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Climate change mitigation and energy efficiency: challenges in the wastewater sector

Experiences in Sweden, France and Australia

Mathilde Mansoz

Supervisors

Naoko Tojo

Åke Thidell

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Published in 2010 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

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Abstract

The wastewater sector provides water sanitation to populations in order to preserve human health and the natural environment. In developed countries, due among others to increasing pressures coming from climate change and population growth, the wastewater treatment is affected and needs to adapt to such changes. As a result, effluent requirements are becoming more stringent, nutrients and organic removal capacity increases. But also new uncertainties surround this sector. For example, how population habits will change in the future in terms of water use, quantitatively and qualitatively? A transition towards more a sustainable society is slowly taking place, and within the wastewater sector the transition towards new innovative systems is happening, as illustrated by the case studies performed in Sweden, France and Australia.

More often than not, these considerations and the pressing necessity of preserving the natural environment lead to an increase of the amount of energy required for processing the sewage. In addition, increasing energy prices, the reduction of availability of fossil-fuel-based energies, and GHG emissions targets impact more and more the way the water and wastewater sector operate. Energy and climate policies as well as legislation also affect wastewater treatment plants. Despite the fact that the wastewater sector is not energy intensive, no sector in today’s society can be exempted from acting on its impact on the environment and from reducing its use of fossil-fuel-based energy. Large organizations are starting to develop strategies to reduce their GHG emissions and develop more efficient energy systems.

Besides operating processes more efficiently in terms of energy and GHG emissions releases, a way forward is to look at the content of wastewater which is rich in resources: water, nutrients and energy. These resources can be valorised as by-products. In the past, it has been common practice in many developed countries to convert the sludge originated from the wastewater treatment into fertiliser for the agriculture purposes. More recently, biogas has started to be produced through sludge digestion, thereby creating synergies between the wastewater sector with other sectors such as transportation, an intensive energy sector. In fact, wastewater treatment can be one of the rare renewable energy sources available in the urban environment. Innovation and technology support these developments, but policies and legislation also need to be adapted to valorise the potentials and opportunities throughout the transition towards a more sustainable urban water management.

Executive Summary

The role of wastewater treatment plants (WWTPs) is to provide sanitation to the populations and to preserve the environment by removing pollutants and substances from the wastewater before discharging the processed water into water receiving bodies. Wastewater from households and industrial activities contains organic matters, nutrients, hazardous and pathogenic substances which put pressure on the environment and constitute risks to human health. In the developed countries, treatments have evolved throughout the years with the legislation playing an important role in establishing water quality objectives, preventing and improving current pollution in water bodies.

The water and wastewater sector is in fact not a high energy intensive sector: it represents 1% of the electrical energy consumed in Sweden (of which approximatively half of it consumed by the wastewater sector) but in terms of GHG emissions, the impact of the activities of the wastewater plants could be more significant. Besides, all sectors of the society have to take action to mitigate and adapt to climate change. In the context of climate change and the development of urban sustainability, there is a need to identify current challenges and opportunities for WWTPs to take part in urban sustainability. The aim of this research is to identify current challenges WWTPs are faced with, and determine the influencing factors for the plants to improve their energy consumption hence contributing to climate change mitigation through experiences in three different countries: Sweden, France and Australia. This research is based on exploratory case studies conducted in several WWTPs. In Sweden, they are medium sized WWTPs: Källby, part of VA SYD and based in Lund in the Skåne county, and Nykvarnsverket, part of Tekniska Verket, located in Linköping in the Östergötland County. In France, the study case has been conducted on three plants part of a regional authority that treats wastewater in the Paris agglomeration, the "Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne" (SIAAP): Seine Aval the largest plant, Seine Grésillons, and Seine Morée a plant currently in construction. The SIAAP is one of the biggest wastewater organization in the world, processing wastewater of 8.5 million people. The case study on Australia has been conducted on Melbourne Water, located in Melbourne, and its two treatment plants: the Western Treatment Plant and the Eastern Treatment Plant to which 3 million Melburnians are connected.

The analytical framework chosen for the purpose of this research is the transition management theory developed by Kemp (Kemp et al., 2007). Transition management is a multi-level mode of governance, which happens in a transitional manner when three levels of governance interact: strategic, tactical and operational (Kemp et al., 2007). Typically, a transition happens in different phases: pre-development, take-off, breakthrough and stabilisation. The three levels of governance defined are operational, tactical and strategic. For each plant studied, measures taken at the three levels were identified through on-site visits, interviews (semi-structured and structured for follow-ups), as well documentation available from the authorities such as sustainable reports and internal documents provided for the purposes of this research. Through analysing case studies, influential factors for WWTPs to take part into climate mitigation and develop more efficient energy systems were established. The degree of interaction leading to assess the transitional degree towards sustainability between the three levels is discussed thereafter.

The two WWTPs in Sweden perform well in energy efficiency. Sweden is one of the early countries in the EU to have integrating energy efficiency concerns in its policies, and Svenskt Vatten, the Swedish Water and Wastewater Association, has been developing an energy project for the water sector since 2005. This might partly explain why those two

plants perform well in terms of energy consumption. Recently both plants have improved their aeration system in the biological treatment, one of the most consuming step of the wastewater treatment. However implementing new processes may not be straight forward. First of all, there must be a recognition and incentives for encouraging plant operators and engineers to develop new solutions. Second of all, it happens that the layout of the plants themselves does not allow improvements due to the initial design. Treatment plants have a life time estimated at 50 to 60 years, and often in the past, units have been stacked onto each other which causes technical issues today. The SIAAP, besides introducing new treatment units at Seine Aval, is extending an existing plant (Seine Grésillons) and building a new plant (Seine Morée) in which energy systems are being valorised through energy recovery (cogeneration) and the development of local synergies. Melbourne Water is adding a tertiary treatment in one of its plants to improve water treatment quality, and the company has been significantly increasing its biogas production. It has set two ambitious objectives: to become carbon neutral and energy self-sufficient by 2018.

These new developments in developing local synergies and developing more performing energy systems challenge somehow the current legislation: the plants are acquiring new competencies, and sewage treatment do not have for example the status of energy producers. In that sense, there is a need for more cooperation between the regulatory authorities and the wastewater sector. What has been emerging recently is that wastewater treatment plants are in fact one of the main sources of renewable resources in the urban environment: water, nutrients (phosphorus and ammonia), and energy potential (biogas, heat). Their role and function within the urban environment need to be adapted and opportunities developed. The development of by-products from resource recovery can be promising.

Besides carbon dioxide, WWTPs also emit methane and nitrous oxide which methane and nitrous oxide have much higher global warming potentials than carbon dioxide. Yet methodologies to estimate GHG emissions vary and are scientifically insufficient. This fact was highlighted in the case of Melbourne Water, which depending on methodologies used emit GHG emissions 237 800 tCO_2-eq. or 478 800 tCO_2-eq. in 2008/2009. This is a significant difference that is important with regards to the development and implementation of strategies to mitigate climate change (Melbourne Water aims at becoming carbon neutral by 2018) and the development of national climate and energy policies to reduce carbon impact. Moreover, WWTPs are confronted with the increase of energy prices and the reduction of fossil-fuel based resources. Increasing energy autonomy by valorizing the energy potential throughout the wastewater processes are another way forward. The Western Treatment Plant at Melbourne Water has the power capacity to meet 95% of its energy need by converting biogas into electricity.

The wastewater treatment sector is at the beginning of a new transition led by the effects of climate change that encompasses today all sectors of the society. This research aims at identifying and understanding what are the challenges today and how WWTPs are responding to it. It also highlights the need for further research in this field to support the development of legislation and policies and to investigate resources recovery from the wasterwater. Synergies with other sectors such as transportation or the waste sectors seems to be promising. Besides biogas production that is increasing and the use of the sludge as fertiliser due to its content in phosphorus, new opportunities need to be further investigated and appropriate policies and legal frameworks to be established accordingly. In that sense, the Melbourne Metropolitan Sewage Strategy might represent a groundbreaking work upon its completion.

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Abbreviations

BOD	Biological Oxygen Demand
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CO_2-eq. / tCO_2-eq.	Carbon Dioxide Equivalents/tonnes Carbon Dioxide Equivalents
GHG	Greenhouse gas
GJ	Giga Joules
GWh	Gigawatt hour
IWRM	Integrated Water Resource Management
KWh	Kilowatt hour
m^3	Cubic metre
MW	Megawatt
MWh	Megawatt hour
N_2	Gaseous form of nitrate
N_2O	Nitrous Oxide
Nm^3	Normal cubic meter. It corresponds to the volume of dry gaseous effluent that occupies 1 cubic meter at a temperature of zero degrees Celsius and at an absolute pressure of 101.3 kilopascals.
p.a.	per annum
p.e.	population equivalent
t.	tonnes
TJ	Tetra Joules
UNFCC	United Nations Framework on Climate Change
WWTP	Wastewater Treatment Plant

1 Introduction

1.1 Background

With the intensification of industrial development in the 20th century came pollution. Heavy industries such as steel, chemical, pulp and paper, or food started to discharge wastewater containing growing quantities of pollutants and hazardous substances in water sources creating environmental problems such as eutrophication disturbing biodiversity. With the development of standards of living, private water consumption also increases: washing machines, dish washers, cooking, hygiene and sanitation, as well as embbeded water present in products such as food or clothing. High temperatures and reduced precipitations levels can lead to shortages in water supplies, reduced surface water and slower replenishment of underground water resources affecting water management. Rising sea levels and floodings led to inundation and blockage of natural drainage structure also affecting water management. Because the water used, also called sewage, is discharged into natural water bodies to maintain the hydrological flow, water consumed by industries and private individuals need to be treated to protect natural resources, biodiversity and human health. The introduction of sewage systems and wastewater treatment in the 19th century have been considered as one of the most sucessful medical intervention of all time (Priestley, 2010).

To that purpose, wastewater treatment plants started to appear in the early 1930s in Europe applying very basic treatment to water. With the development of the industry and the pollution, WWTPs became more prominent in the 1960s. Until the 1970s, the treatment objectives were to remove suspended and floatable materials, to treat biodegradable organics and to eliminate pathogenic organisms. From the 1970s until 1980, concerns on environment and aesthetics started to appear and consequently Biological Organic Demand (BOD) and Total Suspended Solids (TSS) were reduced. Since then, further concerns about health and environment appeared progressively and the degree of treatment has increased significantly (Metcalf et al., 2003) and is still doing so (refer to the Appendix III for more details on treatment processes). Treatment objectives must correlate with water quality objectives established by regulatory bodies and legislation has progressed throughout the years, imposing more stringent treatment and integrating the concept of Integrated Water Resource Management (IWRM). Today, besides negative effects of climate change that needs to be mitigated, worldwide population growth reinforces the need to protect water and causes challenges regarding water availability, distribution, and treatment. In certain parts of the world where droughts are becoming more and more frequent, water is becoming a precious resource that needs to preserved and re-used. Communities at national and local levels are becoming more and more concerned, which globally lead to reflect upon and adapt the concept of urban water management. WWTPs represent an important part of urban water management: they collect, treat wastewater before rejecting it into the natural hydrological and ecological cycle. By mimicking natural chemical systems, they ensure the good perpetuation of the natural water cycle. But the more pollution they have to treat, the more they also pollute and contribute to climate change. Major environmental impacts from WWTPs are human health effects due to non-carcinogens, aquatic ecotoxicity due to residual metal concentrations, terrestrial ecotoxicity due to effects of metals from biosolids disposal, and aquatic eutrophication due to the presence of nutrients such as phosphorus and nitrogen released in the receiving water bodies (Foley, 2008). WWTPs consume considerable energy during their operational life, and consequently contribute to CO_2 emissions (Muga et al. 2007). The other GHG emitted by WWTPs and contributing to climate change are methane (CH_4), Nitrous Oxide (N_2O) and halocarbons (fluorine, chlorine, bromine).

In Sweden, water utilities consumes about 1% of the electrical energy consumption to distribute water and treat wastewater (Olsson, 2010). In the United States and in the United Kingdom, the proportion of electrical energy used in the water sector amounts to 3%, and represents as much as 10% in Israel (Olsson, 2010). Energy consumption to treat wastewater varies from plants to plants, but generally about half of this is used for water treatment. In Sweden, for example, amongst water utilities, 46% of electrical consumption is attributed to WWTPs (Figure 1-1). As such the water sector is not one of the main energy consumers compared to other sectors such as transport. However, as energy prices are on the rise and treatments have become more and more energy intensive, energy expenses come to represent higher proportion of operational costs, between 8 and 12% in Sweden (Lingsten et al. 2008 quoted in Olsson, 2010).

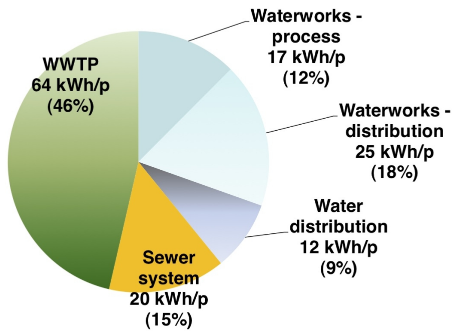

Figure 1-1: Electrical energy consumed in the water sector in Sweden. Source: Svenskt Vatten, 2009.

The Intergovernmental Panel on Climate Change (IPCC), the most recognized authority providing arguably the best approximation of worldwide consensus on climate change, characterises climate change worldwide increasing temperature, precipitation changes, sea-level rise and extreme events happening more frequently. Eleven of the last twelve years are the most warmest years since 1850 (IPCC, 2007). Since the industrial revolution, the earth has warmed by 1.4 Cº due to the accumulation of GHG in the atmosphere. The January-July 2010 period has been the warmest period on record with a global land and surface temperature of 14.5 Cº, 0.68 Cº above the 20th Century average (National Oceanic and Atmopsheric Administration, 2010). Global GHG emissions due to human activity have increased by 70% between 1970 and 2004 (IPCC, 2007). Carbon dioxide (CO_2) is the most important anthropogenic gas: its annual emissions have increased by approximatevely 80% between 1970 and 2004 representing 77% of total anthropogenic GHG emissions in 2004 (IPCC, 2007). Climate instability create storms, droughts also affecting water quality, distribution and treatment. Worldwide population is currently projected to exceed 9 billion people by 2050 (U.S. Census Bureau, 2010) increasing the strain on water resources and environmental protection capabilities. Though not a new issue, climate change reinforces the importance of water availability and its subsequent need to ensure water security, as well as appropriate water distribution.

Furthermore, water is also needed to produce energy: water and energy are inextricably linked. The foundation of western societies still lies mostly on the use of fossil-fuel-based energies whose production requires important quantity of water: hydropower, nuclear power plants, combined heat power plants. Between 1 and 18% of energy is used to treat and transport water and wastewater. New wastewater and water treatment processes are more energy intensive than traditional treatments, and thermic power plants require significant amount of water for cooling. Energy exploration and production also requires important amount of water (Olsson, to be published). As we move towards more sustainable societies, in order to mitigate climate change, water will remain a key element in the development of renewable energies such as the first generation biofuels production. While water resources are decreasing and water and energy demand is augmenting[1], there is an increasing risk of conflicts occurences between water and energy (Olsson, to be published).

WWTPs are experiencing new types of trends and developments (refer to Section 2.1). The content of sewage is changing containing for example less organic materials but more endocrinal substances requiring new or different types of treatments. More frequent stormwaters lead to overflow and innundations in the plants. Urbanism development limits the availability of land space constraining the plants to be built on height hence increasing energy consumption due to the need of pumping the water. Because of visual and odour nuisances, public discontentment is growing. Energy prices are rising. Facing such challenges, new technological processes and innovative designs of WWTPs integrating sustainable functions are being developed. WWTPs have started to valorise by-products coming from sewage to produce energy. And legislation and policies need to be adapted to these new developments.

1.2 Problematization and Justification of Research

Through the United Nations Framework Convention on Climate Change (UNFCCC) and its latest Conference of Parties that took place in Copenhagen in December 2009, countries have taken engagements to reduce their GHG emissions which concerns *all* sectors of the society. For many reasons, the sector of wastewater treatment was not a very prominent actor of urban planning and functions. Until recently, WWTPs tended to be isolated entities generating odour and noise nuisances to their neighbourhood while handling water sanitation. But this trend is slowly changing and sewerage and the wastewater treatment are becoming important actors of the sustainable development of cities as much as waste management and transport sectors. Water treatment has been improved for many years and processed technologies were developed progressively to reduce BOD, COD, nitrogen and phopshorus and create closed-loop materials cycle, for example by bringing back nutrients back to the agriculture. The role of WWTPs is in fact to reconciliate city development with the preservation of natural water bodies in which they discharge treated water. They must do it with the lowest environmental impact possible to mitigate climate change. This represents an important challenge: while cities are growing generating more pollution, they have to reduce the associated environmental impact on water bodies, as well as reducing in relative terms their energy and chemical consumption. In addition, following growing public concern towards sustainability and climate change, developments in legislation and policies to mitigate (and adapt to) climate change, the development of the concept of sustainable cities and urban sustainable planning, and the augmentation of energy prices, WWTPs are growingly considering energy efficiency measures to reduce their carbon footprint. Finally, WWTPs are also producing energy within their structure or in partnership with energy and waste entities to offset their energy consumption. *In fact,*

[1] In 2000, the global demand for water was estimated at 30% of the world available freshwater resources. This number may reach 75% by 2025 (Hoffman, 2004 in Olsson, to be published).

wastewater is one of the rare renewable energy sources available in the urban environment.

There could be various drivers and barriers for WWTPs to reduce GHG emissions and they are likely to be influenced by demographic, political, ecological, technological, economic and social contexts in which WWTPs operates. In developed countries, wastewater treatments are becoming more and more complex. Technology provides immense possibilities and can solve lots of issues. But it comes at a cost. Trade-offs must be considered. Water management must be adapted to the growing needs and changing life-styles of the populations. Investments must be made in anticipation of future regulations. Governments by enacting policies can strongly influence the development of WWTPs and their role in new urban environments. Many research and litterature on technological performance and possible improvements on wastewater treatment exist such as monitoring and indicators tools. But they need to be linked/connected to the current trends and developments of the wastewater sector. In the context of climate change, growing populations and sustainable development and its economic, socio-cultural and environmental pillars, it is important to understand challenges that WWTPs are facing to better identify opportunities and develop sustainable water management accordingly.

1.3 Research objectives

This research aims at understanding the challenges and driving forces for WWTPs to improve the energy performance of their systems. For the purpose of this thesis, the following research question has been formulated:

What are the challenges and the potential for wastewater treatment plants to take part in climate change mitigation ?

To answer this question, the following objectives have been established.

- identify concrete measures taken by WWTPs to mitigate climate change in two areas: the improvement of energy efficiency and the reduction of GHG emissions,

- analyse the driving forces /barriers/influential factors behind the measures identified.

This thesis addresses stakeholders involved in the wastewater treatment sector, energy companies, municipalities, governments, and NGOs. By understanding challenges that WWTPs face to mitigate climate change, findings of this research aim at providing reflective tools to wastewater managers, water institutions and policymakers towards the development of sustainability in the wastewater sector. This research also intends to identify future opportunities in the wastewater sector within the broader context of urban sustainability.

The research is conducted in conjunction with a project for the American Water Works Association (AWWA) on evaluating the climate change impacts and opportunities for regulatory changes in the water sector in the United States, led by Susan Gledhill of the Policy Navigation Group, United States. While this research does not focus exclusively on the regulations and the choice of focus was not constrained by the PNG project, it aims at providing insights to the project by discussing current challenges and actions taken towards mitigating climate change in the case of the wastewater sector in an international context.

1.4 Scope

The water sector comprises many activities and actors in charge of different functions such as water distribution, water treatment, energy production, regulation, research or governance. This thesis work is focusing on the wastewater treatment in the context of climate change. It is based on case studies of seven WWTPs located in three different countries: Sweden, France and Australia. Sweden, a country of 9 million inhabitants was chosen for its long tradition in developing and implementing environmental policies as well as its advance in environmental performance. France, with a population of about 60 million people contrasts with Sweden. Environmental concerns and policies have not been traditionally placed on the same agenda level and the operational structure of wastewater treatment plants are a mix between public and private. Australia is not part of the European Union, and is more directly affected by the climate change than Sweden or France. Droughts have been aggravated by the climate change resulting in increasing water scarcity problems. Taking an approach based on three countries is expected to provide learnings and findings from different perspectives in the developed world. Languages competencies, availability of the respondents and consultations with Policy Navigation Group are also aspects that have been taken into account when selecting countries.

This research focuses on two areas: energy efficiency and GHG emissions resulting from the wastewater treatment in the context of climate change mitigation. In order to clean wastewater, WWTPs consumes fossil-fuel based energy and thereby emit carbon. The process of wastewater treatment also emits methane and nitrous oxide through anaerobic digestion and the use of chemicals. GHG emissions are one the main indicators used by scientists and policymakers to quantify and assess climate change. In addition, the progress towards more sustainable societies and innovative systems involve decarbonisation through the improvement of energy efficiency: the consumption of less energy for the same or higher level of performance in operations.

Mitigation are measures and action taken to reduce resources use and GHG emissions (IPCC, 2007a). Adaptation relates to initiatives and measures taken to reduce the vulnerability of natural and human systems against climate change (IPCC, 2007a). The adaptation towards climate change has not been considered in this research because it appeared to be too premature within the wastewater sector. Considerations with regards to climate change in the wastewater sector are recent and concerns measures taken in order to reduce impact on climate change as opposed to adjustment as adapatation suggests. Besides, within the time and space constraints given for this research, including adaptation would be too broad.

Because this research focuses on energetic aspects, sludge, which is a by-product coming from the wastewater that has been traditionally recycled as fertiliser for agricultural purposes, has been excluded from the scope of this research.

Finally, with regards to wastewater treatment, effluent requirements considered within the frame of this research were Nitrogen, Phosphorus and BOD (these terms are defined in Appendix III). Other effluent requirements such as on Total Suspended Solids (TSS) and the removal of E-coli, metals and hazardous substances are outside the scope of this thesis.

1.5 Methodology

To conduct this research, two approaches were considered within the time, scope and resources allocated to this thesis work. The first approach was to focus on one country and to organise a survey of a certain number of WWTPs within this country to establish national tendencies and/or comparisons of approaches taken by different WWTPs within the same national framework. The second approach was to select a few countries, and conduct few case studies of WWTPs within each country. The second approach has been chosen because it allows investigations in different geographical, cultural and political perspectives useful to the realisation of the project of Policy and Navigation Group that has initiated this research. It has also the advantage to establish a more fruitful and in-depth communication with the selected plants and better understand and analyse findings. Moreover the approach chosen, by offering different perspectives, offers the possibility for international water managers and policymakers to relate this research to their own institutional and organizational contexts and provides tools for reflection and inspiration.

The choice of method depends on the nature of the research.The method used for our qualitative research is multiple exploratory case studies. There are three types of case studies: descriptive, explanatory and exploratory (Yin, 1984). A case is an empirical inquiry that investigates a contemporary phenomenon within its life context using multiple sources of evidence (Yin, 1989). One advantage of the case study method is that it allows to capture “emergent and imminent” properties of life in organizations (Hartley, 1994), which is what we are aiming at in this research. It is about how and why things happens in contextual realities (Anderson, 1994). In this research, the contextual reality is the climate change and the consequent necessity to improve energy performance. In this context, we are investigating why and how WWTPs do so. The cases are exploratory in the sense that we are aiming to find out what WWTPs are confronted with in the context of global change and how they consider, attempt, succeed (or not) in improving their energy performance in order to reduce their GHG emissions, with no preconceptions as to remain objective and open to new aspects and arguments.

In a preparatory phase, case studies were selected according to different criteria: relevance to this research and feasibility. Followed the design of research questions. Primary data/facts collection and basic research were conducted about the plants (size, history, water treatment performed, etc.) based on internal documents such as organizations’ annual reports, previous studies performed, websites and on reference litterature on wastewater aspects. They provided guidelines on how to build the inquiry and were used to cross-checked information provided by respondents. In addition to the WWTPs, preparatory research also included the study of political and legislative contexts in which WWTPs operate. Finally, potential respondents were identified at this stage, using the elements found in the initial research phase, the snowballing mechanism, and the researcher's individual judgement. The interviewees were selected considering aspects such as whether they can provide the type of information needed but also their willingness to provide information and their interest in the research performed (O’Leary, 2005).

The case study was then designed by creating a template for interviews. The fieldwork and secondary facts/data collection were mostly conducted through semi-structured interviews of various respondents coming from different organizations (WWTPs, universities, governments, industry, associations). A total of 17 interviews were conducted either in person or by telephone, in Sweden, France and Australia. Most of interviewees were engineers employed in the WWTPs, but also managers and experts in the field of water. The duration of interviews ranges from 30 minutes to 1 hour 30 minutes. A table listing all interviewees is available in Appendix I. Semi-structured interviews were prefered as they allow flexibility necessary in the case of exploratory case studies. However, follow-ups interviews were in most cases structured interviews as they required clarifications and specific answers on some particular aspects raised during the first set of semi-structured interviews. Some follow-up was also conducted through email correspondence and/or telephone. Whenever possible, face-to-face interviews and visits to the plants were conducted (Sweden). Among others, they allow observation which can also constitute an element of research. When this could not be done due to resources limitations and geographical constraints, interviews were conducted via telephone (France and Australia). Discussion and analyses of the findings were then performed using the analytical framework presented in Chapter 2. The conclusion phase of this research consisted in cross-casing the analysis of the different cases, and draw conclusions in line with the formulated research questions.

Finally, when selecting case studies both private and public organizations were contacted. Upon the preparatory phase of this research to select WWTPs, it appeared that in the case of France, public organizations as opposed to private companies were more accessible and willing to provide information. This explains partly why case studies have been conducted on public organizations.

1.6 Limitations

Energy related GHG emissions represent the main source of GHG emissions. However non-energy related emissions such as methane (CH_4) and nitrous oxide (N_2O) refered as “fugitive emissions” also contribute to GHG gases. Due to uncertainties and research gaps in calculating those emissions within water utilities, this research focuses on carbon dioxide emissions (CO_2). When data and calculations were available for CH_4 and N_2O, they were converted into CO_2 equivalents to facilitate comparisons. The existing gap in measuring CH_4 and N_2O emissions undermines the importance in relating to GHG emissions. This point is being discussed in the chapter 7.

This work constitutes qualitative research. Some quantitative data was collected in order to measure the size of operations of the plants and give some indications on energy efficiency (such as the amount of wastewater treated, energy used and also produced). Collected data has been compiled and verified, and some indicators related to energy efficiency have been calculated. This is presented in Appendix V, however it was not extensively exploited in this research for the following reasons. First of all, data regarding GHG emissions and detailed energy consumption according to different parameters was not systematically available or was provided in different formats depending on the characteristics of the plants and the type of processes used or national units. Data requests were also sometimes interpreted differently by the plants. For these reasons, indicators provided by WWTPs had to be manipulated and interpreted with precaution and cannot be compared with fairness and objectivity. Second of all, quantitative data depends on parameters that can vary between the plants: different treatment processes and infrastruture, different quality of incoming wastewater, different effluent requirements and/or effluent treatment effectively achieved, geographical location. For example, a plant restricted in space that has to stack up its buildings consumes more energy due to the need to pump water than a plant that do not have space constraints. Similarly, a plant that is built in a busy agglomeration has to cover all of its operations in order to avoid odour nuisances and needs more energy to do so. Because of differences and complexities in those parameters and in treatment processes, comparing treatment processes in the WWTPs in terms of energy efficiency would be more appropriate in the case of a quantitative research by focusing on specific treatment phases during a certain period of time. Therefore, very few conclusions in this research were drawn based on quantitative data collected. Quantitative data provided in this research should be considered as indicative, possibly reflecting tendencies, but in any case should be interpreted as absolute values to establish comparisons or used to draw solid conclusions.

This thesis does not aim to provide a generalisation nor to draw comparisons between measures to improve energy performance of WWTPs and factors influencing the uptake of such measures. It soon appeared when starting this research that it would not be fruitful to compare WWTPs because of the many different parameters in which they operate as we have mentioned above. What can be successful for one plant might not work for another. Therefore, the approach chosen is to study some WWTPs in different countries within their national/local context to build stories that may not necessarily represent a general trend but inspire and provide reflective tools on measures and opportunities taken within each plant.

Finally, the selection of interviewees and the way interviews were conducted can include some degree of subjectivity related to personal judgement. Besides, the snowballing mechanism when contacting experts who provide references to other experts can interfere with the selection process of interviews. Some questions remained unanswered due to confidentiality. The level of coverage of the three governance levels (operational, tactical and strategic, refer to Chapter 2) during the case studies in the mean of interviews and consultation of documentation varied depending on the organizations and the type of interviewees who were available at the time of research and on the information available for consultation. Therefore the outcome of the research might have been to a certain extent influenced by the type and source of information provided and/or available at the time of the research. To complement the case studies, some NGOs, governmental bodies and international organizations producing research on sustainability of the wastewater sector such as the UNESCO Institute for Water Education or the International Water Association, or the International Council for Local Environmental Initiatives (ICLEI) were contacted and in some cases informal interviews and discussions were conducted. In addition, litterature produced by such organizations was consulted providing useful and additional background for the case studies.

1.7 Outline of the thesis

The next chapter is dedicated to the analytical framework of this research work. Chapter 3 presents the European legal framework providing the context in which WWTPs operate in Sweden and in France. Chapter 4 analyses the two case studies conducted in Sweden after providing some background on water governance and the climate change and energy policy framework. Chapter 5 is dedicated to the three case studies conducted in France after also providing some background on water governance and the national policy framework related to energy and climate change. Both the legal and policy framework on Australia is presented at the beginning of the Chapter 6 before analyzing the case studies conducted on Melbourne Water. Chapter 7 discusses and analyses the findings of the case studies based on the analytical framework. Chapter 8 concludes this research. Wastewater treatment processes and their associated energy uses and GHG emissions are presented in the Appendix III in order to help the reader who is not familiarized with this sector.

2 Analytical framework

The focus of this research consists in establishing how WWTPs are concerned and respond to climate change through improving energy efficiency in order to reduce GHG emissions. Adapting to climate change is a part of sustainable development. The fundamental idea behind sustainable development[2] is to provide fundamental needs to populations without harming natural systems. This is in nature the role of WWTPs: removing pollutants out of the wastewater before discharging it into the natural water receiving bodies preserving environmental and human health while adjusting to more equal and fair economical and social conditions. But as we have seen in the introduction, increasing pollution requires more and more sophisticated treatments that in fact also increase the burden on the environment through energy consumption and GHG emissions. So put simply the question is how can WWTPs can treat wastewater in a more efficient manner in order to reduce their impact on climate change and thus be sustainable?

2.1 International approaches towards sustainable water management

There are several institutional approaches that relates to sustainability in water management that apply to the wastewater treatment sector. The Dublin Statement on Water and Sustainable Development was one of the first. It was adopted on January 31, 1992 at the International Conference on Water and the Environment (ICWE). The Dublin Statement warned in 1992 that following excessive water use and reckless discharge of municipal and industrial wastes, the situation in the majority of the world's major cities became seriously bad and was getting worse (The Dublin Statement, 1992). In developed countries, legislation has evolved since, and wastewater treatments are becoming more and more effective. But there are still countries or regions that are lacking behind and where urgent action is needed. In developing countries such as India or China, lack of sanitation in wastewater still impacts seriously human and environmental health. The principles found in the Dublin Statement have formed the basis of the Integrated Water Resources Management (IWRM) (van der Steen, 2006) encouraging participatory approaches of users, planners and policy makers at all levels (The Dublin Statement, 1992). Another guiding principle resides in considering water as an economic good due to its economic value "in all its competing uses", underlying the issue of water pricing. How the ownership structure through water pricing and operational costs could influence investments in innovation in order to contribute to energy efficiency ? There has not been significant progress in this area.

The Agenda 21 followed the Dublin Statement. The Agenda 21 is a plan for action issued by the United Nations at the Earth Summit in Rio in 1992 for the 21st century. Some governments have taken dispositions to implement the Agenda 21 at local levels, and its implementation was reaffirmed at the Johannesburg Conference in 2002. It is a comprehensive blueprint of actions for all stakeholders of the society towards sustainable development. One of the objectives of the Agenda 21 is to develop "environmentally sound management of water resources for urban use" (United Nations Department for Sustainable Development, 1992). The quality of the freshwater as an essential component has to be maintained to preserve the hydrological, biological, and chemical functions of the eco-

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[2] Sustainable development is based on three pillars, also called triple bottom line approach: economic, socio-cultural and environment. Sustainable development can be reached by combining economic wealth, environmental protection and social cohesion (United Nations, 1987).

systems (United Nations Department for Sustainable Development, 1992). By cleaning the water at the upstream level, WWTPs play a central role towards this objective, and amongst others, must limit their impact on environment in the processes they use. The Agenda 21 concept has been applied by the SIAAP, one of the case study of this research, by putting in place an Agenda 21 commission establishing a blueprint towards sustainability for the whole organization.

In 2000, 189 countries met in New York to formulate the Millenium Development Goals (MDG). The eight goals[3], formulated to be achieved by 2015, were adopted by all countries. Ensuing environmental sustainabililty constitutes the goal with which water engineers and scientists identify most strongly (Schnoor, 2010). Halving the population with no access to safe drinking water and improve sanitation (1 in 4 people in the world is affected by the lack water sanitation) are part of this goal, yet far from being achieved (Schnoor, 2010).

2.2 WWTPs and sustainability

Technology represents the backbone of WWTPs operations. Technology is fundamental to WWTPs as their history and processes are based on technology development (Phillis, 2009). Quantitative and comparative research and discussions are available on the improvement of technology and energy performance in removing pollutants and hazardous substances. Some litterature also exists about the evaluation of the sustainability degree of wastewater treatment processes. Muga et al. have developed a set of indicators to investigate the degree of sustainability of wastewater treatment technologies in the United States: "chemical" treatment which in this article consists of mechanical, biological and chemical treatments (refer to the Appendix III for a description on treatment processes), and natural processes which are lagoon and land treatment systems (Muga et al., 2008). The indicators are based on social, economical and environmental dimensions that characterise sustainability. Economically, with regards to capital costs, chemical treatment is the most expensive to build. Lagoon treatment is the cheapest. With regards to costs related to operation and maintenance (energy, labor, chemical purchases and replacement equipment), the evaluation shows that chemical treatment is 4 to 5 times more costly to operate than a lagoon system and 4 to 6 times more costly than a land based system. From an environmental perspective, high amount of energy is required to operate the plant, especially for the oxygen aeration and the pumping of water. Activated sludge treatment or biological treatment (excluding reuse of internally produced energy) is a high energy consumer compared to the other two types of treatment. An activated sludge system that serves a population of 1 000 people can produce 1 400 tCO_2–eq. for its operation and 50 tCO_2–eq. for its maintenance. Construction materials such as cement also contribute to a high amount of CO_2 emissions (Muga et al., 2008). Performance of treatment vary significantly depending on the type of treatment applied and the degree of water quality required. From a society perspective, this study contends that public participation is often neglected when it comes to the choice of treatment and the most important elements taken into account are affordability and performance. If lagoons and land based systems seems to be the most sustainable solutions from the triple bottom based approach, it is important to note that those systems require big land area and tend to be more viable when serving small communities. Therefore albeit considered more sustainable, they do not represent

[3] The eight goals are: end poverty and hunger, provide universal access to education, reach gender equality, reduce child mortality rate, improve maternal health, combat HIV/AIDS, ensure environmental sustainability by integrating the principles of sustainable development in countries policies and reduce biodiversity loss, and develop a global partnership for development (United Nations, 2010).

most commonly applied treatments in urban environment, at the exception of Melbourne, one of our case studies.

The Netherlands is known for its innovative approach in water management. As part of a global study initiated in 2008 by the Global Water Research Coalition (GWRC), Stowa, a Dutch foundation for applied research provides further insights on the sustainability of the wastewater sector. It investigated what a WWTP could look like in 2030 when integrating the three pillars of sustainable development (Stowa, 2010): polluted resources coming into the wastewater can be recycled and recovered as in a closed loop system. The approach taken by the Dutch group is interesting as it includes the evolution of the society and its needs. To adapt to this evolution, in conjonction with the development of the technology, the study comes to develop a WWTP functioning as a water, nutrient and energy factory taking into account trends, developments and impacts of the wastewater sector that were identified and that are presented in the table 2-1. They encompass the fields of economy, socio-cultural, environment and technology.

Table 2-1: Trends, developments and impacts in the wastewater treatment sector

Field	Description of trends and developments	Impact
Economy	Declining industrial discharges	Reduction of organic materials
Economy	Increasing operational costs	Operational costs
Environment (policy)	European Water Framework Directive	More stringent effluent standards
Environment	Sustainability	Investments
Environment	Climate Change	GHG emissions
Environment	Sustainability	Water re-use and conservation
Social (society)	Public concern and acceptance	New functions
Social (society)	Higher demands in terms of quality	Operational pressure
Social (demography)	Population growth, urbanisation	Treatment capacity
Technology	New and old WWTPs configurations	Technology
Technology	New treatment methods	Technology
Technology	Energy production	New functions, closed-loops
Technology	R&D, increasing knowledge	Performance

Source: Adapted from Stowa, Foundation For Applied Research (2010.

The framework of this study lies on the definition of four different scenarios to occur between 2010 and 2030. The first scenario “Solitaire and simple” is based on an individual society where technology remains traditional and cheap. “To Live is to experience”, the second scenario consists of a society still based on individualism but prevailing technology is based on high tech end of pipe. The third scenario “Economical and diligence” is happening in a collective society but technology is robust and traditional. Finally, the last scenario and most probably the ideal one is “Sustainable living together” where in a collective society, advanced technology is used in a synergy with the environment. This analysis is based on the principles of sustainability in a static model that does not take into account external forces and interactions with other stakeholders. To develop technology and build a more collective society, policies and legislation are necessary. It is also worth noting that the wastewater sector is in most countries not a market-based sector. It is financed autonomously through water fees paid by citizens. In that respect, water management can involve political constraints rather than being driven by market-based competition.

WWTP's role is changing in new urban environments where patterns of consumption are changing and residents become more concerned with living in healthy environments. Chemical and biological based treatment are the most widely used but not the most beneficial to environment. WWTPs are subject to more and more legislative constraints as well as new types of policies as the technologies develop and governments enact policies to reduce GHG emissions. In this context, a suitable framework for our research consists in a innovation system approach in which WWTPs are not separate entities but are playing a dynamic role in interaction with other stakeholders. Various theories are dealing with innovation systems, and for the purpose of this thesis, three possible theories were reviewed and considered: "Path dependency, path creation and creative destruction in the evolution of energy systems" (Lovio et al., 2010), the innovation system approach based on learning processes developed by Linda Kamp (Kamp, 2007), as well as the transition management theory (Kemp et al. 2007).

2.3 Transition management theory: what type of governance to reach sustainability?

Socio-technical systems as described by Stowa (Stowa, 2010) in the case of wastewater sector needs adaptation to reach sustainability. Adaptation and change are driven by policies and legislation among others. They also have to be regulated to changing conditions. For example, to build the WWTP of the 2030s as described by Stowa, legislation surrounding the water treatment needs to be adapted to the function of energy production. According to the terms of Kemp et al. (Kemp et al., 2007), reducing GHG emissions could be achieved through changes at different levels: beliefs, values and governance that co-evolve with technological changes. To manage these processes of co-evolution, Kemp et al. have developed the transition management theory (Kemp et al., 2007).

The transition management theory is a dynamic and adaptive process which does not aim at one particular path but explore paths towards sustainability in a co-evolutionnary process through the development of visions and transition goals, cycles of learning and adaptation, the monitoring and evaluation of processes, and by engaging the public. WWTPs transition towards sustainability must be studied within a system interacting with other stakeholders in a medium to long term perspective. In that sense, this theory represents a multi-level mode of governance, which happens in a transitional manner when three levels of governance interact: strategic, tactical and operational (Kemp et al., 2007) (Figure 2-2). Typically, a transition happens in different phases: pre-development, take-off, breakthrough and stabilisation. The strategic level sets vision, strategies, policies, legislation and long term goals. The tactical level relates to tools such as benchmarking, cooperation between stakeholders, and the operational level corresponds to implementation, experimentations, technology and innovations.

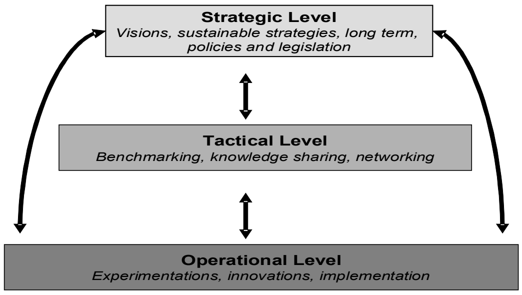

Figure 2-2: Multi-level approach of transition management. Source: adapted from Kemp et al. 2007.

The transition management approach can be applied to large energy systems but also to specific sectors as in the case of the Dutch waste management system (Kemp et al. 2007). A transition is formed of several paths happening in different stages in an innovation system[4]. The wastewater sector is part of an innovation system, in the sense that its activities are based on technologies. This research applies this framework to the wastewater sector by identifying measures and actions taken at each level, and study the interaction between these levels to provide elements of reflection on how WWTPs can become more sustainable. This type of approach also called "goal-oriented modulation" (Kemp et al., 2007) is a middle way integrating incrementalism which tends to lead to suboptimal solutions and planning in order to overcome typical management issues such as locked-in effects, lack of consensus between stakeholders, short term policies (Kemp et al., 2007).

2.4 Other theories

Other possible theories have been considered for the analytical framework. of this research The path dependence theory (Lovio et al. 2010) was considered as a possible concept but it was determined that its scope was too broad for our purposes. However, this theory that has been developed to deal with energy systems includes components such as the Shumpeterian notion of creative destruction and civic activity that go beyond our scope. The transition management theory although developed to deal with large systems and broad sector could be adapted to a smaller scale. We also considered the approach developed by Linda Kemp (Kamp, 2007) but we came to the conclusion that an analytical framework based exclusively on learning processes (learning by doing, learning by using, learning by searching, learning by interacting) would be too restrictive for our purposes.

2.5 Analytical Framework: transition management theory applied to the wastewater sector

For the purposes of our research, each level of governance as defined in the transition management theory has been adapted the scale and specificities of the wastewater treatment sector and the conducted case studies. The operational level corresponds to the

[4] Innovation system is a concept developed by Freeman and Lundvall in the 1980s. It is based on the Schumpeterian notion of innovation that needs to be brought on the market and the need to create effective interaction between innovation/technology and information between stakeholders of the society.

implementation of new processes for treatment, the development of innovation, the technological choices made or considered, and the synergies with other sectors. The tactical level corresponds to communication and information sharing with stakeholders actors, and internal or external actions implemented to develop skills, capacities and informative tools such as carbon assessments. The strategic level englobes strategies developed by the entities at medium or long term, and indirectly policies and legislation. They often would orientate the definition of measures at the tactical and operational levels. As framework of analysis for this thesis, each study case is scanned through each of the three levels in order to identify paths taken by WWTPs. A table with all the measures compiled is presented in the Chapter 7. Ultimately, good governance lies on policy integration in order to create positive feedbacks, the definition of common objectives, indicators, criteria and trade-offs rules, flow of information and incentives, and definition of programmes for systems innovation, including technological niches (Kemp et al. 2005). These elements serve as a guiding/reference criteria for our analysis. In a society based on fossil-fuels energies, innovation is necessary to move towards sustainability in order to increase the use renewable energies, or develop energy production within the plants. Trade-offs have to be considered/made through between energy consumption, energy recovery opportunities and water quality standards defined by the regulatory authorities.

3 Legal framework in the European Union

This section presents the current European legislation in order to understand to what regulations, WWTPs are subject to in the context of climate change. National law and policies frameworks will be presented in corresponding country cases sections.

3.1 European law and directives for the water sector

With the aim among others to harmonise policies in the European Union, a number of directives have been enacted in order to ensure stable and common quality standards and develop sustainable resources management. Member States of European Union have the obligation to implement these laws into their national laws.

The main water directives governing water are:

- Sewage Sludge Directive (86/278/EEC)
- Bathing Waters Quality Directive (76/160/EEC and 2006/7/EC)
- Drinking Water Directive (80/778/EC and 98/83/EC)
- Urban Wastewater Treatment Directive (91/271/EEC)
- Directive on Nitrates from Agricultural Sources (91/676/EEC)
- Integrated Pollution Prevention and Control Directive (96/61/EC and 2008/1/EC)
- Water Framework Directive (2000/60/EC)
- Marine Strategy Framework Directive (2008/56/EC).

3.1.1 The Urban Wastewater Treatment Directive

In the 1980's, eutrophication became a major problem in the North and Baltic Seas and to remedy to this, the EU started to focus on pollutants in the wastewater (WISE, 2008). This led to the Urban Wastewater Treatment Directive (UWWT Directive) 91/271/EC, which was adopted on May 21, 1991. This directive together with the Drinking Water Directive, are considered as milestones of the European water legislation. The UWWT Directive regulates collection, treatment and discharge of wastewater treatment by WWTPs and competent authorities. It addresses water standards, requires implementation of end-of-pipe technology, introduces sampling, monitoring and publication of water quality results. It is based on four pillars:

- **Planning.** Planning consists of designating sensitive areas, applying secondary treatment to discharges from agglomerations of more than 10 000 p.e., and in establishing implementation programme to ensure conformity with the directive (construction of collecting systems and plants must be appropriate).

- **Regulation.** This principle requires the establishment of systems for prior authorisation for discharge of urban and industrial wastewater. National authorities must take measures to avoid pollution from storm and rain water by having separate collecting systems. All agglomerations of more than 2000 p.e. must have collecting wastewater systems in place. Depending on the sensitivity of the areas, all agglomerations must apply a secondary treatment, or more stringent treatment. In less sensitive areas, treatment can be less stringent. Proper construction, design, operation and maintenance must be ensured. Sludge must be treated in accordance with other directives related to agriculture, incineration and landfills. Disposal of sludge onto receiving water bodies is banned.

- **Monitoring.** Among others, monitoring programmes must be in place in accordance with Annex I of the directive based on specific analytical methods and frequency.

- **Information and Reporting.** It consists in ensuring cooperation and exchange of information between member states about transboundary water. Information must be provided to the Commission on transposition of the Directive into national legislation and implementation programmes, status of collecting systems, efficiency of the plants, quality of surface water, and status of discharges from the food industry into surface waters. Public access to information related to status of wastewater collection, and treatment or disposal of sludge is mandatory.

For discharges into sensitive areas subject to eutrophication, the directive amending the 91 UWWT Directive in 1998 (98/15/EC) has set the following requirements of concentration of nutrients:

- Phosphorus: 2 mg/l for agglomeratiosn between 10 000 and 100 000 p.e. and 1 mg/l for agglomerations bigger than 100 000 p.e., corresponding to a minimum percentage reduction of 80%.

- Nitrogen: 15 mg/l for agglomerations between 10 000 and 100 000 p.e. and 10 mg/l for agglomerations bigger than 100 000 p.e., corresponding to a minimum percentage reduction between 70 and 80%.

- BOD5: 25mg/l of oxygen corresponding to a minimum percentage reduction between 70 and 90%.

- COD: 125 mg/l of oxygen corresponding to a minimum reduction of 75%.

The UWWT Directive is one of the most costly directive to implement in the EU legislation and it affects more than 22 000 urban areas in Europe. It also includes requirements for industrial wastewater before entering collecting systems and sewage treatment.

3.1.2 The EU Water Framework Directive

The EU Water Framework Directive (WFD) was established in 2000 following a wide consultation of stakeholders and experts within the water sector. It creates a global and unified approach to water policies in Europe. The WFD combined approach for point and diffuse sources links requirements from other directives, such as the emissions controls set in the UWWT Directive. The WFD addresses pollution prevention which was lacking in the UWWT Directive (van der Steen, 2006). It regroups water sources into "River Basins" beyond national borders encouraging international cross-cooperation between member States of the EU. This reflects the Integrated Water Resource Management approach as defined in the Dublin Statement. River Basins Plans need to be formulated and must include an analysis of characteristics of the basin, the impact of human activity on the basin and an economic analysis of the water use. The Directive aims at achieving "good status" for European waters by 2015: River Basins Agencies define what is good upon specific conditions of each River Basin, also consulting stakeholders such as NGOs. The best possible reduction of emissions and a minimum threshold for water quality in receiving water bodies are two important characteristics of this directive. It also addresses water pricing and polluter pays principle as well as a phase out of discharge of specific contaminants by 2030 (van der Steen, 2006).

3.2 The EU Emission Trading System Directive

In order to reduce GHG emissions and go further than engagements taken by countries within the Kyoto Protocol, the European Directive EU Emission Trading System (EU ETS) 2009/29/EC (amending the directive 2003/87/EC) has set the reduction of the GHG emissions in the EU by 20% by 2020 from the 1990 levels corresponding to a maximum of annual GHG emissions of 564 MtCO_2-eq. Allowances should be 21% below their 2005 emissions level by 2020. To that purpose, it has created a carbon trading scheme, the first international carbon trading system for CO_2 in the world. It applies to approximatively 11 500 energy intensive organizations in the EU such as combustion plants, pulp and paper or cement industries. Large size WWTPs such as the regional wasterwater authority in the Paris region, the "Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne" (SIAAP, refer to Chapter 5) comes under this regulation. These organizations can buy or sell emissions depending on the levels of allocated quotas and emissions. This directive represents an important driving force towards the GHG emissions reduction. The total allowances for the period of 2008-2012 amounts to 2 033 million and from 2013 will decrease annually by a linear factor of 1.74% according to the Article 9 of Directive 2003/87/EC, as amended by Directive 2009/29/EC (European Commission, 2010).

3.3 The EU Sustainable Development Strategy

Based on the 2001 Gothenburg strategy, the EU has developed a Sustainable Development Strategy (EU SDS). Last reviewed in 2009, the EU SDS draws on the importance of integrating sustainability into a broad range of its policies, emphasing the need to fight against climate change and the adoption of a low carbon economy. Although not targeting wastewater treatment sector directly, it covers a wide range of sectors such as transport and public health that can influence the way WWTPs operate indirectly. Moreover the governance structure of the EU SDS is based on best practices sharing and monitoring of progress. To encourage synergies and reduce trade-offs, the EU stresses the importance of integrating policies based on better regulations and develop guiding principles such as the polluter pays principle or the precautionary principle.

This section has been presenting the legal framework in Europe related to wastewater in order to provide legal context to the following case studies (France and Sweden). The next section presents and analyses the findings of the two case studies conducted in Sweden.

4 Sweden

Sweden is the first case study of our research. In this chapter, after providing some background on national legislation and policies including on energy efficiency and climate change, findings resulting from interviews and visits to two medium size WWTPs will be analysed.

4.1 Background: water and environmental policies

Nine million people live in Sweden, a country that covers an area of 450 000 m2. 85% of the population live in urban areas concentrated around Stockholm, Gothenburg and Malmö (Statistics Sweden, 2007). Sweden has the same latitude as Alaska and North Siberia. Water in Sweden is classified as food and is regulated as such.

Sweden has abundant water resources. Swedish laws on water dated back to the 1940s when the Water Act was enacted introducing regulations on wastewater discharge and obligation to have a licensing permit delivered by the county authorities for some industries. Before that, wastewater was discharged back into the nature without treatment. In 1956, a Special Act on supervision of lakes and other water areas was passed. In 1967, the Swedish Environmental Protection Agency (EPA) was created, and soon followed the 1969 Environmental Protection Act. On January 1, 1999, the Swedish Environmental Code entered into force governing disturbance and degradation of the environment. Sweden joined the European Union in 1995, and has since adopted in its legislation EU Water laws. With regards to compliance to the UWWT Directive (refer to Section 3.2.2), Sweden is reported required information and in the required format to the EU (Commission of the European Communities, 2009). Sweden considers all its territory as sensitive area (as do 13 other members countries). Amongst the 18 members states covered in the latest EU report on compliance to the UWWT Directive published in 2005 , 80% of agglomerations representing 81% of the pollution load discharged into sensitive areas. Sweden complies with having collection systems in place (Article 3 of the UWWT Directive). In 2005, Sweden is compliant with Article 4 of the UWWT Directive at 98% and at 67% with Article 5 (Commission of the European Communities, 2009).

4.1.1 Water governance

Sweden is divided into 21 counties each governed by a County Administration Board (Regeringskansliet, 2010). Based on the Local Government Act (1992), the 290 municipalities are responsible for planning, construction and operation of water supply and wastewater sanitation, including the management of storm water. Municipalities are owning WWTPs and most of them are handling water management, financed by tariffs charged by the water utilities. The tariffs include two components: a basic fee and a fee charged per m^3 of water consumed. Citizens also cover the costs of services such as the connection costs. As per the 1964 National Water Act, most of the 2 000 existing water utilities are financially self-reliant. Capital and running costs are covered by the fees, and if any profit is made it must be re-invested within public services or passed on fees charged to citizens within a time-frame period of three years. Recently, some municipalities have established regional cooperation such as Lund and Malmö, as found in the case study. A small number of municipalities have started to contract private entities to operate some part of the wastewater treatment (Finsson, 2010). In 2005, the cost of water supply and sanitation amounted 1.4 billion Euro (Svenskt Vatten, 2008).

Permits allowing WWTPs to run their operations are issued by the county authorities while municipalities are in charge of checking that WWTPs follow their regulation permits. Permits specify targets to reach in terms of water quality that vary depending on the regions and the environmental conditions of the receiving water body (as part of the integrated management strategy of the WFD). WWTPs are free to decide the mode of treatment to apply as long as they meet the targets and the regulations of treatment to apply as defined in the UWWT Directive. Municipalities require WWTPs to report figures related to the quality of water treatment (removal of nitrogen, phosphorus, BOD and COD) on an annual and monthly basis as well as their energy consumption. However, municipalities are generally not requiring specific targets in terms of energy consumption and GHG emissions for WWTPs.

"We shall solve our own environmental problems: we will not pass them onto future generations", is the underlying principle of the Environmental Code. Towards the establishment of a sustainable society by 2020, the Swedish Parliament ("Riksdag") has adopted the Environmental Code, entered into force on January 1, 1999, addressing environmental impacts arising from a wide range of activities, including management of land and water, the protection of plant and animal species, chemical products and waste, and water operations. The Environmental Code is the first integrated body of environmental legislation enacted in Sweden. It is based on the precautionary principle and is a framework law meaning that it does not specify limited values on operations.

The Swedish Environmental Code incorporates previous existing legislation on water including the 1983 Water Act., reflecting a complex governance where different organizations have different responsibilities. The Swedish EPA controls the water. Water boards are establishing water quality standards, while the Ministry of Environment is responsible for water protection. At a local level, the Swedish Association of Local Authorities also englobes water amongst its activities. Finally Svenskt Vatten (the Swedish Water and Wastewater Association, SWWA) is the national water authority.

The Swedish EPA has initially established 15 environmental objectives when it entered into force in 1999, and an additional objective on biodiversity was added in 2005. Along with other Swedish authorities, and depending on the nature of the objective, the Swedish EPA has the responsibility to ensure that they are achieved under the coordination of the Environmental Objectives Council created in 2002 by the Swedish government. However a recent bill enacted in June 2010 will modify this constitution. Five of the 16 objectives directly concern water utilities. They are (Swedish EPA, 2009):

- *A non toxic environment*: the environment must not contain man-made metals that threaten human health and biodiversity.
- *Zero eutrophication*: nutrients such as nitrogen or phosphorus must be in present in such quantity levels in land and water as to prevent eutrophication.
- *Flourishing lakes and streams*: lakes and streams must be preserved.
- *Balanced marine environment, flourishing coastal areas and archipelagos*: biological diversity must be preserved.

- *A good built environment*: cities, towns and physical built areas must be built according to sound environmental principles and "promote sustainable management of land, water and other resources".

These objectives influence how wastewater treatment must perform, particularly nitrogen and phosphorus quantity levels which imply appropriate treatments.

4.1.2 Sweden Climate and Energy Policy

Sweden energy policy is based on the EU policy promoting wider energy cooperation amongst EU members on sustainability, competitiveness, and supply security. In Europe, Sweden is one of the precursor in terms of energy efficiency thus contributing to European harmonisation from the top. The promotion of energy efficiency was a very important aspect brought by the Swedish presidency of the European Union in 2009.

According to the Climate Bill (2008/09:162), Sweden is to reduce its GHG emissions by 40% by 2020 compared with 1990 levels especially targeting transport, waste management, housing, agriculture and forestry sectors . Ultimately Sweden is aiming at zero GHG emissions by 2050 (Swedish EPA, 2010). In line with national guidelines, Swedish municipalities have set their own targets. Lund municipality, where Källby one of the WWTPs studied is located, has set the objective to decrease its emissions by 50% below the 1990 levels and to reduce emissions close to zero by 2050 (Klimat Kommunerna, 2010). Neighbouring city Malmö has set the goal to phase out all its CO_2 emissions by 2030 thus becoming carbon neutral (Naturskyddsföreningen, 2010). Linköping municipality, where Nykvarnsverket the second WWTP studied is located, has drawn a vision towards climate change to reduce the use of fossil motor fuels by 50% by 2020 compared with 1995 levels. The municipality also aims at increasing the proportion of electricity and heating produced from renewable energy sources to at least 95% by 2020 (Linköping Municipality, 2010).

By 2020, 50% of energy needs in Sweden must come from renewable energy, and there must be a 20% improvement in the efficiency of all forms of energy use by 2020 (Swedish Energy Agency, 2009). The Energy Bill voted for the period of 2010-2014 includes a five year programme decided by the government towards energy efficiency, providing a funding of 560 million SEK (58.8 million Euros)[5] per year. It targets notably large scale energy renewable electricity production and biobased motors fuel such as biogas, two types of energy that WWTPs are increasingly producing. The existing programme for Improving Energy Efficiency in Energy-Intensive Industries remains in place together with the Swedish Emision Trading Directory Registry (SUS) in application of the European directive covering 35% of GHG emissions.

4.1.3 Svenskt Vatten Energy Project

The Energy Project developed by Svenskt Vatten, ("Svenskt Vatten Energi Projekt", hereafter the Energy Project), is a good illustration of actions taken in Sweden towards energy efficiency. This project, specifically designed for water utilities, started in 2005 at the initiative of Svenskt Vatten, and is supported by the Swedish Energy Agency. It is due to run until 2012. The objective is to use thermic energy more efficiently and reduce the use of electrical energy by 10% in the water sector which consumes 1.3 TWh electricity and approx. 0.5 TWh of other energy sources excluding the energy content in chemicals

[5] 1 SEK equals 0.10499 Euros. Interbank rate as of July 1, 2010. Source: www.oanda.com. Rate applied to all following conversions.

used in water treatment (Svenskt Vatten, 2008). The first two years (2005-2007) of the programme were focusing on identifying energy use within water utilities including water distribution and wastewater treatment. From 2007 until 2012 in three calls, projects are developed supporting the efforts done by the plants. With a total budget of 11.9 million Euros, it is co-financed by water utilities (74%), the Swedish Energy Agency (24%) and Svenskt Vatten (2%). The recent targets established in 2009 include a further reduction of 50 GWh of energy use, an increase of the biogas production from 0.2 to 0.4 TWh by 2010 by optimising processes and improving the use of organic materials and using biogas and waste heat more effectively (Bergström, 2009). Besides providing technical support and development, this programme is a learning and communication platform for the whole sector. Through seminars, meetings, plant visits and studies, it seeks to increase awareness and benchmarking energy efficiency. Through the snowballing mechanism it is expected to increase R&D focused on energy and the production of more energy efficient equipments from the supply side in the long run. 40 municipalities are participating in the phase 2 (2007-2009) covering 40% of the Swedish water sector. They are 69 to participate in the phase 3 (2010-2012). So far, a total of 44 projects were developed focusing primarily on gas production and heating as well as more efficient use of methane, showing the importance of producing more efficiently by-products rather than improving current processes (Figure 4-3). Both gas production and methane efficiency use represents 60% of the total financial support provided to water utilities (Bergström, 2009).

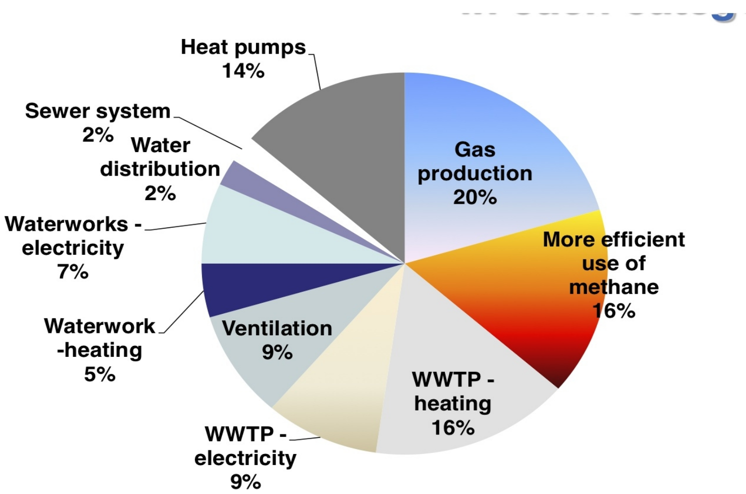

Figure 4-3: Projects Categories developed in the Svenskt Vatten Energy Project. Source: Bergström, 2009.

The table 4-2 shows more specifically what kind of projects have been developed during the phase 2 of the Energy Project (2007-2009). They range from air compression for a small investment of 6 404 Euros to energy optimisation for an investment of about 188 000 Euros. About 6 500 MWh of energy were saved representing a total investment of 10 million SEK (1 million Euros), of which 15% were supported by Svenskt Vatten.

Table 4-2: Svenskt Vatten Energy Project: projects developed during phase 2

Organization	**Description**	**Total amount invested (Euros)**	**Electri -city savings (MWh)**	**Heat savings (MWh)**	**Gas savings (MWh)**	**Financial support (in %)**	**Financial support – total amount (Euros)**
Boräs Municipality	Sludge Heat Exchanger	215 754	n/a	1 955	n/a	8	16 483
GRYAAB AB	Time Optimization	126 303	256	n/a	n/a	10	12 599
Häbo Municipality	New Air Compressor	6 404	60	n/a	n/a	20	1 270
Käppalaförbundet	Optimization of O_2 supply	47 246	343	n/a	n/a	20	9 449
Motala Municipality	Sludge Thickening	115 489	n/a	n/a	634	18	20 998
Mälarenergi AB	Changing Pump	49 240	345	n/a	n/a	32	15 749
Skövde Municipality	Energy Efficiency	132 812	215	n/a	n/a	20	26 562
Sundsvali Vatten AB	Energy Optimisation	188 982	500	n/a	n/a	20	37 796
Ulricehamn Energi	Changing Pump	21 523	230	n/a	n/a	27	5 774
Varbergs Municipality	Pumping	157 485	700	n/a	n/a	10	15 749
Total		**1 061 238**	**2 649**	**1 955**	**1 839**	**15**	**162 429**

Note: few more projects were planned but have not been implemented for various reasons. This table only shows projects that have been effectively implemented.

Source: Adapted from Svenskt Vatten, 2009.

Besides technical measures, measures related to managerial organization, benchmarking, networking, communication are also part of the project. Some of the measures implemented in 2009 are (Svenskt Vatten, 2009a):

- Identification of existing tools such as Life Cycle Assessment, and establishment of a list of most successful projects developed by water utilities.
- Creation of benchmarking and best practices amongst the network of the association. “Demonstration projects” have shown good levels of energy conservation in WWTPs.
- Establishment of a list prioritising the most effective measures. Financial support has been provided for projects reflecting this list. As a result of this, 10 projects have been implemented at a total cost of 10.1 million SEK (1 million Euros) resulting in 2.6 GWh of electricty savings, 2 GWh of thermic energy and 1.8GWh of gas savings representing a reducing cost of 5 million SEK (524 950 Euros), a high return on investment according to Svenskt Vatten.
- Organization of numerous seminars and study tours for technicians, engineers and employees of water utilities.

- A Compendium titled “Effective treatment” was written by Professor Emeritus Gustaf Olsson, detailing strategies to save energy within wastewater treatment processes.
- Consultation with stakeholders in the agriculture and food industry, food retailers, consumers groups, environmental associations and government to develop a certification system for fertiliser produced from sludge called REVAQ®.
- Exploration of opportunities to obtain better prices on selling biogas.
- The following sections of this chapter present the two case studies conducted in Sweden at two WWTPs : Källby located in Lund in the Skåne County and Nykvarnsverket located in Linköping in the Östergötland County.

4.2 Källby WWTP

4.2.1 Background

Källby is part of VA SYD, a statutory authority jointly owned by Lund and Malmö municipalities since 2008. VA SYD activities include the distribution of drinking water, the collection and the treatment wastewater in Malmö and Lund but also surrounding municipalities: Burlöv, Vellinge, Staffanstorp, Svedala and some parts of Lomma (refer to Appendix IV for localisation map). All these municipalities are located in Skåne in the south of Sweden. VA SYD has strategically merged the operations of Malmö and Lund municipalities to better respond to environmental challenges and increase operational efficiency. VA SYD which employs 300 people, serves a population of 500 000 in the Skåne region delivering drinking water, and treating wastewater in 11 WWTPs. VA SYD is also involved in waste management.

Källby sewage treatment plant treats sewage from Lund including Vallkärra, Stångby and Stora Raby, by mechanical, biological and chemical treatments. Källby has been designed for a 120 000 population equivalent (p.e.) load in order to be able to respond to an increasing capacity load in the future. The plant currently serve 84 000 p.e. including students (Lund is the biggest university town in Sweden) and patients under care at the hospital. Once treated, the water is discharged in the nearby river Höje. Källby employs 10 people full time. In addition, other employees from VA SYD work occasionally at the plant.

Källby provides a concrete example of measures that can be taken towards energy efficiency. Despite the fact that Källby is not subject to targets in energy consumption nor GHG emissions, energy efficiency is systematically considered when new projects are developed (Cimbritz, 2010). A fact also corroborated at the Sjölunda WWTP (Paulsson, 2010), also part of VA SYD and based in Malmö. However, in practice, within the existing operational framework and human resources, other elements needs to be considered in the balance resulting in trade-offs illustrating the complexity of energy efficiency and effects of the wasterwater treatment on the environment.

4.2.2 Operational level

The population of Skåne is due to increase within the coming years due to the economic development of the region as well as the possible construction of the European Spallation Source, a large-scale research center on neutrons sources in Europe. To face this challenge, within 1 to 2 years, Källby plans to expand its anaerobic digestion capacity, by adding one or two digestion units to the plant. There are lots of investigations in the choice of operations, including energy efficiency. One considered option is thermofilic digestion that uses more energy because it requires a temperature of about 55 Cº but would generate a higher gas production. The second option considered is mesophilic digestion which requires a lower temperature of 37 Cº, but might not be as efficient. Energy input is very much considered and balanced against other parameters such as the process stability, the gas production, and the risk of nuisances such as odours (Cimbritz, 2010).

At Källby, the biological treatment or activated sludge treatment of nitrogen removal is done through a re-circulation process of the denitrified water using the BOD present in the water instead of adding carbon in the form of ethanol or methanol in the denitrification process. This process consumes lot of ethanol and methanol which indirectly produces CO_2 emissions by preventing its availability for fuel transportation (Finnson, 2010). In the aerobic process, Ammonia (NH_4) present in the influent water is mixed with in the oxygen aerated tank under aerobic conditions creating oxidation, and thus transforming ammonia into nitrate (NO_3). In a second step, carbon usually needs to be added to transform the nitrate into nitrogen gas released into the atmosphere (process called denitrification). At Källby, nitrate, formed during the first step (nitrification), is returned to the anoxic zones for denitrification (removal of nitrogen) avoiding the need to add carbon.

As already mentioned, it is essential to control the aeration process in the activated sludge treatment (BOD, Nitrogen and Phosphorus removal). It is estimated at the lowest to consume about 30 to 35% of the total electricity consumed within a plant. The levels of ammonia present in the wastewater must be regulated. In order to optimise the process, levels must be measured to allow an efficient aeration, i.e. not injecting too little or too much oxygen in the process. The case of Källby provides an interesting and concrete example on how energy can be saved through this way. In recent years, Källby has been focusing in optimising this treatment process and installed a control scheme based on-line metering in two of the "biolines", B3 and B4, for an investment of approximatively 200 000 SEK (20 998 Euros) (Wennberg, 2010). In 2010, there is a plan to develop the advanced control system in the two remaning additional lines, B1 and B2.

The graph below (Figure 4-5) shows how much air is needed per m^3 of water in the two different blocks between October 2009 and May 2010. The regulation of aeration is based on NH_4-N in B3-B4 whereas it is based on oxygen in B1-B2. The average over this period is 9 Nm^3 air/m^3 water in the case of B1-B2, while 5 Nm^3 air/m^3 in the case of B3+B4. This indicates that compared to B3-B4, B1-B2, which have not been equipped with on-line metering controlled process, consumes 1.5 times more air consumption. A rough figure of energy needed to attain 1 m^3 of air is 25 Wh (Wennberg, 2010). The total flow of water in each block is around 15 000 m^3/d, therefore the electricity consumption in B3 and B4 amounts to 730 MWh per annum[6].

[6] 15 000 m^3 water/day x 5 m^3 air/m^3 water x 25 Wh/m^3 air = 1 875 000 KWh/day / 2MWh/day = 730 MWh/p.a.

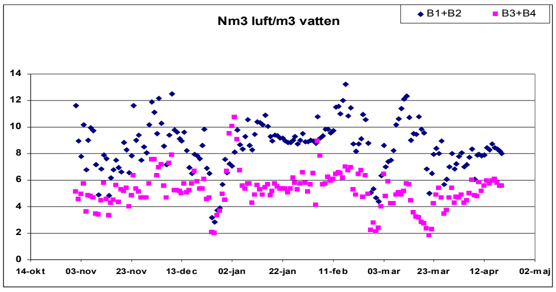

Figure 4- 5: Comparison of biolines with and without on-line metering. Source: VA SYD, 2010.

Therefore B1-B2 consume : 730 MWh/p.a. * 1.5 = 1 095 Mwh/p.a.

And the total energy consumption B1-B4 is: 730+1095=1 825 MWh/p.a.

At Källby, a total of 3 613 MWh of electricity was consumed during 2009. The aeration system consumed approximately 1 825 MWh representing 50% of the total electricity consumption. Energy consumption per m^3 of wastewater treated at Källby has been fluctuating between 0.3 kWh/ m^3 to 0.38 kWh/ m^3 between 2004 and 2008 (VA SYD, 2010). The reasons for the increase have not been identified with certainty by the plant. They could be attributed to differences in loading and possibly to operational strategies (Cimbritz, 2010).

Besides looking at improving internal processes, energy efficiency comes through energy production: in fact a WWTP can become an energy producer, a way to offset its energy use. A lot of WWTPs in Sweden produce biogas from the sludge, which has been supported by the Swedish Energy Efficiency Programme developed by Svenskt Vatten. Biogas is then transformed into energy: electricity and/or biofuel. It is actually more energy efficient to produce electricity out of the biogas, but as an overall effect, it is better for the environnment to produce biofuel because it reduces indirect CO_2 emissions from vehicles, a direction considered by lot of municipalities in Sweden (Wennberg, 2010).

Källby entered into an agreement with Lunds Energi in February 2009 to produce biofuel, an operation estimated to reduce Källby CO_2 emissions by 1740 t. annually. The details of CO_2 –eq.emissions related to this operation are presented in the table 4-3.

Table 4- 3 Biofuel production: potential amount of CO_2 emissions avoided

Energy produced and/or utilised	**Amount of CO_2-eq. (t./p.a.)**
Biogas used instead of petrol in vehicles	-2050[7]
District heating replacing heat produced from gas motor	360
Electricity to buy	230
Reduced methane leakages from gas motor (approx. 3.5%)	-390
Methane leakages due to upgrading (1%)	110
Total	-1 740

Source: Lunds Energi Koncernen, 2010.

7 Numbers preceded by "-" represent emissions avoided, therefore they are subtracted.

Källby provides to Lunds Energi its raw gas which is upgraded from 6 Kwh/m^3 to 11 Kwh/m^3 for to the gas grid using a system called "water scrubbing" developed by Malmberg Water, a Swedish company. In exchange, Lunds Energi provides district heating free of charge to the plant, and reimburse the amount of electricity Källby buy/consume per year (Warderstam, 2010).

This project, initiated by Lunds Energi, represents an investment of 20 million SEK (2 million Euros). It is supported by the Swedish EPA which granted 1.7 million SEK (178 483 Euros) to the energy company. through the"Klimp Programme" which is part of the Swedish Climate Strategy Bill (2001:02/55), supports municipalities and local actors in their efforts to reduce GHG emissions. Besides grants allocated to long-term investments, this programme aims at strengthen cooperation between local actors, and collecting and disseminating information to encourage "climate work" throughout the country. Between 2003 and 2008, measures that were granted funding mainly in energy and transport sectors are estimated to save approximatly 1.1 million emissions CO_2 equivalent, saving about 1.2 TWh of energy per year. This programme is an illustration of actions put in place by Swedish government towards climate change and to encourage synergies between local actors, such as Källby and Lunds Energi.

The payback of Lunds Energi investment is 10 years, and although not immediately profitable, this measure contributes to enhance the environmental profile of the company (Wardestam, 2010) through for example developing local business. Lunds Energi is producing 17 GWh of gas per year (2009), 10 GWh coming from natural gas, and 7 GWh coming from biogas. Of this production, 10 GWh is used in buses running in Lund (by 2020 all the buses in Lund will run on biogas), 4 GWh are consumed by private vehicules, and 3 GWh by waste trucks. This agreement provides a great example of a synergy that can be developed between the WWTPs and other sectors, contributing to develop small-scale systems and urban sustainable management.

4.2.3 Tactical level

At a tactical level, process engineers working at VA SYD are meeting once in month in order to share ideas and transfer knowledge on experiences and developments in treatment processes in the various WWTPs within VA SYD. They are also working on a benchmarking project. Källby has also taken part in the Svenskt Vatten Energy Project participating in a study about benchmarking.

4.2.4 Strategic level

The merging of Lund and Malmö activities into VA SYD has created a new type of organization in Sweden, possibly becoming best practice in Sweden according to a research conducted by Allegretti (Allegretti, 2010).

At a strategic level, the creation of VA SYD in 2008, as well as the closure of the small WWTPs around Lund in the near future are part of VA SYD strategy towards centralisation through the creation of a new public company. In the 1990s, while the public sector was in crisis, a tender was organised and English company, Anglian Water was retained. However shortly after, the new elected majority looked into the problems caused by the privatisation of sector in the UK. The contract was never signed, but the Malmö water company looked at the content of Anglia's proposal and took inspiration from it. Albeit being centralised into one joint authority, VA SYD has developed an original way of merging two entities while respecting political interests and historical identities of the two cities towards the best common interest (Allegretti, 2010).

The idea was to build a “hybrid” company governed at a supra-municipal level (Allegretti, 2010) to overcome management difficulties related to rural areas, sharing management services and professional competency, and also respecting municipalities political orientations and decisions such as the price of water or the quantity of water consumed. Therefore this model provides “a variable geometry of governance bodies ready to welcome new partners in every phase of possible future growth, safeguarding their decisional autonomy in several fields of decision making as well as the municipal ownership of assets” (Allegretti, 2010). Small size neighbouring WWTPs (Dalby, Veberöd, Bjornstörp and Genarp) will be integrated into Källby in 2011 in order to improve the quality of the water effluents (at present nitrogen is not treated in those small plants), as well as increasing operational efficiency. The disadvantage will be the need to pump the wastewater to Källby which will increase energy consumption, as well as introducing Nitrogen removal which was not systematically performed in the smaller WWTPs around Lund. However due to a larger scale of the treatment, the overall energy consumption could very well be reduced. The challenge is to find the right size for managing the Källby plant and how to manage it (Cimbritz, 2010).

VA SYD management strategies are based on vertical and horizontal organization (Allegretti, 2010). The latter transpires through a long tradition from the Malmö water works to cooperate with universities, and to be an active participant into projects developed by Svenskt Vatten. Employees are very much engaged in the process and training is carefully adapted according to personal needs. Vertically, VA SYD owns 50% of Sydvatten, the water distribution body in Malmö. VA SYD is also open to share information and its experience in developing its organizational structure with other plants throughout the country. Consultation of customers through surveys is an important aspect too englobing all stakeholders of the society and facilitating urban integration and management.

While there are no elements to directly quantify the effects on energy efficiency, the organizational structure of VA SYD certainly creates a working environment favorable to the integration of social, economical and environmental sustainability principles. Political differences are acknowledged instead of being ruled-out, information is shared through regular meetings, and employees can play an active role in operational management. By being a bigger structure and bringing diversification, VA SYD also aims at attracting high skilled workers (Cimbritz, 2010), an important element to work towards the development of technology and innovation.

Finally, VA SYD is sourcing electricity for some its plants from energy companies that belongs to the Swedish environmental label Bra Miljöval (“Good Environmental Choice”"), a label created by Naturskyddsföreningen, the Swedish Nature and Conservation Society.

4.3 Nykvarnsverket

4.3.1 Background

Nykvarnsverket I Linköping (hereafter "Nykvarnsverket") is part of Tekniska Verken, a regional public company located in Linköping in the Östergötland County, East of Sweden. The company is involved in several activities including electricity, biogas, district heating and cooling, and waste management. It includes seven different divisions: Water division, Stadpartner (planning and maintenance of pipe and cable networks), Ostkraft & Utsickt (electricity production), Usitall (energy waste), Svenskt Biogas (biogas production), and Bixia (Energy trading). Tekniska Verken has 284 employees, and a net profit of 415 million SEK (43.6 million Euros) (2008). The total income for the company was 5.4 billion SEK (56.7 million Euros) in 2008.

Nykvarnsverket functions as a traditional Swedish WWTP. It was initially build in 1952 and is serving 145 000 inhabitants in the region (refer to Appendix IV for localisation map) of which 133 000 are connected to. Nykvarnsverket has a capacity load of 230 000 p.e. and an actual load of 180 000 p.e. (2008) and can process up to 75 000 m^3 of wastewater per day. 13 people operate and maintain the plant, and five process managers part of the Water division also works for Nykvarnsverket but not exclusively.

The main drivers cited at Nykvarnsverket to improve energy efficency are financial factors (reducing costs) and the branding of a green profile, often politically motivated. "Politicians want to have a good municipality and what we do represents a large carbon footprint for the municipality" (Arnell, 2010). Nykvarnsverket has not developed energy efficiency strategy per se but is looking at environmental progress. Tekniska Verken is ISO:14001 certified since 2001, and therefore have to look at continuous improvement. Since wastewater processing is based on energy, energy efficiency is a good way to fulfill environmental commitments (Arnell, 2010).

Historically, energy prices have been low in Sweden, and this can be seen as a reason why energy consumption in WWTPs was not a concern and why energy performance has not much improved in the past. However this is changing, the increase in energy prices represents a strong driver to reduce energy consumption. But energy efficiency improvements are limited because of the infrastructure of the plants. The plant operations cannot be interrupted for rebuilding, and there are important physical and financial limitations in modifying the infratructure to make a plant more energy efficient (Arnell, 2010). Building better energy performing utilities is technically possible, but it is often not affordable, and would not be profitable only from an energy savings perspective only (Arnell, 2010). To build the same plant with modern technologies and maintain the same treatment level would represent an investment of 1.5 billion SEK (158 million Euros) (Arnell, 2010).

Different types of measures have been taken recently at Nykvarnsverket requiring important financial investments (Arnell, 2010). Energy consumption has remained stable since 2005 compared with incoming flow of wastewater. The rate of nutrients removal has been either constant or in progression (Nitrogen) indicating a relative progress in energy consumption.

4.3.2 Operational level

In 2007, Nykvarnsverket invested in an intermittent aeration process controlled by online instrumentation in the biological treatment. Through supervised online monitoring, this process adjusts the oxygen aeration needed to incoming flows depending on the time of the day, thus saving energy consumed by the air blowers that release oxygen into the tank. However, according to calculations performed, this process allowed to save only 1% of electricity consumed within the plant. But it contributed indirectly to save on approximatively 100 000kg of ethanol which represents 750 mW/h of direct energy content. Ethanol could then be used for fuelling vehicles thereby offsetting CO_2 emissions (Arnell, 2010).

As we have seen previously, European regulations impose a removal rate of 70% of nitrogen which was not met until 2008 by Nykvarnsverket. The improvement in the aeration of the biological system, as well as the introduction of a high-rate nitrogen removal system (the Sharon®[8]process) contributed to meet the nitrogen effluent rate required by the European legislation. This process developed relatively recently operates with minimal sludge retention time which requires a smaller reactor volume than in traditional nitrification and denitrification process. It also requires less energy and chemical input (carbon for denitrification), respectively 25% and 40 % (Arnell, 2010, Pennsylvania EPA, 2002). The project includes the installation of the turbo blower in a strategic location of the plant to feed the Sharon®process but also other parts of the plant, thus maximising its use. While additional capacity has been added, the overall energy consumption has been maintained at the same level compared with previous years indicating relative progress in energy performance.

As most WWTPs in Sweden, Nykvarnsverket produces biogas from the sludge digestion process. The amount of biogas produced amounts to 165 100 MWh and is sold to Svenskt Biogas, a company part of Tekniska Verken, for upgrade to vehicle fuel quality. It is higher than the average produced in most of WWTPs in Sweden (Arnell, 2010) representing an important focus at Nykvarnsverket.

In the past, sewage water and stormwater were both collected in a combined system, stormwater run-off mixed with wastewater diluted the water and reduced the organic content which makes the treatment process less efficient. The pipeline system was renovated in several steps throughout the years since the 1950s by adding 400 km of pipes separating rainwater and wasterwater pipelines networks. It could not be established how this had impacted energy consumption.

4.3.3 Tactical level

In 2008, a new department for environment and quality management was created at Tekniska Verken in order to coordinate and improvement of the efficiency of the operational system. This had a significant impact so far and is expected to contribute further (Arnell, 2010). This measure allows to increase the focus on environmental objectives goals and provide incentives to aim towards higher objectives than what the legislation requires. This department provides support and information on environment such as legislation updates, conducts internal inspection to ensure a good functioning of the

[8] Sharon® stands for Single reactor system for High activity Ammonium Removal Over Nitrite

company units. It relieves managers from administrative burden who can then work more effectively on their tasks (Arnell, 2010).

Extensive renovation of equipment used for mechanical separation of paper and other solid waste in wastewater was performed. While this measure does not relate directly to energy, it has provided significant improvements to the working environment at the purification plant.

Nykvarnsverket, together with five other WWTPs in Sweden have taken part in one of the project developed by Svenskt Vatten in the Energy Programme (refer to Section 4.1.3). In the autumn 2009, Nykvarnsverket was one of several pilot plants where key parameters and numbers were experimented. 300 different parameters were tested and reported to Svenskt Vatten on energy consumption, chemical consumption related to various parameters such as wastewater flows, discharge, load, etc. (Arnell, 2010). This project should contribute to put in place in the future a national benchmarking system through which WWTPs will be able to report their data.

Tekniska Verken is currently working on introducing an internal benchmarking and monitoring system, including energy indicators. This measure will allow to focus more on the value created such as achieving better effluents rate, reducing costs and saving energy. "This is an alternative focus chosen because regular managing on economic value doesn't apply to us since we're not allowed to make profit" (Arnell, 2010).

Sweden is one of the countries in the EU that leads the harmonisation to the top in terms of environmental policies and environmental standard settings. An energy programme especially designed for the WWTPs has been in place since 2005 and is due to run until 2012. Both Nykvarnsverket and Källby are performing very well in terms of energy efficiency. The importance of energy performance is increasing when rethinking treatment processes and developing new strategies. The production of biogas and biofuel from the sewage sludge has been highly encouraged in Sweden where the use of biofuel is being developed in cooperation with municipalities. In the next chapter, we will analyse findings from three case studies conducted in one of the largest plant in France in which strategies are heading towards the optimisation of energy systems, also including the production of biogas.

5 France

France was selected for this research because WWTPs operate in a different context compared to Sweden: a much higher population and traditionally less concern have been given to environmental issues. The first section of this chapter presents the national water governance mode and some environmental policy background. The second section analyses three case studies conducted within the authority that manages the wastewater treatment in the Paris agglomeration (the "Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne", SIAAP hereafter).

5.1 Background

France is divided into 26 administrative regions which are further subdivided into 100 "départements". With a population of 64.6 million of inhabitants in 2010 (INSEE, 2010), France has seven major rivers systems covering 270 000 km of watercourse, coastline, lakes and wetlands. Water resources are estimated at 2000 billion m^3. In 2004, 81% of the population was connected to public sewage treatment plants. France counts 18 830 wastewater treatment plants representing a load of 75 million p.e. and a total capacity of 94 million p.e (Ministère de l'Ecologie, de l'Energie, du Dévelopment Durable et de la Mer, 2010). About three quarters of the plants have a relatively small size, below 2000 p.e. (BIPE/FP2E, 2010). France is one founding members of the EU, and one of the early adopter of the Integrated Water Resource Management concept in 1964. However, full compliance with European legislation has been lacking. France has delayed the identification of its sensitive areas. In 2005, France was compliant only at 50% with the Article 5 of the UWWT Directive which imposes more stringent treatment requirements on sensitive areas (Commission of the European Communities, 2009). As a result, the EU has been warning France of heavy fines for non-compliance. Today, more than half its territory is classified as sensitive areas. In 2005, France complies with having collection systems in place (Article 3 of the UWWT Directive). The required secondary treatment is applied to 93% of the pollution load. In 2005, France has also one of the lowest compliance rate (63%) with the Article 4 of the UWWT Directive related to applying secondary treatment according to the size of the agglomerations (Commission of the European Communities, 2009). In addition, as of the 31st of December 2009, 10% of WWTPs were not in conformity with the UWWT Directive in terms of installations[9]. Following several interventions from the EU, the French government has taken the engagement to have all plants in conformity by the end of 2011 (Ministère de l'Ecologie, de l'Energie, du Dévelopment Durable et de la Mer, 2010).

5.1.1 Water Governance

The French government regulates the relationship between the actors of the water sector and ultimately has the control over national water resources. The first legal provisions related to water in France date back to Napoleon in the 19th century. In the modern times, water is regulated by the 1964 Water Act ("Loi sur l'Eau"). This law has been fundamental to the development of the water policy in France. It has set the current organization of the water policy in six hydrographic basins governed by basins committees ("comités de bassins") in which all stakeholders of the water sector are represented. Basin committees

9 The conformity of installations depends on the effluent quality of the wastewater after treatment.

are in charge of developing water policies which are then implemented by the water agencies. The water agencies in each of the six basins provide financial support to municipalities, the regions and "départements". They contribute to the financial support of the sector and communicate regularly with stakeholders in the water sector: the government who sets the direction for water policies[10], the European Union through the Water Framework Directive (WFD), the Urban Wastewater Treatment Directive (UWWT Directive), Non Governmental Organizations (NGOs) and consumers associations who are consulted on a regular basis by public services. This type of governance based in the IWRM principles was pioneering at the time preempting the WFD. The Water Act was amended in 2006 then renamed "Loi sur l'Eau et les Milieux Aquatiques" (LEMA, 2006-1772). The main aspects of the law include the following:

- Financing of the sewage treatment is separate from that of the general operations of the municipalities in order to ensure full cost recovery by users fees, and all financial resources comes from users fees.
- All domestic consumers must be provided the same quality of service.
- Water services cannot be interrupted at any time.
- Introduction in 1992 of water management plans ("Schémas Directeurs d'Aménagement et de Gestion des Eaux", SDAGE hereafter) in order for each basin to orientate, monitor and determine appropriate measures. Recent measures of the SDAGE for 2010-2015 include the improvement of the quality of the treatment (51% of budget), the fight against pollution originated by agriculture (25% of the budget), and the improvement of biodiversity (17% of the budget), in accordance with the WFD.
- The amendments introduced in 2006 take into account the mitigation of climate change, take the engagement to fully conform to the WFD by 2015, aim at improving the public services and wastewater treatment, as well as provide more transparency in the management of the water sector between the public and private operators.

Water and waste management is in France in the hands of local gouvernments since the French Revolution in 1789. Due to the high number of French communes (36 680), municipalities create grouped organizations ("Syndicats Intercommunaux") to manage water and waste more efficiently. Both sectors constitute priorities at the municipal level in terms of medium to long term investments within the 1992-2006 period. In 2006, 60% of municipalities were considering water and wastewater treatment investments as a priority (BIPE, 2006). In 1994, less than 10% of French municipalities were considering investments in energy as a priority, while the proportion changed to 42% in 2006 (BIPE, 2006). Likewise in 1994, investments towards the development of renewable energies and a better management of energy were priorities for only 20% and 24% of municipalities respectively. In 2006, they both became a priority for 50% of municipalities (BIPE 2006).

Wastewater management which comprises collection, treatment, rejection, and customer service falls under municipalities responsibility as we have seen. Municipalities are free to choose the management mode of wastewater treatment according to their preferences.

[10] The water section of the Ministry of Environnent coordinates State actions in the water sector (Ministère de l'Ecologie, de l'Energie, du Développement Durable et de la Mer, 2009) supported by the National Water Office, ("Office National de l'Eau et des Milieux Aquatiques", ONEMA).

There are two different management schemes, the second being very common (Shahrooz et al., 2003):

- The municipality or the group of municipalities ("Syndicats Intercommunaux") operate the wastewater treatment themselves ("régie directe"). In this case, wastewater treatment is operated by a public operator (the municipalities themselves).

- The management is delegated to an external company which can be either privately owned such as Veolia, or Suez/Lyonnaise des Eaux (two of the main leading worldwide companies in water management) or through a Private Public Partnership ("Société d'Economie Mixte"). The delegation covers the running of the service ("affermage"), and sometimes investments ("concession"). Private companies operates about 5 000 wastewater stations, covering mainly the biggest agglomerations (BIPE/FP2E, 2010).

5.1.2 The Grenelle Laws ("Lois de Grenelle")

In France, the Grenelle Laws ("Lois de Grenelle" also refered as "Grenelle de l'Environnement") represent the (recent) legislative milestone for the environment. Their adoption happened in two steps: in 2008 ("Loi de Grenelle I") and in 2010 ("Loi de Grenelle II"). They set the climate change as one of the priorities for the environment. France has committed to reduce its GHG emissions by 20% compared to the 1990 levels and to reach 23% of renewable energies in the national energy mix by 2020. Regions have to establish climate plans ("Schémas régionaux du climat, de l'air et de l'énergie") to determine orientations in reducing energy consumption and prevent GHG emissions. In addition, local authorities and companies with more than 500 employees are now obliged to calculate their carbon footprint. The new law ("loi 2010-788") adopted on July 12, 2010 includes research plans to develop CO_2 capture and sequestration. Following the Law on Water, it has also added a provision for networks which are not part of the collective (public) wastewater network concerning about 19% of the population or 5 million households (BIPE/FP2E, 2010). This provision will lead local authorities to create an unified public service of wastewater treatment ("Service Public Unifié de l'Assainissement") in which municipalities cover costs for the construction and maintenance of those networks, hence possibly increasing the costs paid by citizens. The water sector is financed through the water fees paid by the citizens, the budget of the communes and the polluters who according to the "polluter pays principle" has to pay for its generated pollution to the water agencies (Ministère de l'Ecologie, de l'Energie, du Dévelopment Durable et de la Mer, 2009).

The Environmental Code, part of the Grenelle Laws ("Code de l'Environnement", Articles 68 and 69) is based on the precautionary and polluter pays principles, the adoption of the best available technology, and the public participation. The Code has five objectives:

- fighting against the climate change

- preserving biodiversity and natural resources

- ensuring social cohesion and solidarity between territories and generations

- the harmonious development of all human beings
- the development of sustainable consumption and production.

5.1.3 Environmental policies

According to the Grenelle Law I (Article 1) the French government has established a national sustainable strategy, “Stratégie Nationale de Dévelopement Durable (SNDD)” for 2010-2013, adopting the EU Sustainable Development Strategy (EU SDS). The objective is to reduce GHG emissions by 75% by 2050. The main pillars of this strategy adopted on July 27, 2010 are the development of sustainable consumption, a governance that include all stakeholders of the society, the development of sustainable transport and mobility, preservation of biodiversity and natural resources, and energy and climate change (Délégation au Dévelopement Durable, 2010). With regards to energy and climate change, the strategy includes the establishment of energy prices that are to reflect the impact of the GHG emissions (externalities), a systematic accounting of GHG emissions at a national level, the suppport to regional, municipal and local authorities towards adaptation and reduction of GHG emissions through various actions, energy efficiency improvements, etc. The strategy addresses all actors of the society with a particular focus on the building and transport sectors, high emitters of GHG emissions.

It is also worth mentioning the National Quota Allocation Plan (“Plan National d’Allocation des Quotas”, PNAQ) of GHG emissions, in application of the Directive 2003/87. It allocates GHG emissions quotas to specific energy and industrial sectors that emit significant amounts of GHG. Sectors such as energy, chemical, pulp and paper and food with an annual combustion of more than 20 MW are concerned by this plan. The amount of GHG emissions allocated to France by the EU in the second plan (2008-2012) is 132. 8 $MtCO_2$-eq. (Commission of the European Communities, 2007).

5.2 The “Syndicat Interdépartemental pour l’Assainissement de l’Agglomération Parisienne”

5.2.1 Background

The regional authority that manages wasterwater in the Paris agglomeration (the “Syndicat Interdépartemental pour l’Assainissement de l’Agglomération Parisienne”, SIAAP) serves 8.5 million inhabitants. It is the largest authority in Europe in terms of population and one of the largest in the world. Its annual budget is 1 billion Euros financed through the water fees paid by citizens and subsidies coming from the Seine-Normandie Water Agency and the Ile-de-France region. The authority manages 382.5 km of network distributed across 7 “départements”: Val d’Oise, Seine Saint-Denis, Hauts-de Seine, Paris, Yvelines, Essone and Val-de-Marne. This public authority is unique in France because it is a group of “départements” in lieu of municipalities. It counts 5 WWTPs (refer to Appendix IV for localisation map): Seine Aval, Seine Amont, Seine Grésillons (under expansion), Seine Centre, Marne Aval. The average daily volume of incoming wastewater amounts to 2.3 million m^3 (2009) (Tabuchi, 2010). One additional plant, Seine Morée, is currently under construction and is planned to start its operations in 2013. Once treated the water is rejected into the Seine and the Marne rivers.

The SIAAP provides an interesting perspective to this research due to its size, the ambitious re-development plans of its plants, and its active commitment towards sustainability as a local authority within the wastewater sector, in accordance with its Agenda 21 Comission and sustainable development strategy.

The re-development of the SIAAP started in 1997, when a sanitation master plan was approved by a committee composed of representatives from the Seine Normandy water agency, the SIAAP, the Ministry of Environment, and the Ile-de-France regional government. It included the construction of new plants (Seine Centre, Seine Morée and Seine Grésillons) and the renovation and/or expansion of existing plants (Seine Aval, Marne Aval, Seine Amont). Fundamentally, the re-development aims at redistributing the treatment capacity amongst all the plants, upgrading treatment quality and performances to comply with the European legislation, and improving stormwater pollution management. Due to non compliance to the UWWT Directive (refer to Section 3.2.2), the redevelopment plan had to be adpated and was reviewed in 2007. Today, all the SIAAP plants are compliant with the UWWT Directive except for nitrogen removal at Seine Aval, Marne Aval and Seine Amont. In addition to the initials objectives of eradicating noise and odour nuisances and improve the quality of the Seine river, came the concept of sustainability and the WFD which introduced new legislation. In this context, the SIAAP is in the process of undertaking enormous changes which ultimately will lead the authority to run high-tech wastewater treatment plants. This represents a huge challenge and opportunities to develop best practices in terms of energy efficiency both for the SIAAP itself but also for the developers of the WWTPs. In addition, an Agenda 21 Commission was established in 2009 in order to guide and implement the environmental vision.

With regards to optimising energy efficiency, one of the main challenge resulting in a strategy axis at the SIAAP is the valorisation of the sludge. It is worth mentioning that Seine Aval, the biggest plant in operation at the SIAAP, was one of the very first plant in the 1940s to re-use the sludge as a fertiliser. France is the biggest agricultural country in the EU, and recently the traditional utilisation of sludge as fertiliser is taking an interesting turn. Consumers and environmental associations are increasingly suspicious about the sludge quality and its impact on environment and human health. Farmers are reluctant to use it due to the complexity in controlling its quality. The reasons for this are fears related to the content of heavy metals, organic micropollutants and potential viruses. In Switzerland, it has been forbidden and the sludge is now incinerated. Landfilling is certainly not a well-regarded option anymore due to concerns for the environment. To remedy to that, Sweden has recently developed a certification label (called REVAQ®) of fertiliser coming from the sludge to increase the control on the sludge and reassure farmers.

5.2.2 Strategic level

5.2.2.1 The Agenda 21 Commission: a “road map” to sustainability

As a strategic top to bottom measure, an Agenda 21 commission has been created in 2007 to guide employees as well as external stakeholders towards the application of sustainable principles. It emanates from an action plan produced by the top management to reaffirm strategies towards sustainability (Schäfer, 2010). “This agenda [...] allows, possibly legitimates current practices and gathers sustainable actions around a common project” (SIAAP, 2009). The action plan for 2010 is organised in five themes: participation in sustainable development within the Paris agglomeration, contribution to improvement of health and living conditions, being a public service open to the society, the preservation of biodiversity and natural ressources and the fight against climate change. The objectives defined for 2010 related to energy consumption and GHG emissions are (SIAAP, 2010):

- Develop and build installations that consumes low levels of energy. This can be achieved by following up carbon footprint assessments, by optimising pumping in Seine Grésillons and by establishing drivers towards sustainability.
- Valorize agricultural and/or energetical potential of the by-products of the wastewater treatment in lieu of products originated from fossil fuel based energy. To achieve this, the objective for 2010 is to increase the yield by 10% in order to respect GHG emissions quotas established in the second National Quota Allocation Plan (2008-2013) as compared to the first plan (2005-2007).
- Develop and exploit processes to reduce the use of chemicals.
- Develop energy savings measures by assessing energy consumption, optimising the lighting in the plants and offices, reducing commuting, using environmental friendly vehicles, encouraging teleconferencing and emails to reduce transportation.
- Realise carbon footprint assessments.
- Promote urban sustainability by developing local synergies. Such a project is being developed for the future Seine Morée where an heat exchanger would produce district heating for a local residence.

It is also interesting to note that the themes, objectives and actions in the 2010 plan have been more precisely redefined than the previous year, showing an increasing commitment towards sustainability. This commission represents an useful tool for employees to develop concerted actions. 70% of the actions planned in the 2008 Agenda have been successfully performed, showing encouraging results (SIAAP, 2009). Employees asked on how they feel about taking sustainable actions such as saving energy, communicated an important concern. “We are asked to systematically consider energy consumption when working on processes and the development of new plants” (Dhenaut, 2010). For the organization, it is important to be consistent. “We are looking at all possible ways to save energy. Despite the fact that the potential to save energy is much higher within treatment processes or at the construction of the plants, we are also taking smaller actions, such as installing lighting electrical sensors. We cannot ask employees to save energy if this is not done at a global level” (Schäfer). Some of the measures that are presented in the next sections show commitment and continuity with the Agenda 21 Commission.

5.2.2.2 Sustainable Development Strategy

The SIAAP defines itself as a “public industrial eco-citizen” acknowledging its responsibility towards the environment. Through its recent sustainable development strategy approved by the board of directors in 2010, the SIAAP aims at taking part of the sustainable development of the Paris region through developing local synergies with other stakeholders, for example by working together with industries to control water pollution at source. The SIAAP also aims at controlling the financing of the redevelopment. The strategy’s objectives also includes improving the quality of life and human health, being an active actor of the society by for example favoring local employment, informing citizens on wastewater treatment and the status of the redevelopment, as well as preserving the ecosystem and natural resources.

Minimising energy and chemicals consumption, as well as valorising the potential of by-products coming from wastewater through biogas production for example are two importants focus developed in the strategy. Within this perspective, we will look at the decision process between different alternatives in creating by-products from the sludge at the Seine Grésillons plant. The assessment of the second plant, Seine Aval, the biggest plant of the SIAAP currently being redeveloped, shows that there is a delicate balance between increasing energy needs and energy efficiency. Finally, as opposed to “retrofitting”, Seine Morée is a new plant under construction to be completed by 2013. The design process and energy solutions provide interesting elements and considerations on how to conceive plants for the future in the context of climate change.

5.2.3 Operational level

5.2.3.1 Seine Grésillons: how to optimize the biogas?

The Seine Grésillons plant, which is currently being expanded, provides an interesting example on the on-going process on how to optimise the use of the biogas, produced from the sludge, a by-product originated from the wastewater treatment. In terms of turnover, the development of the plant is the second biggest construction project in France after that of the new nuclear reactor in Flamanville. Currently a team of 200 persons are working on developing this project. Upon completion, the plant will employ approximatively 80 persons.

The first phase of the Seine Grésillons plant started its operation in 2007. It is located at Triel-sur-Seine in the department of the Yvelines. This plant, largely automated to reduce the need for employees, treats 100 000 m^3 of wastewater per day coming from 18 different communes including some parts of the Paris agglomeration, and will have a daily treatment capacity of 300 000 m^3 in 2012 upon completion of the second phase.

The expansion will allow to reduce the flow of wastewater treated at Seine Aval. Seine Grésillons will then produce an excess of biogas estimated at 2.5 MW in winter and 4.5 MW in summer. Seven different options have been established (Table 5-4).

In order to optimise the use of biogas, each solution includes different considerations that take into account the amount of energy consumed and produced and that have been evaluated financially. It immediately comes to light that the solution (A) is by far the most interesting from a financial point of view generating a revenue of 1.7 million Euros. But solution (A) was based on the assumption that the recent Grenelle Laws II would authorise the SIAAP to sell the electricity back to the grid at a preferential rate applied to households and local authorities. This law eventually did not include this provision[11]. Solution (C) would produce approximatively four times less energy than solution (A), but has the advantage to provide some degree of auto-consumption and not to be dependent of the fluctuating prices of energy. Any potential excess of energy produced would be used for drying the sludge. The Solution (D) takes into account the fact no staff would be required during the week-end. Solution (E) has the advantage to eliminate maintenance costs for the co-generation system: the biogas is sold. However the SIAAP would need to find a buyer, conveniently an industry located nearby. The solution (F) consists of using more biogas for

[11] The Grenelle Laws II allow the selling of electricity produced from renewable sources to the grid for public entities below the size level of a French “département” at the level of “collectivités territoriales”. The SIAAP being a group of “departments” does not enter into this category.

Table 5-4 Options considered to optimize the use of the biogas at Seine Grésillons

Solutions	Description	Estimated Revenue (million Euros)
A	The excess is used in cogeneration (2 x 1,7MW including added natural gas) to produce electricity sold to the grid to EDF[12] at a preferential rate applicable to renewable energy, estimated at 0,9 Euro cents/ kWh.	1.7
B	Same as (A) but the electricity price sold to EDF is the market price.	0.4
C	The excess is treated in a cogeneration system (2 x 0,8 MW). All the energy produced is auto-consumed (8%). The rest is used for sludge driers, 7 days a week.	0.9
D	The excess of biogas is treated in a cogeneration system but alternatively (2 x 0,8 MW). The rest is used for sludge driers, 5 days a week.	0.61
E	Cogeneration is abandoned. All the excess biogas produced is sold for 1 million Euro/p.a..	1
F	The excess of biogas is treated in one cogeneration system during weekdays, and in two cogeneration systems during the week-end. The electricity is sold at the market price. The sludge driers function 5 days a week.	0.8
G	The excess of biogas is treated to fully dry the sludge, and to fuel the boilers and digesters.	0.9

Source: SIAAP, 2010.

the cogeneration which functions autonomously, and stop the dryers which require staff during the week-ends. The solution (G) also eliminates the cogeneration option, the excess biogas is used for the boilers, driers and digesters producing a high energy yield.

Eventually the solution (B) was chosen. Technically, the engineering team is planning the installation of a cogeneration system using a gas motor to produce electricity and heat by combustion of biogas through a thermofilic digestion process. The electrical yield is estimated at 38% and the thermic yield at 42% providing a total energy yield of 80%. With an average quantity of biogas produced in winter of 30 263 m^3 per day, the cogeneration process would produce an estimated 6 500 KWh of energy per day (electricity and heat). Financially, as shown on the table 5-4, this operation provides a revenue estimated at 0.4 million Euros, representing about 20% of the amount forecasted to be spent on purchasing electrical energy (4.5 million Euros) in the operating budget (Dhenaut, 2010). Besides, if the Grenelle Laws II were to be amended in the future, it would potentially provide a higher revenue. Overall, this solution represents a 5% gain on the total cost of operations. Finally, due to organizational reasons and pressure to meet the effluents requirements from the WFD, some investments had already been made towards the solutions (A) or (B). The solution (G) was equally profitable financially, also providing a high yield in terms of energy, but was not retained due to the necessity to have employees working 7 days a week which was not politically acceptable. Solution (E) would have generated a revenue of 1 million Euros but was eventually abandoned due to the current dispositions of the legislation as explained above. Stocking biogas is potentially dangerous, and selling biogas requires complex legislative arrangements.

This example shows what kind of trade-offs are taken into account and considered with regards to the use of the sludge as a by-product through cogeneration systems. Besides financial gains, cogeneration provides an important gain from an environmental point of

[12] EDF is the main provider of electricity in France. Created in 1946 as a national company, it was privatized in 2004. In 2007, the EU has deregulated the electricity market in all member countries, opening the market to competition.

view (Dhenaut, 2010). By producing renewable energy, it compensates the need to use fossil fuel based energy thus avoiding GHG emissions.

5.2.3.2 Seine Aval: rethink of energy performance

Seine Aval is the biggest plant of the SIAAP, built on 800 ha, treating 1.5 million m^3 of wastewater per day, with a capacity load of 7.5 million p. e.. Seine Aval started its operations in 1940. Until the end of the 1980s, the plant has developed together with the urban and industrial development and additional units were progressively added to the existing structure. Only organic matters were then treated, and the treatment was very economical as there was no need for pumping. Sludge was already digested to be converted into energy. However, the treatment was very uneffective for several reasons such as shallow basins and an insufficient treatment time (Tabuchi, 2010). In 1989, changes had to be introduced due to neighbouring complaints, and a concern from the water administration to have all the treated water discharged into one location of the Seine river. Besides all the water discharged was not sufficiently processed and more pollution was added due to the combined sewage system of stormwater and wastewater. Important improvements had to be made. In 2000, a chemical treatment to treat stormwater in rainy conditions and to remove phosphorus was introduced. In 2004, due to the obsolescence of old units and operations problems, the WFD obliges the SIAAP to develop a master plan for the reconstruction of the plant. To develop this master plan, a public debate on the role of Seine Aval was organised in 2007. As a result, a complete redevelopment including a more intensive treatment process has been decided. It will be completed by 2020. The four drivers for the re-development are (Amosse et al., 2010):

- the compliance to the WFD and the UWWT Directive in terms of water effluents quality
- a drastic reduction of smells and visual nuisances
- the reduction of the energy electrical energy consumption and of the use of fossil-fuel-based energies
- the improvement of working conditions.

The redevelopment is happening in several steps. In 2007, a new unit for biological treatment (nitrification/denitrification) was installed. By 2011, in order to comply to the UWWT Directive, the treatment capacity will be being reinforced. In 2016, a new activated sludge treatment will be in place integrating the nitrification/denitrification unit and a new membrane treatment system[13]. By 2018, the Seine Aval plant will acquire a new sludge treatment to dry the sludge thermically. The dried sludge will then be used for agriculture, compost, and construction materials (Tabuchi, 2010). In addition, local geographical considerations also increase the need for energy. The plant will reduce its ground surface area to improve local urban conditions, therefore the new plant will have to be built on height to compensate for the loss of ground space, resulting in need of pumping and thereby more energy use. Finally, Seine Aval is subject to the National Quota Allocation Plan (refer to section 5.1.3). In the first plan (2005-2007), the annual allocation

[13] Membrane treatment systems consist in ultra and micro filtration systems. Nanofiltration and Reverse Osmosis are some types of membrane treatment systems. It is a technologically advanced system that treats water more effectively and that avoids the use of chemicals.

was 10 515 tCO_2-eq. which was reduced to 8 500 tCO_2-eq. in the 2008-2012 plan (a reduction of 22%) stressing the need to reduce the use of fossil-fuel-based energies. The new energy system should allow to reduce GHG emissions of Seine Aval by 22%.

Over the last 10 years, the need for electricity at Seine Aval has increased by 88% (Amosse et al., 2010), and is due to continue to increase due to the redevelopment. Seine Aval estimates its energy needs at 830 000 MWh annually upon the redevelopment, compared to 658 422 MWh in 2009, an increase of 26% (Tabuchi, 2010). Energy represents 5.5% of the operating budget (2010, prevision)[14] . In order to meet its energy needs and decrease its use of fossil-fuel-based energy, Seine Aval plans to use different sources of energy: biogas coming from the sludge process (digestion), solar energy to dry the sludge in green houses, and heat contained in the treated water (Figure 5-6).

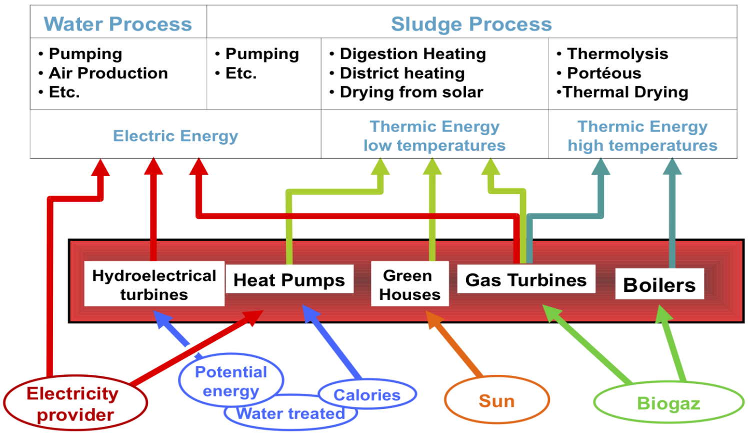

Figure 5-6: Different sources of energy used at Seine Aval. Source: Adapted from SIAAP, 2010.

The energy yield can be improved by valorising the different energy potentials: electricity production represents a high energetic potential while thermic energy has a less energetic potential. The new energy system will be equipped of two new gas turbines fueled by renewable energy (biogas) to produce twice more electricity than today (2 x 5 MW) and to use heat (thermic energy) coming from the turbines under the form of hot water at 90 Cº (2 x 8.4 MW) to heat all the digesters of the plant and the buildings. In addition, gas turbines have a lower maintenance cost for a higher yield, and use less energy.

The valorisation of biogas plays a central role in the rethink of the energy system. It dates back to the 1940s when it was used to provide some heating, to produce energy from thermic motors for self-consumption and to activate air injection into the biological treatment (Amosse et al, 2010). Until recently, the conception of biogas systems was developed in independent units due to the typically fragmented construction process to deal with the increasing amount of wastewater flows throughout the years. The reconsideration of energy systems started in the 1990s by centralising the biogas systems. In 2005, the biogas provided an energy self-sufficiency ratio of 70% (72.6 million of m^3 produced annually). But due to the 47% increase in energy needs between 2005 and 2008 for the nitrification/denitrification process, the self-sufficiency has been reduced to 60.5% in 2008 (Amosse et al., 2010). In order to regain a higher self-sufficiency ratio in the new energy system, the amount of biogas produced will increase to 474 GWh per year from 386 GWh in 2008. Purchased electricity will be reduced to 230 GWh from 238.2 GWh in 2008. 28%

[14] The total operating budget for 2010 is estimated at 530 million Euros (28 million Euros for energy expenses, 229 million Euros for investments, and 300 million Euros for other expenses).

of the biogas produced will fuel the cogeneration (against 9.9% in 2008) producing 50 GWh of electricity. 27% will heat the digesters (against 29.4% in 2008) and 7.6% will provide district heating (against 29.4%) and 35% will dry the sludge (against 36.8% in 2008).

The redevelopment represents a total investment of 112 million Euros with an estimated pay back period of 3 years (Amosse et al., 2010), a rate facilitated by the large economies of scale. Besides a better energy management, the new energy system aims at centralising the electricity and heat production, facilitating the maintenance and control (Amosse et al., 2010).

5.2.3.3 Seine Morée, a high-tech WWTP

Seine Morée provides another interesting example starting from the design stage in terms of technical and organizational possibilities, decisions to make, and trade-offs related to the potential of energy efficiency. To develop this project, designer and builder of WWTP are working together to create a less standardised plant from an engineering point of view. For Seine Morée, it is a complete new start for which many different possibilities are investigated (Michel, 2010). While energy consumption has been a growing challenge for the past few years, designing and building new WWTPs integrating the energy efficiency component is just at its beginning and require some level of experimentation and experience.

The plant is currently under construction and will be in operation by 2013. It will be operated by the SIAAP and will have a capacity load of 300 000 p.e. It will treat daily 75 000 m^3 of wastewater coming from the communes of Blanc-Mesnil, Aulnay-sous-Bois, Vaujours, Sevran, Tremblay-en-France, and Villepinte, serving 200 000 inhabitants. The cost to build this new plant is estimated at 112 million Euros.

Seine Morée will be a high-tech plant, but will consume a high amount of energy due to several factors. To comply to the EU water effluents requirements and due to the limitation of land space, the plant will be equipped with a membrane treatment system for Nitrogen removal which consumes a high amount of energy. The effluent treatment required is very stringent because of the high level of current pollution in the water receiving body. Due to ground limitation in terms of space, the plant has to be built in heights which results in the necessity of pumping the water which is another element requiring a high amount of energy. Finally, the plant will be located in an urban zone requiring the need to confine the smell which also lead to increase the amount of energy consumed, for ventilation, air quality, heating and cooling. Finally, Seine Morée will be the smallest plant of the SIAAP, which limits the possibility to make economies of scale, that can be compensated by the production of renewable energy. Overall, the energy consumption has been evaluated at 23 950 MWh/p.a. (16 450 MWh/p.a. of electricity for the water treatment, 1 400 MWh/p.a. of electricity for the sludge treatment, 5 500 MWh/p.a. of electricity for air ventilation and removal of odours, and 600 MWh/p.a. to heat the buldings) (Michel, 2010).

Following the commitments towards sustainability from the Agenda 21 Commission, a carbon impact assessment has been done for the operation of plant based on a co-digestion process as sludge valorisation (the other considered alternatives were incineration and drying). It excludes the emissions originated from the construction phase (those are counted in the depreciation ratio related to operating). This assessment, done in 2009 using the Bilan Carbone® method[15] developed by the French Agency for Environment and Energy ("Agence de l'Environnement et de la Maîtrise d'Energie"[16]) helped the engineers to identify the most impactful parts of the treatment in order to make decisions on the new plant design. The plant would emit a total of 6 700 tCO_2-eq. per year. Chemicals contributes to 32% to GHG emissions, followed by energy (mostly electricity, 28%), freight and employees travelling (20%), sludge treatment and waste including non digested sludge (8%).

A second study based on the Life Cycle Assessement (LCA) method which takes into account a wider scope and include other elements than GHG emissions such as eutrophication or waste production, has also been performed for the main phases of the treatment. It includes required energy production for the operation of the plant, chemicals production, treatment, valorisation of by-products, as well as transportation of chemicals and by-products. For this assessment, the global warming is calculated according an indicator contributing to the greenhouse effect, taken into account CO_2, CH_4 and N_2O emissions. From a life cycle perspective, the result is similar: Seine Morée is estimated to emit 6 000 tCO_2-eq./p.a.. But the energy represents a much higher part of GHG emissions with 43%, followed by chemical production (29%), sludge treatment (co-digestion, 13%), and transport (3%).

Based on the assessments above (among other things), and to compensate with the high energy consumption of the plant, the strategy is to develop the production of renewable energy notably through local synergies:

- A codigestion unit for the sludge and domestic waste which technically produce a high energy yield due to minerals present in the household waste and the nitrate contained in the sludge. This unit is being developed jointly with the SIAAP and the Intermunicipal Organization for the Treatment of Domestic Waste ("Syndicat Intercommunal de Traitement des Ordures Ménagères de l'Agglomération Parisienne", hereafter SYCTOM) for environmental but also political reasons. The neighbourhood did not wish to have a waste treatment entity in the vicinity in addition to a new WWTP. However, this project encounters some difficulties from a legal perspective. Due to its status as WWTP, the SIAAP is not allowed to process household waste. Therefore, the SYCTOM will be designing, constructing and exploiting the digestion operation, and the SIAAP will remain the co-owner. The recent reduction of waste quantity, that can probably be attributed to the recession, is impacting the initial plans of the project and there are discussions to include only organic waste (Michel, 2010). The codigestion has been retained over two other alternatives for treating the sludge: incineration or drying.

- A heat exchanger to produce district heating for 450 flats in a nearby residency. The SIAAP will own and exploit this part of the operation. This also represents a synergy between the SIAAP and the municipality of Aulnay-sous-Bois to produce district heating for 1350 residents representing 3 323 MWh/p.a. and covering 89% of energy needs for the building. This is estimated to be 2 to 5 times more sustainable than gas heating, and can reduce the carbon footprint by 50-80%

[15] The Bilan Carbone ® method is well recognized and includes CO_2, N_2O, CH_4, HFC, CFC and SF6 gases. It is calculated based on impacts of energy sources coming from the wastewater treatment (electricity, heat, etc.), as well as freight, employees traveling, materials and services inputs, waste and depreciation.

[16] The French Agency for Environment and Energy ("L'Agence de l'Environnement et de la Maîtrise d'Energie", ADEME) is a public organization in charge of the development of green technologies and negociations on climate change. It is a governmental agency placed under the French Ministry of the Environment.

(Michel, 2010). This project also has some legal constraints. The residency association has to buy the heat pump to transport the heat, and a convention with the association needs to be signed before the construction starts in order to avoid public claims on the heat production which would be legitimate since the plant belongs to the municipality and is financed through water fees.

- The retrieval of energy by installing a reversible heat pump to provide district heating to the administrative buildings of the plant. Similarly, the heat produced by the air compressors can be retrieved and may be used to provide district heating to the operational unit of the plant.

- The installation of solar panels which would provide 60% of energy needed to heat the water. Initially, there was a project to install photovoltaics panels but it has been abandonned. Since the law does not authorise the SIAAP to sell electricity back to the grid at preferential tariffs, it would limit the return on investment.

5.2.4 Tactical level

The redevelopment of the SIAAP was a process in which high political instances have been involved (Tabuchi, 2010). The wastewater treatments at Seine Aval (refer to Section 5.2.3.2), the main plant of the SIAAP were build in successive phases and were not very effective in terms of quality. They were generating bad odors and in the 1990s there has been an important public discontentment. A public debate followed and the redevelopment has been established upon consultation of public stakeholders. Other tactical measures at the SIAAP include environmental monitoring of for example odors generated by the wastewater treatment. Although not required by law, the SIAAP is monitoring the population of fishes in the Seine River in order to control the quality of the water. This contributes to improve quality and the management of the wastewater treatment. Carbon assessments as well as Life Cycle Assessments are also conducted in order to better understand environmental impacts and help with the decision process for future energy systems.

The SIAAP, one of the largest WWTPs in the world in terms of wastewater treatment capacity load, has been treating wastewater since the 1940s in the Paris agglomeration. The initial treatment units did not perform well which has led to severe pollution in the Seine and Marne rivers. As a result over the years a redevelopment has been undertaken including the construction of new plants. The case of the SIAAP illustrates well the complexity in finding a balance between the rising energy consumption and the implementation of more efficient energy systems. The case studies reflected the beginning of a transition in which legal and policy frameworks needs to be developed and adjusted to new opportunities in order to mitigate (and adapt to) climate change. The next chapter analyses two case studies conducted at Melbourne Water in Australia, a country strongly affected by the climate change.

6 Australia

This chapter is dedicated to two case studies conducted at two WWTPs located in Melbourne, in the State of Victoria, the most densely populated State in Australia. Some background on the legal and climate change/energy policies is provided beforehand in order to understand in which context the two plants to which 3 million people are connected operate.

6.1 Background

Australia counts about 22 million inhabitants. It is composed of six States: New South Wales where Sydney is located, Queensland, South Australia, Tasmania, Victoria and Western Australia. State legislation prevails except for areas such as military defence or currency. Australia also counts two major mainland territories: the Northern Territory and the Australia Capital Territory where Canberra the capital is located. In those territories, the Commonwealth Parliament can override State legislation. This research will focus on the State of Victoria and its capital Melbourne, located in the South-East of Australia.

The State of Victoria is located on the South East coast of Australia and has a temperate climate. It is the second bigger State in Australia in terms of population, but the smallest State in terms of size. With a population of 4.9 million people (2006), it is the most densely populated state in Australia. More than 70% of the population live in Melbourne which consequently has a large urban carbon footprint. Water usage, droughts and low rainfall are significant issues for Melbourne and the State of Victoria. Melbourne is faced with droughts since 1997. Various programmes intending to raise awareness on the importance of water consumption, re-use and conservation programmes have been implemented. Melbourne City vows to become carbon neutral by 2020. In 2010, the State of Victoria has adopted an action plan to fight climate change, namely “Taking action for Victoria’s future”. One of the target is to reduce GHG emissions by 20% by 2020 compared to 2000 levels (which represents a reduction of 40% per capita). The State of Victoria which relies heavily on coal for the source of their energy, has introduced mandatory energy, water and waste resource efficiency program for the biggest commercial energy and water users, and an integrated energy technology development policy (Victorian Government Department of Premier and Cabinet, 2010).

6.1.1 Water Governance in the Victoria State

There are a total of 16 state-owned water utilities (including distribution and wastewater treatment) in Victoria, established under the Water Act 1989 including Melbourne Water and its two main wastewater treatment plants, the Western Treatment Plant (WTP) and the Eastern Treatment Plant (ETP), which are the subjects of this chapter. All WWTPs report to the Victorian government. As State enterprises, water utilities pay a dividend to the State and are subject to a regulated operation expenditure limit. Profits are reinvested into projects and/or infrastructures development and must be approved by the State. The water fee paid by citizens consists of both a fixed and variable consumption based fee, a wastewater disposal charge (related to water consumption) and in the case of Melbourne a one-off yearly charge for parks and gardens.

The *Water Act 1989 (Vic)* represents the central legislation of the water sector. There is an existing water allocation framework, that leaves all rights to water to the Victorian government in terms of use, flow and control of all surface and groundwater on behalf of the population. It considers all water resources for both consumption and environmental purposes at all phases of their life cycle. It includes a provision (section 93, added in 2006) on sustainable management with regards to the performance and exercise of powers of utilities. According to this section, based on the precautionary principle, the water sector is due to consider water conservation, involve communities in conservation, use and management of water resources, fundamentally respect biodiversity, and adopt short, medium and long term environmental, social and equitable considerations. Each water utility report to the Victorian Ministry of Water via the Department of Sustainability and Environment. The ministry regulates the aspects of water management, develop policies, set standards and obligations, while the Department of Sustainability and Environment plays the role of liaison between the Minister and utilities. It also implements governmental policies. Water utilities have to report to the Department of Treasury and Finance whose role is to ensure a sound management of resources from a financial perspective. The Federal Government Department of Water, Heritage and the Arts has limited power and is mostly dealing with issues related to national water resources issues such as the Murray Darling Basin Authority. The Water Act was reviewed in 2007 introducing a significant change in water regulation by changing the governance status of the Murray Darling Basin Authority under one agency in order to facilitate the management of the basin. It contains many rivers, the biggest being the Murray and the Darling rivers. It is a very important water resource and the most significant agricultural area across several States (Queensland, New South Wales, Victoria, South Australia) and the Australian Capital Territory. Its management represents a sensitive political issue amongst communities.

In addition to the Water Act, various other acts apply to the water sector. One of them is the Environmental Protection Act 1970 whose role is to prevent pollution through objectives and programmes settings. The Water Industry Regulatory Order (WIRO) under the Essential Services Act 2001 regulates standards of prices and services set by the industry. The Water Industry Act 1994 issues licenses to the water utilities such as Melbourne Water to operate (Victorian Water Industry Association, 2010).

The EPA Victoria is in charge of setting the effluent discharge standards by providing individual licences to WWTPs. The standards set upon the quality and conditions of the water receiving body vary. With regards to the Western Treatment Plant, the maximum annual limit of Nitrogen load discharged to Port Phillip Bay is set at 3 100 tonnes corresponding to a median limit of 10mg/liter (Melbourne Water, 2009/2010). Both the Western Treatment Plant and the Eastern Treatment Plant are complying with the EPA (Melbourne Water, 2008/2009). Effluent requirements for discharge to water are detailed in the tables 6-5 and 6-6.

For the ETP, the ammonia levels should be below 5 mg/liter. Some other requirements are set for the Carbonaceous Biological Organic Demand (CBOD)[17] which are 20 mg/l for the ETP and 10mg/l for the WTP (median values).

[17] Carbonaceous Biological Organic Demand (CBOD) is a similar measure than BOD (refer to Appendix III for definition). It measures the depletion of 02 by biological organisms in water in which nitrogenous bacteria have been removed. The values for BOD are not specified.

Table 6-5 Wastewater discharged requirements for the Eastern Treatment Plant

Indicator	Median Annual	90th Percentile Annual[18]
Carbonaceous Biochemical Oxygen Demand (CBOD) (mg/l)	20 mg/l	Not Specified
Ammonia as Nitrogen (mg/l)[19]	30 mg/l	Not Specified
Total Phosphorus (mg/l)	Not Specified	15 mg/l

Source: EPA Victoria, 1975.

Table 6-6 Wastewater discharged requirements for the Western Treatment Plant

Indicator	Median Annual	90th Percentile Annual
Carbonaceous Biochemical Oxygen Demand (CBOD) (mg/l)	10 mg/l	20 mg/l
Ammonia as Nitrogen (mg/l)	10 mg/l	Not Specified
Total Phosphorus (mg/l)	Not Specified	15 mg/l

Source: EPA Victoria, 1992.

6.1.2 Effects of climate change and policies

Water availability is a significant issue in Australia due to geographical and natural conditions that are accentuated by the effects of climate change. Water scarcity highly influences water utilities and government when developing strategies and policies. According a report developed by the CSIRO, climate change in Melbourne is resulting in increased temperatures (from 0.3 ºC to 1 ºC by 2020, and 0.6 ºC to 2,5 ºC by 2050), and in more and more extreme and unexpected events such as rain storms (CSIRO, 2005). The Year 2009 was the warmest year on record since 1910 (Australian Bureau of Meteology, 2010). Melbourne and a large part of the State of Victoria are also subject to severe droughts which although being part of the natural climate of the country, are worsened with the effect of climate change, resulting in the need to find more sources of water for the future. "Over the past 10 years, run-off into the Murray Darling Basin, a critical resource to Victoria's and the nation's well-being, has reduced by half compared to the pre-1997 average. Never, at the end of a 10 year drought, has such a significant reduction in inflow occurred as in 2006" (Victorian Government, 2007).

As a result, WWTPs are affected in several ways: increased potential for corrosion and odours in the sewerage network, increasing of sewer overflows which disturbs the flow of water treated and can cause flooding, higher risk of pipe failure collapse due to dry soil conditions, increased salinity levels in recycled water due to rising seawater levels which get infiltrated in the sewerage network and at the plants (CSIRO, 2005). Those effects can lead to additional costs for maintenance, equipment and energy use. Increasing water availability while minimising energy consumption represents a significant challenge for WWTPs.

[18] 90th Percentile limits indicates that if more than 10% of the relevant tests exceed the value specified, limits will be exceeded.

[19] Effluent requirements in the UWWT Directive (refer to Section 4.2.2) are expressed in Total Nitrogen. In the case of the ETP, value requirements are indicated for Ammonia as Nitrogen. Requirements for Total Nitrogen are not specified. In addition for samples at a reference point located before discharge into the sea, the limit fixed for Ammonia as Nitrogen is 5mg/l.

At the State of Victoria level, water policies are part of the programme developed by the State, "Our Water Our Future" started in 2004 focusing on saving water but also on increasing water supplies. To do so, the latest 2007 plan allocated 4.9 billion A$[20] (3.4 billion Euros) to increase recycling water potential, build a desalinisation plant, expand the water grid to pipe water within the State, and upgrade the ETP with tertiary treatment by 2012 in order to increase the amount of recycled water. The plant is to increase the supply of water by 240 billion litres per year, half of the current consumption. Water supply-demand strategies are a key part of the policies developed. "Target 155", another action of the programme, aims at reducing the water usage of residents by setting levels of water use depending on water availibility. It has saved an estimated 16 billion of water in the year 2007/2008. A web page providing constant updates, displays how much water Melburnians are using every week (for example, 132 liters per person during the week of August 9). Watering lawns with drinking water is prohibited. Conserving and recycling water can contribute to a better energy management further down the water stream due to smaller quantity of wastewater to treat. However, less quantity to treat can also complexify the treatments as a certain flow needs to be maintained. Besides desalinisation for drinking water, an important way to increase water availability, requires very important amount of energy. Overall there is a delicate balance to find between energy and GHG emissions and management efficiency of the water sector.

In order to provide support to improve resource efficiency and reduce GHG emissions, the EPA Victoria has developed Environmental Resource Efficiency Plans (EREP) for entities that consume more than 27 777 MWh/p.a. (100 TJ) or 120 million litres of water annually addressing water usage, waste and energy issues. The environmental agency supports and provide tools to businesses to develop plans to improve resources efficiency. So far this program has allowed to save 1 250 GWh (4 500 TJ) of electricity corresponding to about 1 $MtCO_2$-eq. and 5 billion of water savings across all businesses. Besides the Australian Government has put in place an Energy Efficiency Opportunities Programme (EEOP) to which entities that consume more than 139 GWh/p.a. (0.5 PJ) have to participate.

At a national level, the national water commission of the Australian government started in 2004 the National Water Initiative (NWI), a blueprint for water reform. The NWI aims "to achieve a nationally compatible market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes" (NWI, 2010). Some of its objectives relates to secure water access, improve environmental management practices, maintain sustainable levels of water extraction, to develop water accounting, ensure efficiency of water use, and create a water market in order to allow water trade between States to ensure an efficient water distribution. Implementation is done at States level that develop implementation plans to be accredited by the National Water Commission.

Australia, following the mandate set by the Kyoto Protocol, has set targets to reduce its GHG emissions by 60% by 2050 compared with 2000 levels within the Carbon Pollution Reduction Scheme (CPRS), a cap and trade system. The CPRS implementation has been delayed by the government who is waiting for clarifications on actions to be taken by big economic powers such as the United States or China (Australian Government, 2010). The National Department of Climate Change and Energy Efficiency introduced in 2008 a National Greenhouse and Energy Reporting System (NGERS), which specifies a

[20] 1 A$ equals 0.69312 Euros. Interbank rate as of July 1, 2010. Source: www.oanda.com. Rate applied to all following conversions.

methodology in reporting emissions. This is a national approach that is being implemented across all Australian States. Melbourne Water as a facility that consumes more than 27 777 MWH/p.a. (100 TJ) and therefore is due to report its GHG emissions. There is yet no limit determined in GHG emissions but this measure precedes a future emissions trading scheme in order to help reaching emissions targets reduction.

Energy used by WWTPs for pumping and treatment varies between cities (Table 6-7). Perth is the highest energy consumer, consuming four times more energy than Sydney, followed by Melbourne. Adelaide, Brisbane and Sydney are fairly comparable both in terms of energy consumed per wastewater treated and per capita. These disparities illustrate once again the differences between WWTPs. Sydney disposed most of its wastewater directly onto the ocean after a primary treatment, while Melbourne after applying secondary and tertiary treatments has to transport the water over a hilly terrain before discharging it onto the ocean.

Table 6-7 Energy consumption of wastewater treatment plants in Australian cities (2006/2007)

	Sydney	Melbourne	Perth	Brisbane	Gold Coast	Adelaide
Population (million)	4 300 000	3 621 000	1 538 000	1 006 000	492 000	1 095 000
Wastewater Collected (million m^3)	508	296	119	86	47	89
Energy used for wastewater pumping (MWh)	33 310	127 698	25 778	11 035	13 897	8 907
Energy used for wastewater treatment	193 946	205 346	193 945	38 341	33 164	51 443
Total Energy (MWh)	227 256	333 044	219 723	49 376	47 061	60 350
Energy used per wastewater collected (MWh/million m^3)	447	1 125	1 846	574	1 001	678
Energy used per capita (KWh/capita)	50	90	140	50	90	60

Source: Adapted from Water Services Association Australia, 2006/2007.

6.2 Melbourne Water

Melbourne Water sewerage system is 391 km long and manages two wastewater treatment plants in the city where most of the sewage in Melbourne is treated: the ETP in Bangholme and the WTP in Werribee. Melbourne Water treated 262 million m^3 in 2008/2009, 1.8% less than the year before due to water restrictions and conservation measures (Melbourne Water, 2008/2009). Melbourne Water is ISO:14 001 certified. This section presents and analyses findings resulting from the case studies through the operational, tactical and strategic levels.

6.2.1 Operational level

6.2.1.1 The West Treatment Plant

The WTP treats about 52% of Melbourne wastewater which represents about 415 000 m^3, coming from sewerage in Central, Northern and Western parts of Melbourne. Treated wastewater is discharged into Port Philip Bay. The WTP is in a wetland area, and several of the wetlands are protected by the Ramsar convention. Therefore preservation of biodiversity is another important aspect for Melbourne Water. WTP was Melbourne's first sewage treatment plant. It started its operations in 1897 when the Melbourne and Metropolitan Board started to buy some land in Werribee for its low rainfall and good soil conditions.

The WTP is a lagoon based treatment plant which uses a natural cleaning process through micro and macro-organisms and plants. A conjunction of large man-made basins with shallow water depths, no wind, a lot of living organisms, high temperatures creates natural conditions for micro-organisms to ingest particulate matter and thus cleaning the water instead of applying biological treatments. Modern lagoons were installed in 1986 replacing the old ones which had been there since the 1940s. Besides being natural, advantages of this system are low operating costs and energy consumption because there is no need to create aeration and thus inject oxygen into the effluents. Pumping is also reduced. However, this system requires lot of space for the large basins and it emits high quantity of CH_4 that needs to be captured effectively.

A major 160 million A$ (110.9 million Euros) upgrade, based on a four-year CSIRO study of the Port Philip Bay was undertaken in 2004, in order to improve nitrogen removal to preserve the marine environment. In 2008/2009, 1 619 tonnes of Nitrogen have been discharged into Port Philip Bay (below the 3 100 limit set by the EPA Victoria). The upgrade also improved significantly the capture of biogas to produce more electricity. In addition, it provided an increasing amount of recycled water due to a water recycling disinfection plant. This water is used for irrigation use or parks for example. In 2008/2009, the WTP recycled 41 000 m^3 of treated water.

The first methane covers to capture the methane gas were put in place in 1992 and more were installed in 1999. Today, the plant is producing about 87 000 m^3 of biogas a day resulting in the production of 71 500 MWh of renewable electricity per year. The annual production of electricity from biogas has increased by 44% between 2005/2006 and 2009/2010 from 38 893 MWh to 57 752 MWh. The biogas power station has a 10MW capacity and produce enough electricity to meet 95% of electrical need of the plant (Melbourne Water, 2010). In a new project started in 2010, additional biogas is going to be captured by redirecting the flow from the 115 East lagoon (which is being decommissioned) to the more efficient 25 and 55 East lagoons. To develop further the production renewable energy, some studies have also been undertaken on the possibility to use the wind as power. In addition, to increase the efficiency of biogas production, the plant is also installing a deslugding system for one of the lagoon. By 2012, the WTP should become self-sufficient saving about 750 000 A$ (519 840 Euros) in energy costs and reducing its GHG emissions. This project is due to be completed in 2012. Besides enhancing the production of renewable energy, it also contributes to reduce impacts on the marine environment and minimise odour and land contamination. Further investments are also being made such as the installation of fibre-optical cables to be able to transport the electricity produced to the grid.

6.2.1.2 The Eastern Treatment Plant

The ETP plant was built in 1975 and provides 41% of Melbourne Sewage serving 1.5 million people in the South-Eastern and Eastern parts of Melbourne agglomeration. It treats on average 295 000 m^3 per day which once treated is discharged at Boags Rocks into the marine environment (Melbourne Water, 2008/2009).

A major 380 million A$ (263.4 million Euros) upgrade, announced by the Government of Victoria and introducing a tertiary treatment is currently underway. The two main objectives of this upgrade is to meet the EPA guidelines to significantly improve the water effluents quality before discharge and create a high quality "fit-for-purpose" recycled water use for non potable purposes such as watering sports ground or agriculture irrigation (Black & Veatch Australia Pty Ltd, 2009). Energy wise, the upgrade will also eliminate the use of diesel in the plant and will provide most of the plant's heating needs (Melbourne Water, 2010). The advanced tertiary treatment will include a tertiary supply pump section to lift the water from the secondary treatment to the tertiary phase, an ozone treatment, biological media filters, chlorine and UV Disinfection, increasing energy needs[21]. Despite expected growth of the connected population, due to strong demand side policies implemented, the flow of wastewater to be treated is expected to diminish (Melbourne Water, 2008/2009).

To face water shortages and increasing needs of water, the upgrade should provide 7 million m^3 of additional recycled water, on top of the current 21 million m^3. Investigations are underway to reach a flow of 40 million m^3 of recycled water by 2030. In order to use the water more widely, quality of recycled wastewater must be improved from Class C to Class A.[22]

6.2.1.3 Mini hydro-electricity plants

It is interesting to note that Melbourne Water has constructed 9 mini hydro-electricity plants near reservoirs from which water is supplied (including one that is due to be completed in 2010). Electricity produced is sold into the grid, in order to make use of the energy present in the water flow. They have a potential of creating up to 51 000 MWh/p.a. of electricity, offsetting an estimated 62 000 tCO_2 eq. per year (Melbourne Water, 2010). Although this is an activity related to the supply side of Melbourne Water, the development of mini hydro-plants represents an interesting synergy and illustration of the importance of the water-energy nexus.

[21] It was not possible to obtain a quantified amount at the time of the research.

[22] Different treatment requirements are issued by the EPA ranging from Class A to Class D (EPA Victoria, 2003) depending on the water usage. There has been a sustained drought in the State of Victoria for the past 10 years and the inflows to Melbourne's water storages from 1997 to 2006 were 35% lower than the pre-1997 average (Victorian Government, 2007). Due to this reduction in water resources, one of the objectives of the Victoria State Government is to continually promote and increase the use of recycled water when drinking water is not necessary. Together with distribution retail, in 2008/2009 Melbourne Water has managed to recycle 23% of the total Melbourne metropolitan wastewater, slightly above the government target of 20% (Melbourne Water, 2008/2009). The WTP treats Class A water and the ETP treats Class C water. The upgrade of the ETP with a tertiary treatment phase will allow the plant to treat Class A water. There are several challenges associated with recycling water. Balancing the demand and supply is a delicate issue. 31% of recycling water is used for agricultural purposes and its supply cannot be interrupted. Due to water restrictions and conservation policies, the amount of wastewater incoming to the plants is decreasing causing the increase of salinity levels in the water, which then becomes more energy consuming to process. Implications of energy consumption for water recycling process at Melbourne Water could not be quantitatively determined for the purpose of this study but the necessity to use recycled water will inevitably increase due to the effects of climate change.

6.2.2 Tactical level

A series of measures have been undertaken at the tactical level over the past several years. Environmental monitoring in the ocean at Boags Rock where the ETP discharged the water has been in place since 1999 upon EPA requirements. According to the latest sustainability report, environmental monitoring and trials at the ETP before starting the upgrading works contribute to identify more effective solutions in terms of treatment processes but also in general to determine future management options. It includes effluent monitoring, near shore nutrients analysis, beach water sampling, routine direct toxicity assessement and also routine beach inspections for aesthetics parameters (Melbourne Water, 2008/2009). The WTP, in accordance with EPA requirements, is also proceeding to an Effluent Monitoring Programme to evaluate the impact of its discharge into the ocean. Other studies are being performed on the wetlands to better understand nutrients levels and migratory birds. Eventually these studies allow to better manage wastewater treatment while preserving biodiversity and the environment (Melbourne Water, 2008/2009).

Melbourne Water has developed a risk management system to check the quality of the wastewater. The system is ISO:22000 certified and is based on best practices. The system assesses chemical risks associated with water recycling and discharges, providing reassurance to governments and customers in terms of sewage quality management. It will be extended in the future to the protection of treatment processes and workers safety.

In 2008, as part of the Energy Efficiency Opportunities Program (EEOP), the WTP which consumed 70 548 MWh (253 972 GJ)[23], was assessed and several opportunities were established (Australian Government, 2008):

- Change the effluent reuse water pump Station no.6 control algorithm from pressure control to pressure and flow control. Estimated savings: 644 MWh p.a. (20/30% of energy savings).

- Paint one Motor Control Center cubicle white to absorb less heat and reduce energy consumption. Estimated savings: 2,6 MWh p.a.

- Select an energy efficient aeration method to meet the increased aeration demand of the 55 East lagoon system.

Besides, Melbourne Water is conducting energy audits with a plan to assess 90% of Melbourne Water by the end of 2010, as well as workshops for employees about strategies on how to reduce GHG emissions.

6.2.3 Strategic level

Melbourne Water started measuring its energy consumption and GHG emissions in 2000. Since then Melbourne Water has actively researched and worked on possibilities and measures to mitigate and adapt to climate change together with a myriad of stakeholders including the federal government, water authorities and agencies, and the Australian Bureau of Meteology (Melbourne Water, 2010). In 2009, a Greenhouse and Energy Strategy was finalised by an internal team. Currently, Mebourne Water is working on the development of a Metropolitan Sewage Strategy.

[23] With +/- 5% accuracy

6.2.3.1 Melbourne Water Greenhouse and Energy Strategy

Electricity represents the fourth largest expense at Melbourne Water (including water distribution and treatment) and is the main source of GHG emissions. In 2008/2009 (fiscal year)[24], the company spent 17 million A$ (11.8 million Euros) on energy representing 5% of the operating expenditure (Melbourne Water, 2008/2009). The energy consumption at the treatment plants is expected to increase due to the installation of a tertiary treatment at the ETP and increasing requirements to pump water (Melbourne Water, 2008/2009). Depending on the calculation method used, GHG emissions of Melbourne Water originated both from wastewater treatment and water distribution are estimated at 237 800 tCO_2-eq. or 478 800 tCO_2-eq. in 2008/2009. Melbourne Water is developing a Climate Change Management Framework that includes a Greenhouse and Energy Strategy to mitigate its contribution to climate change by reducing GHG emissions. With regards to adaptation to climate change, Melbourne Water is planning on developing a separate climate adaptation strategy (Melbourne Water, 2010a). The targets set in the strategy since 2006/2007 are to achieve zero GHG emissions and to use 100% of renewable energy by 2018. In 2008/2009, the use and generation of renewable energy amounted 156 945 MWh (565 000 GJ), representing 51% of the total energy use against 41% the previous year. However Melbourne Water had to buy some renewable energy certificates to achieve the target of 54% (Melbourne Water, 2008/2009). Since 2000/2001, Melbourne Water has reduced his GHG emissions by 53.8%. This strategy is a top to bottom approach which consists in avoiding GHG emissions first followed by improving energy efficiency, recovering resources and use renewable energies (Figure 6-7). To do so, opportunities are being explored such as converting algae into biodiesel at the WTP, or developing small-scale wind generation at Melbourne Water sites (Melbourne Water, 2008/2009).

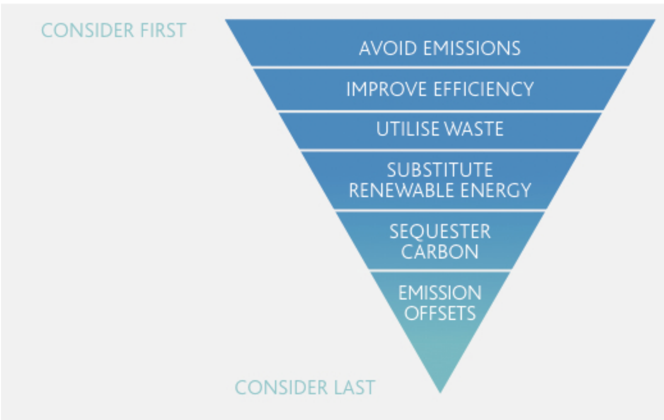

Figure 6-7: Melbourne Water Greenhouse and Energy Strategy. Source: Melbourne Water, 2008/2009.

Melbourne Water expects to reduce its GHG emissions to 320 000 tCO_2-eq. by 2030 without further action. However, there are a number of challenges associated to this strategy including the current lack of regulatory framework in terms of funding support and legislation related to GHG emissions and renewable energy which may impact current forecasts. Calculation methods to measure of GHG emissions more effectively are still lacking. Trade-offs may need to be done in terms of business opportunities due to climate change and global financial crisis established as priorities (Melbourne Water, 2010a).

[24] In the literature consulted with regards to Australia, a year corresponds to a fiscal year that begins on July 1 and finished on June 30. Therefore 2006/2007 covers the period from July 1, 2006 to June 30, 2007. The same applies to 2008/2009.

6.2.3.2 The Melbourne Metropolitan Sewerage Strategy

In the perspective of climate change, population growth, increasing prices of energy and food, and of technology development, Melbourne Water is working on a Sewerage Strategy for the next 50 years for its two treatment plants and its water distribution entities. This strategy is developed together with the Australian Commonwealth Scientific and Research Organization (CSIRO), Halcrow Pacific Pty Ltd and Urban Water Solutions Pty Ltd. It is based on the idea that opportunties for future WWTPs lie in resource recovery, as evocated in the model developed by Stowa (refer to Section 2.2). It is currently in development and it was not possible to access its content at this stage. This section presents one aspect of it (resource recovery) which provides insights on what kind of assessment tools are developed underlying fundamental parameters and potential outcomes in the optimisation of resource recovery.

According to Phillis (2009), the future is hardly predictable, especially in the light of technological developments and population and urban changes. Importantly, technology evolves and a technology that is costly today can become more affordable in the future. Therefore an approach based on scenarios rather than historical trends is more appropriate in order to establish path towards sustainability. Two main scenarios were established for the next 50 years in order to test different strategic approaches. Scenario 1 is based on a Melbourne population of 8 million, a significant urban densification, severe climate change, significant recycling and a 50% fall in wastewater. Scenario 4 is based on a Melbourne population of 6 million, continuing urban expansion, mild climate change and no recycling. Input elements considered to build the scenarios are: climate change, pollutants concentration and treatment systems, changes in urbanism and population and potential changes coming from the demand side for water, recycling and sewerage systems (Falconer et al., 2010). To enable a holistic evaluation of the future impacts of the sewage system based on the scenarios, modelling and assessment tools were developed (Falconer et al., 2010). Quantitative results allow comparisons output of flows, nutrients, energy use, potential energy production, corrosion rate of the sewage pipelines, GHG emissions and production and costs associated with the system (Falconer et al., 2010). This method allows quantitative results to be adjusted according to changes occuring in the input elements, towards a new paradigm by assessing new ideas such as transporting kitchen waste to boost energy and nutrient yield in the wastewater (Phillis, 2009).

While meeting effluent standards, sewage can be considered as a resource through recovery processes rather than being a disposal problem. Current wastewater treatment processes converts organic carbon present in the wastewater to CO_2 and solid biomass with only a minor fraction converted into methane. Similarly nitrogen and phosphorus removal consumes resources (energy and chemicals) but none of the resources are effectively recovered (Priestley et al. 2010). One of the aspect of the Melbourne Sewage Strategy consists in optimising the recovery of energy and nutrients from the incoming wastewater. According to calculations made by Priestley et al., currently water accounts for 86.7% of the value present in 1 000 m^3 of domestic sewage, energy recovered from organic carbon 5.7%, while ammonia and phosphorus represent 4.3% and 2.4% respectively (Priestley et al. 2010). The figure 6-8 shows the potential values in the four components. The value of energy, ammonia and phosphorus could excess that of the water in the future especially in the scenario 1 characterised by an important urban densification, severe climate change but significant recycling (scenario 1). The monetary values are based on assumptions that the increase of the prices of water, nitrogen and phosphorus will increase due to a reduction in their availability. These values are indicative and could not be accessed in detail, but they nonetheless illustrate an existing potential in resources from the sewage treatment if recycling occurs. There is some interesting potential in recovering energy, phosphorus and nitrogen depending on the scenarios.

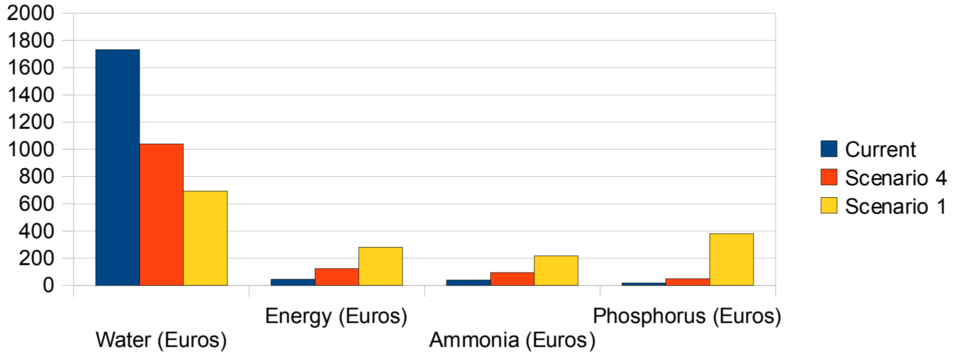

Figure 6-8: Gross Value of Sewage (Euros/1000 m^3). Source: Adapted from CSIRO, Sewage Strategy in Phillis, 2009.

Two of the models developed in the strategy ("Hydraulic Model" and "Energy Module") aim at determining the amount and potential of energy and nutrients present in the wastewater to be recovered depending on the configuration of the plant. The models establish different distribution matrixes of mass flows of incoming Carbon (C), Nitrogen (N), Phosphorus (P) into and through the plants and allow the calculations of potential energy and nutrient recovery depending on the type of processes in order to optimise resource recovery. As an example, the table 6-8 shows a possible distribution based on a process designed to capture organic carbon as methane and to convert nitrogen and phosphorus to fertiliser, as opposed to another possibility of capturing phosphorus in the plant biosolids (sludge) more appropriate in an extended aeration activated sludge plant (Priestley et al., 2010).

Table 6-8: Possible Final Distribution Matrix on a Mass Basis for Carbon, Nitrogen, and Phosphorus

	Liquid effluent	**Biosolids**	**Fertiliser**	**CH_4**	**CO_2**	**N_2O**	**N_2**
Carbon	10%	15%		60%	15%		
Nitrogen	10%	20%	60%				10%
Phosphorus	15%	10%	75%				

Source: Priestley et al., 2010.

Importantly, the method developed also allows the evaluation of GHG emissions originated from energy use and fugitive emissions related to the plant processes and the strategy chosen for energy and nutrient recovery (for more details on the process related to energy sources and GHG calculations, refer to Appendix III). The other two models developed in the strategy consist in evaluating operational and capital costs based on proportion across the system and characteristics of the sewage flows and in evaluating the economic, social and environmental criteria of sustainability. The results allowed to identify increases in odour and corrosion, wet weather spills, capacity constraints, WWTP limitations and aging infrastructure (Priestley et al., 2010).

6.2.3.3 Others

Melbourne Water is preparing for the federal Carbon Pollution Reduction Scheme (CPRS), a cap and trade system (refer to Section 6.1.2). As of today under the current dispositions of the CPRS, the water authority would have to buy a lot of emissions permits for fugitive GHGs (N_2O) emitted at the ETP and WTP, illustrating that carbon trading is becoming a challenge. Finally, various technical projects have been envisaged in an action plan and will be evaluated through financial benchmarking such as the cost of renewable energy. The most cost effective projects will then be assessed through the Triple Bottom Line (TBL) approach that evaluates economic, environmental and social aspects, in line with the principles of sustainability (Melbourne Water, 2010a) in order to balance benefits to community, efficiency requirements for public spending, environmental and social effects (Melbourne Water, 2008/2009).

Over the past five years, Melbourne Water has engaged in a significant amount of projects to improve its wastewater treatment quality at the ETP and the WTP and to become more energy efficient. While energy needs are increasing, Melbourne Water aims at becoming self sufficient in terms of energy and has set the ambitious goal to become carbon neutral and energy self sufficient by 2018. Facing uncertainties such as the estimation of GHG emissions, these objectives are continuously assessed throughout strategies developed and a close cooperation with governmental authorities such as the EPA Victoria.

This chapter closes the case studies conducted in three different countries (Sweden, France and Australia). In the next chapter, findings from the case studies are discussed according to the analytical framework presented in the Chapter 2.

7 Discussion

Based on measures taken by WWTPs and the governance levels of the analytical framework of this research, this chapter identifies the influential factors to mitigate climate change. For ease of reference, measures identified during the conduct of case studies are presented in the table 7-9 (on the next page). The type of interaction between the different levels underlines challenges for the wastewater sector to take part in climate change.

7.1 Influencing factors

This section discusses what elements can drive, impede or support the wastewater sector to mitigate climate change and to improve the performance of energy systems at the different levels of governance considered. Levels are highlighted in bold in each paragraph.

7.1.1 Rising energy prices

At **the operational and strategic levels**, the rise of energy prices constitutes an important driver to reduce energy consumption, a fact that has been mentioned as one of the main reason by most of the interviewees in WWTPs to improve energy efficiency. WWTPs have to reduce their own environmental impacts as well as preserving the natural environment by cleaning the water, but as we have seen more and more energy is required for processing the treatments. The WWTP Seine Aval expects its annual energy consumption to increase by 26% from 658 422 MWh in 2009 to 830 000 MWh upon the redevelopment in 2020. Energy consumption is also expected to increase at the Melbourne Water Eastern Treatment Plant due to the introduction of the tertiary treatment and the increasing need of pumping water. Facing rising energy prices, increasing *energy autonomy* is an effective way for to reduce the dependence of WWTPs on the fluctuating energy prices, and the consumption of fossil-fuel based energies in order to reduce GHG emissions. Seine Aval hopes to reach 70% of autonomy upon the redevelopment by 2020, and the Western Treatment Plant has significantly increased the electricity production produced from biogas, as well as its production power capacity to meet 95% of its electrical needs. However, this might be more easily achievable by medium to big size plants due to the scale of their operations.

Sourcing renewable energy instead of fossil-fuel based energy is also an aspect considered by the plants. One of the ambition of Melbourne Water is to use 100% of renewable energy by 2018. So far, the use and generation of renewable energy amounts to 156 945 MWh (565 000 GJ), representing 51% of the total energy use against 41% the previous year (2008/2009). However Melbourne Water had to buy some renewable energy certificates to achieve its 2008/2009 target of 54% (Melbourne Water, 2008/2009). At the SIAAP, in the 2009 invitation to tender for electricity supply, among the conditions established for the supply of electricity, 5% were related to include renewable energy in the offer (90% were related to the price itself). However in 2010, there was no such condition for including renewable energies due to financial reasons. There is a 5% surcharge for electricity produced from renewable sources, compared to fossil-fuel based sources (Tabuchi, 2010). At VA SYD to which Källby belongs, electricity for some of its plants is purchased from companies part of Bra Miljöval, an environmental label which guarantees the source of renewable energy. However this is not yet the case for Källby, but this is being envisaged in the next procurement round (Gruvberger, 2010).

Table 7-9 Identified measures taken by the WWTPs to mitigate climate change

	Operational level	Tactical level	Strategic level
Källby (Sweden)			
	Pre-denitrification process of the activated sludge treatment. Optimisation of treatment by installing on-line metering. Biofuel upgrade in synergy with Lunds Energi Koncernen.	Monthly process engineer meetings within VA SYD. Participation in the Svenskt Vatten Energy Project. Internal benchmarking to be implemented in the near future.	Merging of Lund and Malmö activities. Wastewater treatment of small nearby communes to be processed at Källby WWTP.
Nykvarnsverket (Sweden)			
	Oxygen aeration improvement in the biological treatment. Sharon® process introduced along with a new air blower system.	Participation in the Svenskt Vatten Energy Project. Internal benchmarking to be implemented in the near future.	n/a
SIAAP (France)			
	Optimisation of the sludge treatment at **Seine Grésillons**: sludge digestion, electricity production. Development for synergies at **Seine Morée**: water energy content valorisation and co-digestion of sludge. Rethink of the role of the energetic centre at **Seine Aval**.	Environmental monitoring of the fishing population in the Seine river. Carbon footprint assessments. Public meetings with neighbourhood. Public consultation for the development of the SIAAP.	Agenda 21 Commission created in 2007. Sustainable Development Strategy approved in 2010.
Melbourne Water (Australia)			
	Tertiary treatment upgrade at the **Eastern Treatment Plant** to increase the quantity of recycled water. Major upgrade in 2004 at the **Western Treatment Plant** to improve nitrogen removal, increase biogas production and recycled water. Increase production of biogas to produce electricity (2010-2012) to become energy self-sufficient. Production of renewable energy (hydro-plants, wind).	Employees workshops and communication with experts to assess options to reduce GHG emissions. Environmental Resource Efficiency Plans and Energy Efficiency Opportunities Program. Energy audits. Integrated risk management system for sewage quality. Environmental monitoring.	Melbourne Water Greenhouse and Energy Strategy currently being finalised. Development of Melbourne Metropolitan Sewerage System. Preparation for the State of Victoria Government Carbon Pollution Reduction Scheme. Use of Triple Bottom Line (TBL) guidelines.

7.1.2 WWTPs infrastructure

Existing infrastructures of the plants can constitute barriers in improving energy effiency depending on how plants layouts have been designed in the past. In addition, when retroffiting existing plants having processes working with new processes can cause issues **at the operational level.**

However, the design of the layout can represent an important barrier in implementing or improving such processes. In the case of Sweden and France, new units have been added successively and stacked onto each other in the past as of when capacity load needed to increase (Nykvarnsversket and Seine Aval). This can result in the wastewater flows not going straight within the plants and fragment the treatment reducing efficiency (Paulsson, 2010). When adding capacity load or improving treatment units by for example, the introduction of the tertiary treatment at the Eastern Treatment Plant, it is important not to create sub-optimal solutions but integrate processes within the plant (Arnell, 2010). For example, at Nykvarnsverket, when a new air blower was installed together with the Sharon® system, the air blower was installed in a location in the plant to benefit other units of the treatment. But this type of measures is not always possible to implement. If the layout has been poorly designed, it can be very difficult to improve energy efficiency (Olsson, 2010). However the design can be favorable, as in the case of Källby. The plant is located in the suburbs of Lund, has sufficient space to have aerated basins outside that do not need to be covered since there is no immediate neighborhood, a fact that contribute to the good energy efficiency of the plant. Lagoon systems as in the Western Treatment Plant at Melbourne Water also do consume less energy than biological systems, but also require lot of land space. Therefore it is important to consider the layout of the plants before introducing new processes when considering energy performance.

Moreover, environmental and sustainable concerns emerged relatively recently. Having old infrastructures and new processes co-existing can create issues in operation findings thereby complicating future strategies and the sustainable development of the plant at **the strategic level.** For example, Seine Aval is a 50 years old plant used to be based on economical processes (refer to Section 5.2.3.2), and due to the evolution in the treatments nowadays the plant has evolved and functions differently. This creates issues within the treatment, such as a too short aeration time in the old process creating bacteries that are difficult to remove by the decanters in the new unit (Tabuchi, 2010).

7.1.3 GHG emissions estimation methodologies

An important barrier resides in uncertainties and differences about **GHG emissions estimation methods which impact operational, tactical and strategic levels**. For example, indirect emissions other than energy are not estimated within the method used so far by Melbourne Water until 2008/2009. The Greenhouse and Climate Strategy includes direct emissions coming from energy use, fugitive emissions and indirect emissions coming from Melbourne Water use of electricity (Melbourne Water, 2010a). The methodologies used by the National Greenhouse and Energy Reporting System (NGERS) introduced in Australia in 2009 differs from the methodology used by Melbourne Water. As we have seen, depending on the calculation methods used, GHG emissions are estimated either at 237 800 tCO_2-eq. or at 478 800 tCO_2-eq. (Melbourne Water, 2008/2009). Melbourne Water is integrating the NGERS methodology and note that this may affect interim results towards the objectives defined for 2018 (Melbourne Water, 2008/2009). Furthermore, Melbourne Water is in discussion with the department of Climate Change through the Water Services Association about methodologies to reflect on emissions produced from the wastewater treatment (Melbourne Water 2008/2009).

The methods developed nationally and internationally to estimate GHG emissions and the definition of sources of GHG emissions are relatively recent and their scientific validity is uncertain. Depending on the methods used, results can vary greatly and make international comparisons difficult. The Greenhouse Gas (GhG) Protocol developed by the World Business Council for Sustainable Development (WBCSD) provides guidelines used by national standards such as the Bilan Carbone® in France developed by the French Agency for Environment and Energy (ADEME) or the method developed by the United Kingdom Water Industry Research (UK WIR) in 1993. The method developed by UK WIR for the water sector includes biogenic[25] emissions which are not included in the guidelines developed by the French Intergovernmental Group of Experts on Climate Evolution (“Groupe Intergouvernmental d’experts sur l’Evolution du Climat”, GIEC), and does not include indirect emissions coming from other sources than energy as opposed to the Bilan Carbone® method developed by the French Energy Agency (ASTEE, 2009).

Equally important are the strong uncertainties in quantifying methane and nitrous oxide emissions for which poorly developed and unreliable methodologies exist (Foley et al., 2007). In this area, Foley et al. have identified three major knowledge gaps: the potential for methane formation in anaerobic wastewater treatment and the associated concentration of dissolved methane, the nitrous oxide emissions from some advanced biological nitrogen removal processes, and nitrous oxide from effluent discharges to some specific environments (ocean, estuaries, riverine). According to these authors, by including those emissions, in Australia, the water, sewerage and drainage economic sector might contribute as much as main sectors such as transportation to the National Greenhouse Gas Inventory (NGGI). Therefore, despite not being an energy intensive sector, in terms of GHG emssions, the wastewater sector might greatly affect the environment. The authors also conclude in their study that the fugitive emissions and indirect emissions coming from energy consumption are comparable. Therefore fugitive emissions should be considered as important as the other types of emissions (Foley et al., 2007). GHG emissions can also be estimated through Life Cycle Assessment (LCA) which would then encompass the life time of the plant. A comprehensive LCA study on the trade-offs between nutrient removal and the total environmental burden performed by de Haas et al. on GHG emissions coming from WWTPs in South-East Queensland in Australia come to similar conclusions highligting the existence of fugitive emissions of methane and nitrous oxide coming from various sources (incoming wastewater, treatment and disposal of sludge) (de Haas et al., 2008).

Therefore, it is essential to be able to estimate with more certainty the potential of GHG emissions from the wastewater sector in order to make interactions between the three levels effective, as well as defining appropriate policies and legislation. The research gap in GHG emissions calculation is significant leading to questioning the relevance of energy and climate policies such as emissions trading systems.

[25] Biogenic emissions are emissions produced by living organisms (Oxford English Dictionary).

7.1.4 Policies

European, national and federal policies play an important role in the way WWTPs develop the potentials that lie in resources recovery, both at the **strategic and operational levels**. In Sweden for example, the promotion of the use of biogas for the transportation sector is one of the orientations of the national energy action plan defined in 2008 (SOU 2008:110) (Swedish Energy Agency, 2009a) which represents a strong driver for WWTPs to produce biogas thereby offsetting their GHG emissions. A multisectoral biogas production plan developed by the Swedish Energy Agency, the Swedish EPA and the Agricultural Administration has recently been submitted to the Swedish government who commissioned it. This plan contends that different production modes of biogas provide different economic benefits and that socio-economic values of biogas production are greatest when biogas is produced by anaerobic digestion, thus limiting fugitive emissions (methane). The total volume of biogas from sewage sludge, but also from manure and food waste generated could more than double from an estimated 1.5 TWh to 3 or 4 TWh (Swedish Energy Agency, 2010). Besides, in order to fulfill their ambition to become carbon neutral in the near future, many municipalities such as Lund develop prospects and support the use of biofuels. Bus fleets are being equipped and more and more buses are running on biofuels. In 2009, Källby entered into an agreement with Lunds Energi Koncernen to produce biofuel from biogas. Nykvarnsverket produced 165 100 MWh/p.a. in 2008 through his sister company at Tekniska Verken which represents a significant amount proportionnally compared to other plants of this study (refer to table in Appendix IV). Such policies and initiatives taken by governments represent important drivers for WWTPs.

At a strategic level, sources of electricity generation influence the regulation surrounding GHG emissions coming from energy use. In France, nuclear energy accounts for 78.3% of electricity generation (European Commission Energy, 2004), therefore reducing GHG emissions coming from energy is not as relevant as it is in the State of Victoria where coal represents 92.9% of electricity generation (The ºClimate Group, 2009). Hence the differences in emissions per capita vary greatly: in 2008, France is emitting 5.74 tCO_2-eq. per capita, Sweden 4.96 tCO_2-eq, and Australia 18.48 tCO_2-eq (IEA, 2010). From a driving perspective, policies and measures taken towards mitigation and adaptation of climate change and the reduction of GHG emissions resulting from energy consumption are not required in the same amplitude.

7.1.5 Legislation

Legislation by regulating water effluent quality has been forcing plants to improve their processes, and in most cases, it represented opportunities to rethink energy performance at the **strategic and operational levels.** Most of the plants studied had to improve their wastewater treatment in terms of nitrogen removal in order to comply with the legislation: the SIAAP ("Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne") in France, Melbourne Water in Australia and Nykvarnsverket in Sweden. Melbourne Water upgraded the Western Treatment Plant in 2004 to improve nitrogen removal and a tertiary treatment is being added at the Eastern Treatment Plant. At Nykvarnsverket and the SIAAP, the improvement in wastewater treatments mostly in terms of nitrogen removal were not primarily initiated to be more energy efficient but to comply to the UWWT Directive and the WFD. Issues with compliance to European legislation have prompted positive evolutions in the wastewater sector, a fact reflected in the case of the SIAAP. European legislation is playing an important role in the redevelopement of the SIAAP which had to adjusted due to delays in compliance with the European legislation which has had impacts on how energy systems have been redeveloped. The Seine Aval plant was due to be completed by 2015 but the date had to be advanced to 2011 since the French government took the engagement to have all its WWTPs compliant with the WFD and the UWWT Directive by 2011, which caused to review initial plans of the redevelopment. Besides, initially the Seine Aval plant was going to be redesigned to accomodate 2.7 m^3 of water per day but due to public and governmental pressure, the capacity had to be reduced to 1.5 m^3 per day and as a consequence some plants are expanded (Seine Morée) and a new plants is constructed (Seine Grésillons). The close cooperation with River Basin Agencies in the context of IWRM in the case of the SIAAP, and with the EPA Victoria such as CSIRO with which the Melbourne Metropolitan Sewage System is being developed also represent important driving forces in improving energy efficiency.

Also at the operational level, along with the development of the technology, environmental concerns and potential economic benefits, there is a clear tendency to re-think alternatives uses of resources contained in the wastewater: the water itself, nutrients and energy to valorise their conversion into by-products. This is a relatively new emerging area which implies firstly that the potential in recovering resources should be further investigated and evaluated and secondly, based on this, that the status and competencies of the WWTPs should be adapted from a legal perspective. For example, in France, Seine Grésillons had established several options to valorise the use of the biogas. One option was to use the biogas to produce electricity through a cogeneration, expecting that the Grenelle Laws would allow the SIAAP to sell the electricity produced from renewable resources (the biogas) into the grid at preferential tariffs.This solution allowed not only to obtain a good energy yield but also to gain financial revenues. The cogeneration is an effective way to develop sustainable energy production and represents an adequate answer from pressures from stakeholders to reduce carbon footprint. But it represents important legislative challenges since WWTPs do not have the status of energy producers (Michel, 2010). However, when the law was adopted in June 2010 by the French Parliament, it did not include this provision. Investments had already been made towards the realisation of this option, so it was decided to produce electricity from the biogas but to sell it at a standard rate. This option provides less financial revenue, but still leave the possibility to sell electricity to the grid should the law be amended in the future. When asking at the SIAAP why the Grenelle Laws did not include this provision, given explanations varies. One explanation contends that it had been forgotten due to the unique status of the organization in France (as we have seen, the SIAAP is the sole organization in France to be formed of “départements”) while another explanation attributes it to the fact that the SIAAP through an increased potential in energy production would play a growing role on the energy production market.

Another example with regards to the importance of the role of the legislation in the development of energy systems is that of Seine Morée, which is focusing on developing local synergies. One of the synergies considered consists in a co-digestion system of the sludge and the household waste. Technically, it produces produce a high energy yield due to minerals present in the household waste and the nitrate contained in the sludge. However, because the SIAAP does not have the competency in handling household waste from a legal perspective, the waste authority (the SYCTOM) and the SIAAP have to establish a legislative setting in which the SYCTOM is operating the system and the SIAAP remains a co-owner. This kind of synergies bring to light new aspects that may have not been considered by the regulatory authorities.

The regulatory environment also gives rise to uncertainty regarding Melbourne Water's future obligations and the likely costs of energy and emissions products as noted in Melbourne Greenhouse and Energy Strategy (Melbourne Water, 2010a).

Finally, it is important to note that the Sewage Sludge Directive (86/278/EEC) related to the use of the sludge as fertilser in agriculture is currently being reviewed by the EU and this might have further impacts on strategies developed to valorise the sludge.

7.2 Connecting the dots: how the levels interact

Through the identification of measures during the course of the case studies, we have determined some of the drivers and barriers for the wastewater sector to mitigate climate change and develop more efficient energy systems. Influencing factors can be found at different levels. This section looks at how drivers and barriers can contribute to develop the interaction between the three levels, hence providing insights on how to integrate sustainability in the wastewater sector and what are the associated challenges.

The development of sustainable strategies within the plants is very recent, constitutes emerging measures to guide the development of water and wastewater authorities towards sustainability and tends to happen in large organizations. The administrative board of the SIAAP in France has approved a sustainable strategy in 2010, while Melbourne Water at the time of this research is finalising its Greenhouse and Energy Strategy from a mitigation perspective. In the future, there is a plan to establish a separate strategy from the adaptation perspective. Tekniska Verket, the mother company of Nykvarnsverket orientates the development of its activities towards clean energy production such as waste energy recovery and biogas production throughout all its divisions, but no distinctive strategy such as becoming carbon neutral, could be identified. Both Källby and Nykvarnsverket plants reported not to be subject to any objectives and/or targets to reach in terms of energy and GHG emissions. However, the establishment of such specific targets to reach are starting to appear in large organizations as the case studies conducted in France and Australia have shown. With the development of policies at the European level, large sized organizations are allocated specific GHG emissions quotas and would need to buy emissions on the carbon market should they exceed their allocations. A carbon market is already in place in Europe, while Australia is working on establishing such a market. The implementation and effectiveness of such policies is still to be determined and it might be interesting to look at how they will affect and be connected with the operational level. . For example, in France, the cost to buy additional quotas of GHG emissions is not very prohibitive yet (Tabuchi, 2010).

As noted in the section 1.6 (Limitations), in some organizations, access to environmental management was more restricted than access to employees working in the engineeering field. This can partly be attributed to availability of respondents at the time of the research but also to the fact that the integration of sustainability principles in the wastewater sector is recent. Engineers have been working on energy efficiency in the past, while the development of sustainable strategies is at its beginning as we have seen. It is therefore yet too early to evaluate the effects of sustainable strategies on the operational level, as well as their nature. Sustainable strategies and policies are also in fact closely linked to the work done on processes by engineers at the operational level due to the technicity of the operations. When designing new plants and working on processes to reduce GHG emissions and make them more energy efficient, engineering departments must be aware of policies and guidelines by the top management towards sustainability to include them, and in return the management needs to understand and evaluate the overall effect on the environment of operations to make decisions and define strategies. This might represent new challenges in terms of organization and management within the organizations. The connection between **operational and strategic levels** will become crucial reinforcing the necessity to work in systems instead of looking for suboptimal solutions at the different levels.

In order to connect the operational and strategic levels, the tactical level plays a central role. The participation to energy programmes (either voluntarily or obligatory), benchmarking, monitoring as well as estimating GHG emissions can help the plants to improve energy efficiency and reduce their GHG emissions by identifying their impacts and the level of potential that can be realistically achievable. They can also support evolutions and adaptation in legislation and policies in providing an understanding of challenges in the wastewater sector.

Because WWTPs are public entities managed by local authorities, it is important to note that the development of sustainable strategies is also politically motivated. The public concern towards the environment and the development of urban sustainable systems is growing. Public acceptance is an important element in the development of strategies to highlight the connection between the **strategic and tactical levels**. In the case of the SIAAP, the public has played a significant role in the redevelopment of the organization. Public meetings were conducted with the neighbourhood and the redevelopment of the authority has been developed following a large public consultation. Public acceptance is also important in Australia with regards to water recycling and water consumption behaviours (Priestley, 2010). The public is deemed to play a growing role in the development of sustainable societies, and impact the development of policies targeting GHG emissions from social and political perspectives.

During the course of the case studies, we have seen that energy programmes are in place in Australia and Sweden: the Energy Efficiency Opportunities Programme (EEOP) and the Svenskt Vatten Energy Project. The EEOP was created by the Australian government to which entities that consume more than 139 GWH/p.a. have to participate. This programme established opportunities to save 646 MWh per year of energy at the Western Treatment Plant. This does not represent a significant amount of energy at the scale of the plant, but it is important to identify opportunities and continuously investigate processes. The Eastern Treatment Plant is going to be assessed in the near future (Melbourne Water, 2008/2009).

The Svenskt Vatten Energy Project aims at using thermic energy more efficiently and reducing the use of electrical energy by 10%, and promote biogas production. About 40% of the wastewater sector have been participating and many projects have been implemented through this programme. This programme gathers the water and wastewater sectors in Sweden which is relatively small, economically strong and very cooperative (Magnusson 2010). There is a strong willingness to share information both at formal and informal levels which is encouraged by the Energy Project and the role of Svenskt Vatten as water association which is a strong and well-reputated organization of which most of the plants are members. These strong characteristics explain partly why the Swedish energy agency was willing to support the Energy Project developed by Svenskt Vatten since 2005, despite the fact that the wastewater sector is not energy intensive (Magnusson, 2010). In turn, this project allows a high level of interaction between the **tactical and operational levels** reinforcing practical experimentations and implementations and contribute to establish best practices within the wastewater sector.

Benchmarking and monitoring also constitute effective drivers towards energy efficiency. Despite having good energy performance, both at Källby and Nykvarnsverket, there is an acknowledged lack in benchmarking and monitoring energy efficiency. GHG emissions produced by the plants are not estimated. The plants are recognizing the need for having such systems in place and have engaged in projects to develop a benchmarking system including energy indicators in order to establish requirements and targets in terms of energy consumption and/or GHG emissions in the future. This might consequently impact measures taken at the operational level. It is important to use the right indicators, and some key parameters have been developed by Olsson (refer to table in Appendix IV). They are presented in a report published by Svenskt Vatten (Olsson, 2008) available to the water utilities. They include parameters based on electrical energy such as the quantity of energy used for areation or pumping, heat energy and removal rates achieved. The electrical energy used depends very much on how much organic content or nitrogen is removed. Measures based on the quantity of BOD or Nitrogen removed per energy consumed (i.e. kwh/kg of BOD removed) provide a better indication of energy efficiency within the plants. As an indication, in Sweden an average consumption ranges between 2 500/3 000 kWh/t. of BOD removed, depending on the size of the plants. Calculation of this indicator is provided in the WWTPs indicators table in Appendix V for reference.

According to a survey conducted by Svenskt Vatten in 2009 (Bergström, 2010)[26], 95% of technicians in WWTPs believe that they "certainly" and "possibly" can reduce electricity consumption with the current available technologies. 65% believe that they "certainly can" which is quite significant. Process operators and engineers understand how the plant functions and its layout. However, resources and incentives are lacking according to the survey. Finding the right way to motivate operators represents one of the driving forces in improving energy efficiency (Olsson, 2010). Providing adequate training can be an effective solution, as shown in the example of Renseanlæg Øst in Esbjerg in Denmark (refer to text box "Employee Training and Awards in Denmark"). Similarly, communication and information sharing between the operational level and strategical level is essential: 88% of board members, 56% of technicians and 38% of managers were not aware of the budget spent for electricity, heat and fuel. It is important to communicate such information in order to raise awareness and trigger initiative among employees. 65% of the board members interviewed think that more resources and more work on energy would help to reach financial objectives, highlighting the fact that energy efficiency contribute to financial savings.

Employee Training and Awards in Denmark

Five process operators at the Danish WWTP Renseanlæg Øst located in Esbjerg have developed energy measures that cut the electricity consumption by a third, corresponding to 900 000 kWh a year saving the plants 675 000 DK (90 612 Euros[27]) in electricity bills as well as 450 tCO_2-eq. emissions annually to the environment. This was achieved through simple measures such as changing the operating hours of the plants stirrer which run 3 minutes at a time and then pause for 90 minutes before starting again instead of running 24 hours a day, seven days a week. This is attributed to training provided by the company allowing the employees to understand processes much better instead of focusing primarily on technical aspects (Eriksen as quoted in DANVA, 2009). As a result of the training, the team has also invented a new energy saving system for the returning sludge from the sedimentation tanks. The operators have been awarded the Danish Water and Wastewater Association's Energy Award in 2009 (Esbjerg Commune, 2009), in addition to the Municipality of Esbjerg's Environmental Prize in 2008. This experience illustrates how important and how effective it can be to provide training and incentives to employees.

[26] For the purpose of the survey conducted by Svenskt Vatten, 150 persons have been interviewed in water utilities, including board members, senior management and technicians.

[27] 1 DK equals 0.10499 Euros. Interbank rate as of July 1, 2010. Source: www.oanda.com.

Estimating GHG emissions and identifying their source is essential to determine appropriate and effective measures and strategies, at entities level but also at the national/federal level to enact policies and legislation. Besides GHG direct and indirect emissions coming from energy consumption, indirect emissions coming from embedded products used or by-produced by wastewater treatment can be very significant. A carbon assessment conducted in 2006 by the Seine Aval WWTP shows that intrants materials amount to 19 102 tCO_2-eq, by far the highest GHG emitter after imported energy (5 253 tCO_2-eq.). Among those 19 102 tCO_2-eq. emissions, 93% were coming from chemical products (Picard et al., 2009). Although this figure applies to the specific case of Seine Aval and might not be representative for other plants, it shows that the amplitude of the impact coming from chemicals is actually far higher than that of the energy used. Therefore one question to prioritize and to ask at the strategic and operational levels could be: how it is possible to avoid/minimize the use of chemicals within the treatment? The predenitrification process in use at Källby in the activated sludge treatment that uses the carbon content of the wastewater for denitrifrication in lieu of chemicals reduce the quantity of chemicals required. This process will be adopted by Seine Aval in the future activated sludge treatment due to be installed in 2016 (Tabuchi, 2010). Källby and Nykvarnsverket do not calculate their carbon footprint. The WWTP Sjölunda based in Malmö and part of VA SYD is employing a PhD student to calculate GHG emissions of a specific step of the sewage treatment, but information was not available at the time of the case study.

In the case of Sweden, according to the case studies performed, drivers in energy efficiency improvement are not initiated from strategies or action plans established at each entity level. Energy efficiency per se is not established as a priority but represents more an aspect taken into account when developing projects or defining strategies (Cimbritz, 2010). Källby and Nykvarnsverket WWTPs are not subject to specific targets in terms of energy consumption and GHG emissions. This can be explained by the fact that the sector is not energy intensive and also that the government does not want to strongly interfere or impose conditions that might affect the wastewater treatment (Magnusson, 2010). Yet Källby and Nykvarnsverket perform well in terms of energy efficiency. When measuring energy to the amount of BOD removed, both plants rank below the Swedish average of 2 500/3 000 KWh/t. of BOD removed (Olsson, 2010): 2 078 KWh/t. of BOD removed (2008) and 2 225 KWh/t. of BOD removed (2009) respectively (refer to table in Appendix V). Besides, at Nykvarnsverket, in relative terms, although no quantitative data on energy efficiency was available, it was ascertained at there has been an improvement due to the fact that the total nitrogen removed has increased to 71% in 2009, from 53% in 2006 (Arnell, 2010) due to the introduction of more performing processes (such as the Sharon® system and a computerised monitored aeration system). In 2007, an intermittent aeration process has also been implemented, increasing the efficiency of the treatment. It has not led to significant energy savings (1% of electricity consumed by the plant) but has offset GHG emissions by avoiding the use of chemicals. At Källby, the installation of online monitoring in two biolines in the activated sludge treatment (biological treatment) led to decrease the air consumption by 1.5 times compared to the biolines without monitoring. This process also led to identify that half of the electricity at Källby was consumed by the aeration system. Therefore energy considerations are considered when treatment processes had to be updated. When rethinking plant processes, energy considerations are increasingly taken into account in the choices of new equipment such as pumps and processes. Considerations and questions related to energy performance raised when conducting case studies will certainly become systematic in 10 years time (Cimbritz, 2010). It takes time to establish new decision systems and to change organizational structures to adapt to new challenges imposed by the climate change and the integration of sustainability. In Sweden, there is a certain tradition of integrating environment and sustainable aspects in policies including energy policies and a practice to attempt to exceed legislation requirements which represents an *informal* driver. For example, at Källby, nitrogen is removed at 79% while the legislation requires a minimum of 70% (Cimbritz, 2010). This fact is also corrobated by Arnell (Arnell, 2010). Doing so is not dictated by entities themselves but represents a tendency, reflecting the fact that Sweden is one of EU member leader in terms of environmental policies and practices.

According to the analytical framework of this research, transition management happens in a transitional manner when the three levels of governance interact: strategic, tactical and operational (Kemp et al., 2007). However this framework does not provide criteria allowing to evaluate precisely the degree of interaction between each level in order to determine in what stage the transition is happening: predevelopment, take-off, breakthrough and stabilisation. Nonetheless, through our case studies, we can conclude that we are the beginning of a transition oscillating between the pre-development stages and the take-off. In the case of Sweden, the tactical level interacts strongly with the operational levels, but the strategic level is weak, however national policies which have early integrated environmental concerns informally influencing the sector. In France, the tactical level is not very prominent, and European legislation has lead to significant changes including the reassessment of its energy systems. There are strong interactions between all the levels in the case of Melbourne Water which has set ambitious targets towards the climate change. This could be attributed to the fact that Australia is being more strongly affected by the effects of climate change (droughts).

In the introduction of this research, we have mentioned that WWTPs tended to be isolated entities not well-perceived by citizens. As WWTPs are becoming more and more integrated into the urban environment, new considerations are starting to appear. Architecture become an important aspect from environmental and esthetical points of view, which also facilitate public acceptance. Seine Morée will not look like a traditional WWTP, the building will include green walls and green roofs as well as aquatic ponds (Figure 7-9), complying with the French HQE®[28] construction label, also providing a better working and living environment.

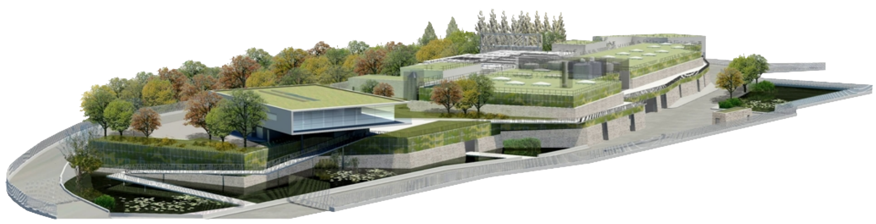

Figure 7-9: Architectural View of Seine Morée upon completion. Source: SIAAP, 2010.

[28] "Haute Qualité Environnementale" (HQE®) is the most recognized French label for building construction. It takes into account the environmental management of the project and its architectural and technical performance based on construction, management, comfort, and human health criteria.

8 Conclusions

The principal function of WWTPs is to provide sanitation to populations and return cleaned processed water into the hydrological cycle. In doing so, plants consume energy, directly and indirectly (embedded energy). Due to the climate change happening, although the wastewater sector is not an intensive energy sector, in the developed countries, there is a recent trend in considering energy consumption and assessing GHG emissions. Besides, the development of policies and legislation are integrating more and more the concept of sustainability, and the necessity to reduce GHG emissions initiated by the Kyoto Protocol which impact the wastewater sector. However, there are several challenges associated to this such as the methodologies to estimate GHG emissions which are scientifically lacking.

In the context of climate change, this research aimed at identifying current challenges in the wastewater sector, and how WWTPs have started to integrate and respond to them, through case studies conducted in Sweden, France and Australia. To that purpose, exploratory case studies of WWTPs were conducted on site and/or through telephone interviews. The objectives were to understand to which extent energy efficency represent a concern, what type of measures are taken towards improvement and what are the potential and possibilities for the plants to mitigate climate change. The wastewater sector is auto-financed and is traditionally not a high energy intensive sector, but population growth, the energy price increases, reduction in availability of fossil-fuel-based energies constitute elements that are affecting it. Sewage entities along with municipalities that own them need to identify what challenges are associated to these changes. Based on this, strategies need to be defined towards the development of sustainable urban water management. WWTPs have the opportunity to become important actors of the development of urban sustainability.

As a way of analysing cases, the transition management model developed by Kemp et al. (Kemp et al., 2007) was used. According to the transition management theory, sustainability happens at different levels: beliefs, values and governance that co-evolve with technological changes. This research is based on three governance levels operational, tactical and strategic. (Kemp et al. 2007). Adapted to the purpose of the research, measures have been identified at each level. At the operational level, measures are related to the process itself and the technology. The tactical level includes tools used and developed by entities to evaluate, monitor and benchmark such as carbon footprint assessments and knowledge sharing. The strategic level defines measures established to guide and implement sustainability at all levels typically through the development of sustainable strategies applying the three pillars of sustainability: social, economic and environment. Such strategies have been recently developed by the SIAAP and Melbourne Water.

Energy efficiency can increase by improving processes and using more efficient equipments. Technically, we have identified several ways to improve treatment processes such as improving the aeration process in the biological treatment, implementing monitoring and benchmarking including energy indicators, encouraging the exchange and knowledge between the plants. In fact, energy consumed by WWTPs can be difficult to quantify and vary between the plants (refer to table in Appendix IV). This is due to many factors such as the resources available and motivation for the staff to initiate energy savings, the amount of organic content in the incoming wastewater flow, and measures have to be taken accordingly. This is why benchmarking and monitoring within the plants themselves as well as involvement of employees at all levels are essential and can prove to be very effective. Sweden is one of the first countries amongst EU member States to have integrated energy efficiency within its policies. The Svenskt Vatten Energy project in place since 2005 aims at reducing 10% the use of electrical energy in the water sector by 2012. Such a project co-financed by the Swedish Energy Agency and the plants themselves have been gathering the plants and contribute to establish best practices and cooperation between the plants at the national level. Improving energy efficiency ranks second in the Melbourne Water Greenhouse and Energy Strategy, after avoiding GHG emissions. Melbourne Water has also been taking part in energy projects in order to identify energy savings opportunities.

However, some interviewees at the WWTPs studied contended that energy savings in plants can be limited. Historical layout of the plants that have been built progressively as the populations and industries were growing in the 1950s and the 1960s can be problematic, as found at Seine Aval in France. Integrating more technologically efficient and innovative treatment processes to old process units can affect some parts of the treatment process. This fact was also highlighted by Melbourne Water. Because the operation of WWTPs cannot be interrupted, modernising plants can encounter complex difficulties which can hinder changes. More importantly, WWTPs cannot make any compromises in the treatment not to cause any risks to human health and their environmental surroundings. Therefore looking at increasing energy self sufficiency and resources recovery through by-products within the wastewater is considered by the plants as being the way forward. Plants are investigating further on how to optimise the use of the sludge, which can be converted into biogas/biofuels and electricity, as well as of the energy contained in the water (hydroplants), and nutrients (phosphorus, nitrogen). New opportunities also exist in using the sludge for construction materials. The case studies of the SIAAP in France illustrate very well from a technical perspective different options to develop more efficient energy systems through recovery of high and low potential energy, and the development of local synergies (district heating and co-digestion of the sludge and the waste). They highlight different criteria for selecting which option to take and consider various trade-offs within these criteria. Melbourne Water is also looking at developing a Metropolitan Sewage Strategy to amongst others maximise nutrients recovery such as nitrogen and phosphorus, natural resources that are in fact limited. Biogas production is an important prospect for the future in the three countries studied. Not only it is a renewable energy, but also its use in the transportation sector contributes to avoided GHG emissions. The Swedish Energy Agency is encouraging the development of biogas production and it has been established that the biogas produced by anaerobic digestion offers the highest socio-economic values. The role of policies and legislation is critical as they can support measures taken by the plants and provide incentives, as well as direct investments and strategies towards new opportunities, as we have seen in the case of Seine Grésillons. According to the analytical framework of this research, the transition towards sustainability happens at the interaction of the three levels suggesting that we are in an innovative system. Through these interactions, the transition process can be adaptative and progressive avoiding lock-in effects and sub-optimal solutions. In Sweden, we can see that a good interaction exists between the tactical and operational levels. Svenskt Vatten gathers WWTPs by establishing best practices, and sharing information and knowledge. This research is highlighting the need to develop more strategic orientations by monitoring energy consumption, determining energy targets, and benchmarking to create formal drivers and reflective tools. In France, strong strategic measures have been established at the SIAAP resulting from strong concertation with the public and the government and also non-compliance to the European legislation. In terms of operational measures, a lot of ressources are devoted to develop better performing systems to maximise energy recovery

(Seine Aval). There is a good interaction between operational and strategic levels characterized by a continuity between the two levels. The establishment of the Agenda 21 Commission had an impact on projects developed. This research also witnessed he role of legislation and the complexity in integrating legislation and policies into the operational level (Seine Morée and Seine Grésillons). Australia, a country affected by the climate change through droughts and subsequent water scarcity, has to take this element into account which also becomes a driver in the wastewater sector. Water has to be recycled and its use promoted instead of drinking water whenever possible. At Melbourne Water, there is a strong strategic support, at the tactical level strong relationships with the legislation and other stakeholders have been built, and there are strong cooperation between the federal government, water associations and the operating sites. There seemed to be strong concerted actions between stakeholders at the strategic level which are leading to effective operational measures. One characteristic of Melbourne Water is the fact that the entity is working in a long term perspective: the objective to become carbon neutral by 2018, and the development of the Melbourne Metropolitan Sewage Strategy by 2050.

Further research is needed. Estimation of GHG emissions is an essential aspect in order to quantity the global impact of WWTPs on the environment and to identify which elements within processes are the most impactful. Criteria to assess interactions between stakeholders to define global objectives in the wastewater sector need to be established in a more systematic manner and to be regularly re-assessed with all relevant actors. The effects and the nature of sustainable strategies must be evaluated and monitored by reinforcing the connection between the operational and strategic levels. And more international exchanges of formal and informal knowledge and experiences could be very beneficial. For example, recycling water which is necessary in countries like Australia affected by water scarcity could be considered by other countries. Further research could be done to compare energy use for treating water to be discharged into water bodies against treating it for recycling purposes. Depending on its use, recycled water does not need to be processed through the same levels of treatment. This would require to reconsider water supply side policies and integrate them into the development of sustainability. Water efficiency needs to be further considered and a reflexion upon the value and access rights to water must be engaged. Water is as much as oil a natural resource that needs to be more effectively managed and more so in regions of the world impacted by water scarcity. The wastewater sector can be more energy efficient and reduce its GHG emissions, but studies have shown that there is a much bigger potential in energy saving at the households levels. It takes 0.25 kWh of energy to treat one cubic meter of water, while heating 1 cubic meter in an household requires 52 kWh (Olsson, 2010). If water heating processes could be improved, much more energy could be more effectively saved.

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Wardestam, Sofie. (2010, July 8). Personal interview.

Wennberg, Marika. (2010, July 8). Personal interview.

The table of interviewees can be found in Appendix I.

Appendix I: Table of interviewees

Person	Type, date and time	Objective
Magnus Arnell. Process Manager. Tekniska Verken.	Personal interview on June 28, 2010 from 1pm to 4.30pm. Telephone Interview on August 24, 2010. from 1.10pm to 1.40pm. Follow-up by email and telephone.	Sweden Case Study, Nykvarnversket.
Michael Cimbritz. Process Engineer. Källby WWTP, VA SYD.	Personal interview on June 23, 2010 from 9am to 12pm. Follow-up by email.	Sweden Case Study, Källby.
Quentin Dhenaut. Main Engineer for the Operation and the Expansion Plan of the Grésillons Plant (“Ingénieur Principal pour la Conduite d’Opération et d’Extension de l’usine des Grésillons). SIAAP.	Telephone interviews on July 30, 2010 from 10.15am to 12.55pm and on August 6, 2010 from 3pm to 4pm. Follow-up by email and telephone.	France Case Study, SIAAP. Seine Grésillons WWTP.
Felicia Dobos. Environment Inspektor (Miljöinspektör) .City of Malmö.	Personal interview on July 5, 2010 from 2pm to 4pm.	Sweden Case Study. Understanding the role of municipalities in the wastewater treatment sector.
Anders Finnson. Svenskt Vatten.	Telephone interview on June 23, 2010 from 2pm to 3pm and on July 7, 2010 from 3.30pm to 4.10pm.	Svenskt Vatten Energy Project, legal and policy background.
Jan E. Magnusson. Energy Efficiency Programme Manager. Swedish Energy Agency.	Written interview.	Svenskt Vatten Energy Project and energy policy in Sweden.
Thierry Michel. Engineed. SIAAP.	Telephone interviews on July 22, 2010 from 3.45pm and 4pm and on July 26, 2010 from 4.30pm to 4.50 pm, on July 27 2010 from 3.15pm to 5.30pm.	France Case Study, SIAAP. Seine Morée WWTP.
Ronan Nedelec. Head of Studies and Methods at the Development and Prospects Direction, SIAAP. (Responsable du service Etudes et Méthodes à la Direction du Dévelopement et de la Prospective du SIAAP).	Telephone interview on July 20, 2010 from 8am to 9am. Follow-up by email and telephone.	France Case Study, SIAAP. Seine Aval WWTP.

Person	Type, date and time	Objective
Owen Phillis. Manager of Sewage Strategy and Ressources. Melbourne Water.	Telephone interview on August 8, 2010 from 11.30pm to 12pm.	Australia Case Study. Melbourne Water.
Mattias Paulsson. Process Engineer. Sjölunda WWTP, VA SYD.	Personal interview on July 13, 2010, from 10am to 12pm. Follow-up by email.	Sweden Case Study, in complement to Källby.
Tony Priestley. Honorary Fellow. CSIRO Land & Water.	Telephone interview on July 26, 2010 from 7am to 7.40am. Follow-up by email.	Australia Case Study. Water legislation and policies in Australia.
Gustaf Olsson. Professor Emeritus. Industrial Electrical Engineering and Automation. Lund University.	Telephone interview on August 16, 2010, from 12.40pm to 13.25pm.	Sweden Case Study. Background on the WWTP sector and water legislation and policies.
Emmanuelle Schäffer. Sustainability Manager. (Chargée de mission dévelopement durable). SIAAP.	Telephone interview on July 30, 2010 from 2.30pm to 3pm.	France Case Study, SIAAP. Agenda 21 Commission.
Jean-Pierre Tabuchi. Manager in Coordination and Integration of Changes. (Chargé de mission coordination, intégration des mutations). SIAAP.	Telephone interview. August 17, 2010 from 11am to 12.40pm. Follow ups by emails and telephone.	France Case Study, SIAAP. Seine Aval, water legislation and policies in France.
Sofie Wardestam. Project Leader. Lunds Energi Koncernen.	Personal interview on July 8, 2010, from 1pm to 2.30pm.	Sweden Case Study, Källby WWTP.
Marika Wennberg. Process Engineer. Källby WWTP, VA SYD.	Personal interview on July 8, 2010 from 10am to 11am.	Sweden Case Study, Källby.

Appendix II: Experts and practitioners consulted for the collection of secondary data

Stéphane Amosse. SIAAP. France

Jan Andersen Egelund. Coordinator for DANVAs energy saving campaign. Danish Water and Wastewater Association (DANVA). Denmark.

Milla Battle. Director Carbon Finance. Veolia Water Solutions and Technologies. France.

Li Choong. Project leader, Corporate Planning and Sustainability Group. Melbourne Water. Australia.

Vincent Ferstler. French Ministry of Ecology, Energy, Sustainability and Sea (Ministère de l'Ecologie, de l'Energie, du Développement Durable et de la Mer). France.

Christopher Gruvberger. VA SYD, Sweden.

Daniel Hellström. Svenskt Vatten, Sweden.

Jon Herd. Water Campaign State Manager, Victoria. International Council for Local Environmental Initiatives, ICLEI Oceania. Australia.

Ulf Jeppson. Associate Professor. Industrial Electrical Engineering and Automation, Lund University. Sweden.

Steven Kenway. Commonwealth Scientific and Industrial Research Organisation (CSIRO). Australia.

Caroline Laget. Veolia Water Solutions & Technologies. Carbon Coordinator. Denmark.

Jean-Pierre Maugendre. Co-director of sustainability (Directeur adjoint du dévelopment durable). Lyonnaise des Eaux, groupe SUEZ. France.

François Mauvais. Director ("Directeur Général"). Scientific and Technical Association for Water and the Environment. (Association Scientifique et Technique pour l'Eau et l'Environnement, ASTEE). France.

Debborrah Marsch. University of Technology, Sydney, Australia.

Thuy May. Programmes Officer. International Water Association. The Netherlands.

Annika Nillson. Head of Section. Swedish Ministry of Environment. Division of Natural Resources. Sweden.

Per Pedersen Overgaard. Project Manager, Operational and Maintenance Department. Aarhus Water ("Århus Vand"). Denmark.

Pascale Peignen. Head of Pedagogical Department ("Responsable du service médiation pédagogique"). SIAAP. France.

Peter Van der Steen. Senior Lecturer in Sanitary Engineering. UNESCO-IHE Institute for Water Education, Department of Environmental Resource. The Netherlands.

Appendix III: Wastewater treatment processing

This appendix provides basic definitions, and describes the wastewater treatment process. There are various existing processes depending on the built structure and size of the plants. We present here in a simplified manner the most traditional treatment process.

Definitions

Wastewater, also called sewage, refers to water used by an agglomeration. It is classified as domestic or sanitary when it comes from residential households (for example laundry water), commercial, industrial, agricultural or surface runoff (rain and/or storm water). It is mostly composed of water, and it is characterised by its volume, chemical constituents and bacteriological organisms it contains. Depending on countries, regions, seasons, weather and time of the day, wastewater contains various pathogenic organisms, organic matters and nutrients such as nitrogen and phosphorus.

The **content of wastewater** is classified by the size and the matter of the particles (solutions, colloidal solutions, suspended matter, suspended solids). Chemical pollutants in the wastewater are divided into inorganic and organic matter, the latter being based on hydrocarbon. Pollution measurements are based on Biochemical Oxygen Demand (BOD7 or BOD5 depending on countries), which is the quantity of oxygen needed to oxidise biologically the discharges of polluted effluents produced, whereas Chemical Oxygen Demand (COD) is the quantity of oxygen consumed by the chemically oxidisable matter. The most common nutrients present in water discharges are nitrogen and phosphorus. The level of these nutrients needs to be reduced in order to avoid eutrophication in receiving water bodies. Pathogenic organisms, classified as bacteria, viruses and worm eggs, constitute a risk to human health.

The sewage is carried through a system of sewer pipes called sewerage that can be either combined or separated from the incoming distributed water. In developed countries, most of communities are connected to the sewerage system. In the case it is not, often due to remotness, wastewater can be collected by pipes into septic tanks and then transported by vehicles to a wastewater treatment station.

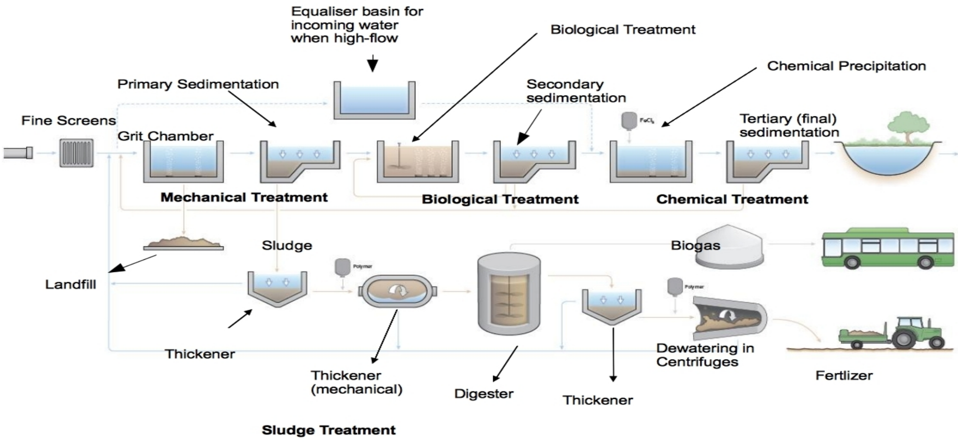
Sludge is a by-product of wastewater treatment and is composed of water, dissolved and suspended matter. This semi-liquid waste is generated from the separation processes. By removing water and pathogen from the sludge, the sludge can be either landfilled, incinerated, used to produce biogas and fertiliser.

WWTPs measure their load in **population equivalent (p.e.)**. This unit is based on the quantity of pollution generated per person per day. Article 6 of the Urban Wastewater Treatment Directive defines one p.e. as the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day.

Wastewater treatment process

The role of a WWTP is to collect pollutants and remove them out of the sewage water to minimise environmental impacts such as eutrophication and not to present a risk to public health. In this section, the treatment steps described are explained.

Figure: Schema of wastewater treatment process. Source: Adapted from VA SYD, 2010.



The **mechanical treatment** of wasterwater aims at removing coarse materials. It starts with a fine screening process where big solids such as cans are removed in order not to damage the equipment further down the treatment. It is followed by a sand and grit removal process where the wastewater is aerated to create a flow velocity to allow heavy particles to sink and lighter particules to remain suspended at the surface. Finally, the primary sedimentation step removes relatively large particles while wastewater passes through large basins while suspended materials sink to the basin floor removing BOD/COD. Typically, one third of the organic solids have been removed. Some plants add chemical substances to facilitate the process at this stage in order to remove more organic solids, increasing the organic content of the primary sludge. The primary sludge can then be processed in a digester after being pumped into a centrifuge for mechanical dewatering facilitating the sludge treatment.

There are several types of **biological treatment** methods and these methods can be utilised under anaerobic, anoxic or aerobic conditions. The main objectives of this treatment step is to remove remaining organic matter, nitrogen and phosphorus. The aerobic biological treatment activates the sludge by using the oxygen dissolves in the water. This is the most commonly used water treatment process. High concentrated sludge is mixed with the incoming wasterwater in areated tanks creating favorable conditions for micro organisms, mainly bacteria to develop and feed on the organic matter thus removing it from the wastewater and generating biomass. This is a complex process and the difficulty is to ensure a constant flow of sludge concentration in the activated sludge line. In the first step, the nitrification, ammonium (NH_4) is transformed to nitrate (NO_3), and in the second step, called denitrification, nitrate is transformed into nitrogen gas (N_2)

that evaporates into the atmosphere. This transformation is performed by anoxic bacteria. An anaerobic process takes place in an oxygen free environment, requiring much less energy. The biggest part of phosphorus can be removed at this stage. Phosphorus is assimilated by the growth of bacteria, therefore 45% to 50% of phosphorus is eliminated naturally. Biological phosphorus removal can be enhanced by creating particular conditions for biomass. Biological treatment can therefore be reinforced and reach a yield of 65% to 70%. To reach a more stringent yield, it is necessary to add chemicals such as FeCl3 (ferric chloride) (Tabuchi, 2010).

The **chemical treatment** can differ depending on previous treatment steps, but generally this treatment phase removes the remaining phosphorus and "polishes" the water filling the gap between what has been achieved through previous treatments and desired/required effluent quality of the water before being discharged back into the receiving waters. It can also be integrated with the aeration step (simultaneous precipitation) or before,with primary treatment (pre-precipitation) (Cimbritz, 2010). Final quality can also be adjusted depending on the water re-use purposes. Chemical substances are added to create precipitation, thus creating a mechanical separation. Membranes techniques such as ultra filtration, reverse osmosis, or activated carbon filtration (UV disinfection or ozonisation) can be utilised.

The **Sludge treatment** is done through three steps: sludge thickening, sludge stabilisation and dewatering. Sludge, a by-product of wastewater treatment, is a renewable resource rich in carbon, nitrogen and phosphorus typically used to produce biogas and/or fertilizer for agriculture, offsetting GHG emissions of the WWTPs. Biogas can be produced using anaerobic digestion that transform the sludge into CH_4. Biogas typically consists of 75% of CH_4 and 25% of CO_2. To be injected into the grid, biogas needs to be upgraded to increase the concentration of CH_4 and make it usable as biofuel or biomethane.

The first step is to thicken the sludge to reduce its volume. Sludge generated from the primary mechanical treatment is usually best thicken in sedimentation tanks or gravitational thickeners. Sludge originated from chemical and biological treatments can also be treated by flocculation.

It is necessary to "stabilise" the sludge to limit the fermentation of the organic matter. It can be done through anaerobic digestion. The sludge is heated at a temperature of 37 degrees Celsius and digested by anaerobic micro organisms in a digestion chamber. The amount of solids is reduced by 40 to 50%, and the sludge volume by 35%. This process produces methane and carbon dioxide gases which can be used as biofuel, or heat. The second way to stabilise the sludge is through aerobic digestion in which sludge is aerated for approximatly two weeks. Lime, by raising the pH value, can also stabilise the sludge by raising the pH-value. It is a simple process, but entails high costs.

Once thickened and stabilised, the sludge still contains 90 to 98% of water, which makes it heavy and costly to transport. Mechanical processes are used for dewatering, such as centrifugation. For better results, polymers can be added.

Identification of high energy consuming and GHG emissions sources

Energy consumption can vary greatly depending on the age of equipment, maintenance, and the configuration of the plant, as well as the type of treatment processes, and often reliable and comparative data is not readily available. Other basic variables such as a flat or hilly geography can greatly influence the energy consumption. As an example, in Källby, one of the case study, water flows to the plant through gravitation due to the geographical disposition of the region. When gravitation cannot be used, water must be pumped to the plant requiring considerable amounts of energy. It is challenging to find the right balance between the energy needs and the flow rate of the wastewater in order to maximise the efficiency of the pumping (Olsson, 2008). Flow rates vary depending the time of the day or the season. Therefore variable speed drives should be considered. The same apply to internal pumping in the plants where wasterwater needs to be recirculated. Friction losses must also not be overlooked. To avoid them, it is important to select the right size of pump.

Controlling and distributing aeration is of "fundamental importance" (Olsson, 2008) to maximise energy efficiency and also to maintain a consistent effluent quality. According to a study done at two plants which are part of VA SYD, Sjölunda and Klagshamm (Rydh and Åkesson, 2007), 30% of electricity is consumed by the blowers whose role is to supply oxygen in the activated sludge treatment process. Therefore it is important to be able to control the dissolved oxygen concentration all along the aerator (Olsson, 2010) using sensors for example. Besides aeration, mixing in the aerator and in the denitrification process could also be an important energy consumer. A good aeration and mixing could contribute to very much improve energy efficiency.

Other factors that should be taken into account are the losses of energy throughout the different processes, including losses of energy present in the wastewater in the form of organic matter. The content of the incoming wastewater therefore matters for the energy performance of the plants and vary depending on the type of industries served by the WWTPs. Wastewater coming from the dairy industry for example contains a high content of organic matter (Arnell, 2010). The more organic matter the wastewater contains, the more energy could be produced (Wennberg, 2010). This is an important element to consider since WWTPs are growingly becoming energy producers, offsetting their energy consumption.

The wastewater treatment contributes to the **GHG emissions** mainly through CO_2, CH_4 and N20. CO_2 emissions produced during the wastewater treatment are originated from the degradation of organic matter (animal or anthropic). CH_4 emissions are released into the atmopshere from the biological treatment in anaerobic conditions. N20 emissions are generated from nitrification and denitrification processes (ASTEE, 2009). CH_4 and N_2O emissions are two of the significant greenhouses gases listed under the United Nations Framework Convention on Climate Change (UNFCCC). The damage they create to the atmosphere is potentially larger than CO_2 emissions. N_2O has a Global Warming Potential (GWP) 310 times higher than CO_2. CH_4 has a GWP 21 times higher than CO_2. Therefore N_2O emissions have an impact far more higher than CO_2 and CH_4 in terms of GHG emissions.

We can distinguish three different scopes of GHG emissions coming from WWTPs: (ASTEE, 2009):

- direct emissions from processes or equipements such as combustion and decomposition of the organic matter.

- indirect emissions coming from imported energy use (electricity and/or heat).

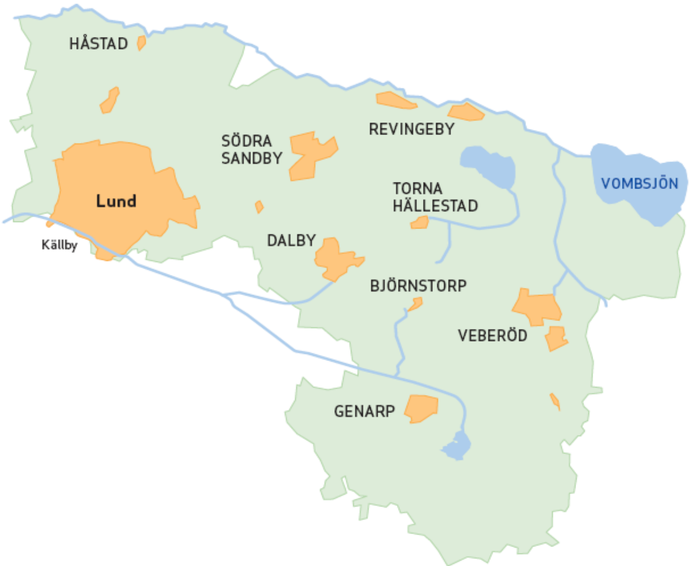
- other indirect emissions (than coming from imported energy use) that are embedded in products used for treatment processes. Typically, they originate from the production and the transportation of chemicals, the sludge and other by-products treatment and their transportation.

It is also important to mention fugitive emissions which in the case of the wastewater treatment are methane and nitrous oxide coming from leaks (when producing biogas for example), or from the nitrification/denitrification process.

Finally resource recovery of by-products from the wastewater treatment such as biofuels can account for “avoided emissions”. By using biofuels, one can “avoid emissions” that would have been emitted by using fossil-fuel-based energy instead of renewable energies.

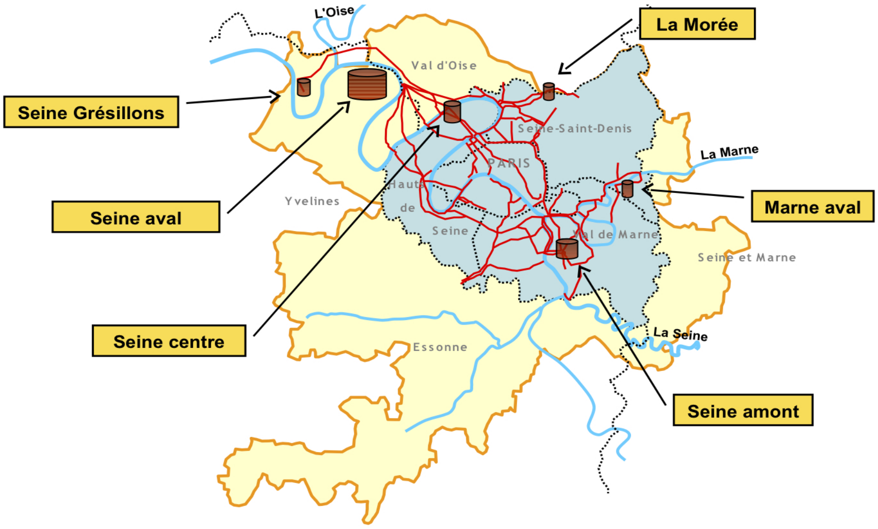
Appendix IV: Localisation maps of WWTPs

- ***Källby (Lund, Sweden). Source: VA SYD, 2010.***



- ***Nykvarnsverket (Linköping, Sweden). Source: Tekniska Verket, 2010.***

- ***SIAAP WWTPs, current and future (Paris Agglomeration, France). Source: SIAAP, 2010.***



- ***Melbourne Water (Melbourne, Australia). Source: Melbourne Water, 2008/2009.***

Appendix V: WWTPs Indicators

Indicators	Källby (VA SYD) (2008)	Nykvarnsverket (Tekniska Verken) (2009)	Seine Grésillons (SIAAP) (2008)	Seine Aval (SIAAP) (2008)	Seine Morée (SIAAP) Previsions upon construction	ETP (Melbourne Water) (2008/2009)	WTP (Melbourne Water) (2008/2009)
Wastewater treated (m^3/p.a.)	10 339 275	15 400 000	35 525 420	575 591 000	17 520 000	107 696 000	153 696 000
Nitrogen (removed, t/p.a.)	332	623	1411	8 455	1 200	5 741	9 469
Phosphorus (removed, t/p.a.)	59.1	132	190	3 221	195	538	778
BOD5[a](removed, t/p.a.)	1 866	4 700	6 000	104 639	5 200	3 500[b]	409[c]
COD (removed, t/p.a.)	n/a	10 600	14 100	239 327	12 830	83 233	n/a [d]
Sludge treated (m^3/p.a.)	9 039	n/a	n/a	5 001 927	143 000	1 277 000	n/a[e]
Energy consumption (MWh/p.a.)	3 878	10 460	27 339	658 422	25 500	93 481	75 569
Gas consumption (MWh/p.a.)	703	3 930	9 472	419 237	600	42 184[f]	536[g]
Electricity Consumption (mWh/p.a.)	3 878	6 530	17 867	238 230	22 500	93 111	75033
Kwh/t.BOD removed/p.a.	2 078	2 225	4 565	6 292	4 903	n/a	n/a
Energy consumption (kWh/m^3)	0,38	0.68	0,77	1.15	1.4	0.86	0.49
Biogas produced (MWh/p.a.)	n/a	165 100	64 571	386 589	45 000	122 406	296 388

Sources: Cimbritz, 2010. Arnell, 2010. Tabuchi, 2010. Michel, 2010. Choong, 2010.

[a] BOD7 in the case of Källby and Nykvarnsverket

[b] This figure provided is not in line with the rest of the plants and it was not possible to obtain an explanation at the time of the research. Therefore it is provided for information only.

[c] This figure provided is not in line with the rest of the plants and it was not possible to obtain an explanation at the time of the research. Therefore it is provided for information only.

[d] Data set not complete

[e] Desludging does not happen continuously at the WTP.

[f] Gas used to produce electricity and heat which are used on site.

[g] Natural gas for office heating

Appendix VI: Key parameters to measure energy efficiency of the wastewater treatment

Energy per m^3 water (kWh) • Total • Pumping of incoming water • Aeration • Stirring	**Heat production** • Out-take of heat content in water going out (GWh/year) • Produced volume of biogas (Nm^3/year or MWh/year) • Internal heat production from biogas (MWh/year) • Sales of biogas (MWh/year) • Production of electricity from biogas (MWh/year) • Purchase of heat energy (oil, district heating, etc.) (MWh/year)
Cleaning result per kWh • Kg of removed nitrogen per kWh • Kg of removed BOD per kWh • Kg of removed COD per kWh	**Chemical use** • Phosphorus removed (g) per chemical use (g)

Source: Adpated from Olsson, 2008