary sludge, resulting in a better digestion and a higher biogas production. However, more chemical sludge is produced by the addition of metal salts, which causes extra costs for sludge disposal. Attention should be paid to the effect of a better primary clarification on the nitrogen removal later in the waterline. Usually a higher efficiency results in an unfavourable BOD/N ratio and can cause problems with respect to the denitrification. Application of energy conserving sidestream techniques for nitrogen removal can provide a solution. A lower BOD loading rate can also affect the bio-P removal.

5.5.5 Pre-treatment of sludge

S22. Sludge disintegration techniques prior to digestion: ultrasonic/hydrodynamic.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 500.000 €

By applying sludge disintegration techniques prior to the digestion process (ultrasonic, hydrodynamic), an improved degradation can be affected in the digestion. In addition the biogas production can be increased. The extra energy required for sludge disintegration has to be optimised with the extra energy from the biogas. Cost reduction by reduction of the final sludge volume can be achieved.

S23. Sludge disintegration techniques prior to digestion: high pressure, thermal hydrolysis, Cambi.

% Effect	Pay back time	Extra investment
1 – 10%	> 15	> 1.500.000 €

By applying sludge disintegration techniques prior to the digestion process (high pressure, thermal hydrolysis, etc.) an improved degradation can be affected in the digestion. High temperature and pressure disrupts the biomass in the sludge and releases components which can be digested. In addition the biogas production can be increased. The extra energy required for sludge disintegration has to be optimised with the extra energy from the biogas. Cost reduction by reduction of the final sludge volume can be achieved. Also dewatering characteristics improve.

5.5.6 Operation

S24. Constant feeding of the digester.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

Uniform supply to the digester enables a constant biogas production. As a consequence the gas engines can operate at a constant rate and the need for flaring biogas peaks is reduced. Uniform supply can be realised by buffering the primary sludge in the primary clarifier, the thickener or a new buffer tank, thereby preventing a peak gas production during the first flush.

S25. Proper mixing in the digester.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 50.000 €

Proper mixing in the digester is required to ensure uniform distribution in the tank. Adapt operation with existing means, by adapting the mixture regime with operational measures (process control of mixing: frequency, intensity). By this an optimum gas production can be achieved. Mixing costs energy, so the costs and profits have to be considered.

S26. Mixing in the digester with a mixer instead of blowing gas to the digester.

% Effect	Pay back time	Extra investment
1 – 5%	< 5	< 100.000 €

Replacing the gas input by a mixer, energy can be saved in mixing. Energy efficiency depends on size of digester. Specific design must be made.

S27. One-time removal of sand from the digester.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

See S8 for explanation. This specific measure is the removal of sand from the digester. For that the digester has to be set out of operation. The removal can be done when the amount of sand accumulation obviously is too high, or can be done on a more regular basis to prevent an unacceptable accumulation.

S28. Maintenance removal of sand from the digester

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 500.000 €

See S8 for explanation and S27.

5.5.7 Third parties**S29. Use waste heat from surroundings.**

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Waste heat from the surroundings, for example from an industry, can be used for heating buildings, digesters, influent and for dewatering or drying of sludge.

S30. Supply waste heat to third parties.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

The waste heat released from cogeneration that cannot be used at the WWTP, can be supplied to third parties such as industries or urban settlements. Attention has to be paid to legal aspects such as supply guarantee.

5.5.8 Thickening**S31. Mechanical thickening instead of gravitational thickening of sludge.**

% Effect	Pay back time	Extra investment
Dependent on residence time and digestion process	Dependent on situation	< 500.000 €

By applying mechanical thickening instead of gravitational thickening a higher dewatering level can be achieved. As a consequence the sludge enters the digester with a higher suspended solids concentration and the retention time can be increased, resulting in a higher biogas production.

S32. PE dosing.

% Effect	Pay back time	Extra investment
Dependent on residence time and digestion process	Dependent on situation	< 10.000 €

By dosing a polymer (PE) in the gravitational sludge thickener the suspended solids concentration can be increased. As a result the residence time and the biogas production in the digester can be increased. The achievable suspended solids concentration through PE dosing is lower than in case of mechanical sludge thickening. The investments for dosing equipment are also lower, however.

5.5.9 Return liquor treatment**S33. Treatment of return liquors with SHARON.**

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	0,5 – 1,5 € / kg N removed

In the SHARON process (Stable and High rate Ammonia Removal Over Nitrite) first ammonium is oxidised into nitrite under aerobic conditions (nitrification) and subsequently converted into nitrogen gas by addition of a carbon source under anoxic circumstances (denitrification). The denitrification process is particularly intended for pH correction of the process, assuming that nitrite is easily denitrified in the process. Compared to conventional N-removal, energy is saved. A temperature of 30-40 °C is required.

S34. Chemical nitrogen precipitation to struvite.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	Dependent on situation

In the struvite process phosphorus is removed from return liquor by precipitation of the phosphate with magnesium and nitrogen into struvite (MgNH₄PO₄, Magnesium-Ammonium-Phosphate (MAP)). The composition of the MAP is a critical factor to utilise as fertiliser.

S35. Anaerobic de-ammonification.

% Effect	Pay back time	Extra investment
10 – 20%	5 – 15	0,5 – 1,5 € / kg N removed

De-ammonification is a biological treatment process for the degradation of ammonium from wastewater, by converting ammonium into nitrogen gas under anaerobic circumstances by using nitrite. This process is autotrophic and does not require the addition of a carbon source. The process consists of two steps: nitrite formation from ammonium and the combining of nitrite and ammonium to nitrogen gas. The process is applicable for highly concentrated waste waters such as return liquors. Low C/N ratio and high temperatures are a requisite. (Techniques: Anammox – Anaerobic AMMONium Oxidation, DEMON – DE-amMONification)

S36. Two-stage Sharon-Anammox process with 2 reactors.

% Effect	Pay back time	Extra investment
10 – 20%	> 15	1,0 – 3,0 € / kg N removed

Nitrite formed in a separate Sharon process without denitrification reacts anaerobically with ammonium in the Anammox process and is converted into nitrogen gas. In the anaerobic oxidation of ammonium specifically Anammox bacteria are involved. The Sharon process converts ammonium into nitrite until a suitable ratio between ammonium and nitrite is reached. From this process 1 large scale reference is available. Nowadays processes can be performed in 1 step (S19).

5.5.10 Reuse of heat

S37. Reuse of low value heat

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

The effluent, digested sludge and excess sludge contain low value heat. This is heat with a relatively low temperature (typically less than 80 °C). This residual heat can be reused in various ways. The heat energy of digested sludge can be used to preheat the sludge that is supplied to the digester. Using a heat pump the low value heat from a big flow can be converted to a small flow of useful heat. This energy can be used to heat up buildings, heating of influent or sludge that has to be dewatered, or for drying of the sludge.

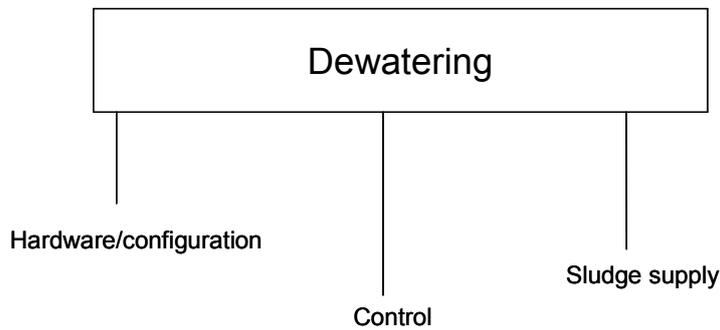
S38. Reuse of heat from gas engine exhaust gases.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In case of surplus heat production in e.g. a gas engine, heat can be used to maintain the right temperature in the digester, heat the influent, or heat the sludge to the dewatering installation. The effect of heating the influent on the actual energy saving is strongly dependent on the situation. There is a positive effect due to the fact that less sludge is required and a negative effect due to a higher required oxygen input at higher temperatures. When the sludge is warmer it has better dewatering properties. At the same dewatering percentage this results in a lower energy and polymer consumption. These values can also be kept con-

stant, resulting in a higher final dewatering percentage. This can result in lower costs for the final sludge deposition. The latter does not yield energy saving, but it is important for efficient chain management.

5.6 Dewatering



S39. Feasibility of dewatering

By dewatering the sludge, for example to a dry solids content of 20-25%, cost for transport is saved. Also the caloric value of the sludge is increased, due to the removal of water. Whether dewatering economical feasible is site specifically determined and depends on the costs of transport and sludge disposal. For reasons of economy of scale, the dewatering can be regionally centralised at larger wwtp's. Sludge from smaller wwtp's can be thickened on site and transported to the central dewatering facilities. The dewatering characteristics of sludges may differ. Appropriate mechanical dewatering units should be used depending on the sludge properties, considering the demands on percentage dry-solids and the energy requirements.

5.6.1 Hardware/configuration

S40. Belt press instead of centrifuge after thickening.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Applying a belt press instead of a centrifuge for sludge dewatering after thickening of the sludge reduces the energy consumption. Take into account the achievable dry matter content.

S41. Cascade line-up and belt press for direct sludge dewatering.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Application of a cascade line-up with a belt thickener and belt press or belt press with extended dewatering table instead of a 1-stage centrifuge for direct sludge dewatering reduces the energy consumption.

S42. Belt press for sludge dewatering after digestion.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Application of a belt press instead of a centrifuge for sludge dewatering after digestion leads to reduced energy consumption. Take into account the achievable dry matter content.

S43. Dry matter content in the dewatering installation.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By choosing for a type of sludge dewatering with a high residual suspended solids percentage (for example membrane filter presses) energy can be saved with respect to the transport mileage and the final sludge processing. Optimise the energy consumption for the dewatering, the transport of sludge and the final sludge processing.

S44. Drainage of water from the activated sludge storage.

% Effect	Pay back time	Extra investment

Dependent on situation	Dependent on situation	< 50.000 €
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Costs and energy consumption for transport can be decreased by improving the drainage of water from storage of activated sludge. Proper design of settlers/buffers with sufficient residence time is required.

5.6.2 Control

S45. Back drive operation on centrifuges

% Effect	Pay back time	Extra investment
< 1%	No investments required	None

Generate electricity with an energy recovery unit during deceleration of the centrifuge.

S46. Control system for operation of the centrifuges.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 50.000 €

A control system can be designed to cope with fluctuations in the suspended solids concentration of the supplied sludge (flow rate), whilst producing a constant final dry matter content. For this purpose the flow rate and the suspended solids of the incoming flow are measured, as well as the suspended solids of the centrate. By operating on the basis of the actually measured value of the supply flow rate and/or the centrifuge operational settings, a constant final dry matter content can be reached. This results in a lower transport volume to the final sludge processing and the saving of energy in the chain. In this operation mode the dewatering process will consume less energy and polymer.

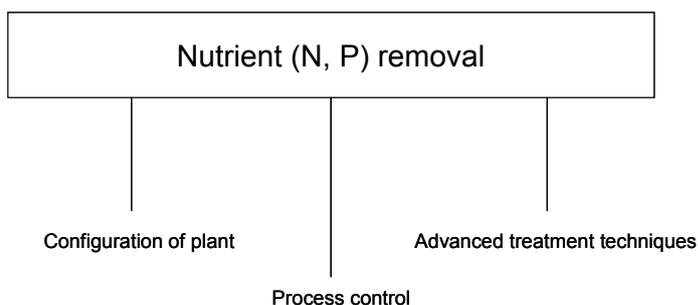
5.6.3 Sludge supply

S47. Well mixed sludge to the dewatering installation.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

By transporting well mixed sludge to the dewatering installation the process will operate at more constant conditions. This results in a lower transport volume to the final sludge processing and a reduction of the energy consumption in the chain. Likely the dewatering process requires less energy and polymer dosing. Regular feeding can be realised by buffering primary sludge in the primary clarifier, thickening tank or new buffer tank.

5.7 Nutrient (N, P) removal



W33: Removal of nutrients

Whether removal of nutrients (nitrogen, phosphorous) is required depends on specific legislation and local conditions related to the receiving surface water. With the removal of nutrients significant costs and energy consumption is involved. In agricultural areas, and specifically dry areas it might be an option not to remove nutrients and use the effluent for irrigation purposes in agriculture. In this way water and nutrients are re-used.

5.7.1 Configuration of plant

W34. Creation of additional anoxic volume.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 10.000 €

By realising additional anoxic volume in order to enhance denitrification, aeration energy can be saved, because oxygen is recovered through the conversion of nitrate.

W35. Choose the energetically most favourable design.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By finding the optimum system with respect to hydraulics and technology energy can be saved, especially with respect to recirculation flows. An example of this is the Phoredox process which is interesting from an energetic point of view, whereas from a technological point of view the M-UCT process is generally preferred. This measure relates to the position of compartments, tanks, piping to reduce hydraulic head loss and minimise energy requirement for pumping, recirculation and mixing.

W36. Managing return sludge flow rate.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 100.000 €

The return sludge flow rate can be managed by measuring the sludge level and the turbidity in the clarifier, the influent flow rate, the suspended solids concentration in the aeration tank or on the basis of a mass balance over the clarifier. Pumping of return sludge takes place as required. An interesting possibility for systems with a high head of discharge could be to return sludge from the clarifiers alternately, effecting thicker sludge to be returned.

W37. Regulate nitrate recirculation to the anoxic zone.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 100.000 €

Energy can be saved by regulating the recirculation from the aerated zone to the anoxic zone on the basis of the nitrate concentration using an additional nitrate or redox sensor. The location of the sensor(s) depends on the situation.

5.7.2 Process control

W38. Couple aeration rate to process parameters.

% Effect	Pay back time	Extra investment
10 – 20% (oxygen)	< 5	< 100.000 €
1 – 5% (redox)	< 5	< 100.000 €
1 – 10% (ammonium/nitrate)	< 5	< 100.000 €

By making the supply of oxygen by the blowers dependent on the online dissolved oxygen concentration measurements, redox measurements or ammonium/nitrate concentration measurements the system can be operated on the basis of the actual oxygen requirement. To this aim a sensor (or multiple sensors) should be implemented in the controls of the process.

W39. Optimise position and number of sensors.

% Effect	Pay back time	Extra investment
1 – 5% (position)	< 5	< 10.000 €
1 – 5% (number)	< 5	< 100.000 €

By adjusting the position or the number of sensors the aeration input can be controlled more accurately on the basis of the actual oxygen requirement of the system. Modelling the process can be used to optimise the position and the number of sensors. The position depends on the configuration of the tanks. Typically ammonia, phosphate and nitrate sensors are placed at the overflow to the secondary settling tank, position of oxygen sensors strongly depends on specific situation.

W40. Regular calibration of the sensors.

% Effect	Pay back time	Extra investment
1 – 5%	< 5	< 10.000 €

The accuracy of sensors (oxygen, ammonium, nitrate, redox) decreases in time. Regular calibration can provide more accurate operation of the system on the basis of the actual oxygen requirement.

W41. Optimise phosphorous removal.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Phosphorus has to be removed as much as possible biologically, thereby minimising the chemical dosage for phosphorous removal. Chemical phosphorous removal results in a higher (chemical) sludge production and a higher energy consumption during sludge treatment. This might result in less BOD to be available for denitrification, but no clear judgement is available about this. Chemical sludge has a positive effect on the ability of dewatering of the sludge. The advantages and disadvantages of minimising the dosage of chemicals for P-removal is specific for each WWTP and should be optimised for each case.

5.7.3 Advanced treatment techniques

W42. De-ammonification

% Effect	Pay back time	Extra investment
Research phase	Research Phase	Unknown (research phase)

Anammox (de-ammonification) bacteria convert ammonium and nitrite in the wastewater into nitrogen gas, which provides a significant energy reduction with respect to nitrogen removal. Technology is developing. Full scale applications are known for higher temperatures and concentrated wastewaters (for example treatment of return liquor from sludge dewatering).

W43. Aerobic granular sludge (Nereda).

% Effect	Pay back time	Extra investment
Research phase	Research Phase	Unknown (research phase)

Nereda is a fed-batch operated process with aerobic granular sludge for the treatment of municipal wastewater. On the basis of pilot-scale experiments and calculations for full-scale application an energy reduction can be expected compared to conventional wastewater treatment, mainly because of a higher applicable water head and the advantages with respect to aeration. Full-scale experience is still required to confirm this. Depending on the rate of clarification a drum sieve has to be installed to remove fine particles.

W44. Urine separation.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By separating urine and faeces more efficient wastewater treatment is possible. The scale of treatment plays a major role and a thorough analysis has to be made. Process can also be applied in rural areas where sewage networks are absent. Applications in city's might also be considered, for example for new city extensions and larger buildings like apartment complexes, hospitals, offices, etc.

6 Cases and Examples

6.1 Cases from Turkish practice

To test whether this energy efficiency guide line, the decision tree and the accompanying measures are fit to the purpose, three different Turkish cases were selected for testing:

1. Existing central wwtp Ankara
2. The design of the Temelli wwtp in the south of Ankara
3. The planned Kizilcahamam wwtp (small scale)

The cases were discussed with representatives from these projects.

From the cases it was concluded that the decision tree is a helpful tool to identify energy efficiency measures. Concrete measures could be selected. An overview of the measures selected is given below. The numbers refer to the numbers of the measures from the guide line.

Selected measures for central wwtp Ankara

W2/W6	apply bubble aeration or plate aeration
W7	centrifugal compressors instead of displacement or root compressors
S12	high efficiency co-generation + ORC
S31	mechanical thickening of sludge to increase retention time in digestion
S19	convert biogas in to methane gas
S26	mechanical mixing in digestion
S40	apply belt presses in stead of (new) centrifuges
S21	dose poly-electrolyte on primary settlers
S32/S35	apply reject water treatment for future nitrogen removal
S7	Insulation of (old) digesters
S18	Extra gas storage
W38	Control of oxygen concentration
S27/S28	remove sand from digestion
Others	apply mechanical sand-trap in stead of aerated sand-trap apply frequency converters for blowers (presently soft-starters are used)

Selected measures for Temelli wwtp

W6	apply plate aeration
W38	ammonium control of aeration
W14	lower depth of construction to lower energy for pumping of influent
W11	process operation on the basis of sludge age
S4	apply digestion (including primary settling) and co-generation
W35	apply pre-denitrification
S40	apply belt presses in stead of centrifuge/decanter
Others	apply mechanical sand-trap in stead of aerated sand-trap

Selected measures for Kizilcahamam wwtp

W14	Optimize configuration <ul style="list-style-type: none"> - use available hydraulic head, prevent pumping - reduce number of piping and connections to reduce head loss - one secondary settling tank in stead of two
W35	apply pre-denitrification
S40	apply belt presses in stead of centrifuge/decanter
W6	apply plate aeration
S4	apply digestion (including primary settling) and co-generation, consider co-operation with neighboring small scale wwtp's to consider central digestion