# Waternet Climate Neutral

Mitigation measures for the reduction of GHG emissions

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# Acknowledgements & foreword

This thesis was written from an intrinsic desire to deliver academic research with high practical applicability. As intern and graduating student, the strategic center of Waternet has offered me the chance to do so. Aside from my wish to synthesize academic and practical knowledge, I desired to build bridges between technical specialist knowledge and strategic policy making. In this research I have been able to gather specialist knowledge from various directions to perform a techno-economic potential analysis for mitigation options in the Amsterdam context and to translate this to the needs of strategic decision-making. This thesis allowed me to combine my wishes, and would not have been possible without the many relevant contributions of colleagues at Waternet and external experts to whom I am highly indebted.

I would like to thank Maarten Claassen for offering me the chance to experience and research strategic planning for sustainability at Waternet first-hand. Stefan Mol and André Struker: thank you for your endless inspiration, brainstorming, sharing of information and contact details. Last but not least, I am grateful for the academic support offered by Carel Dieperink and Robert Harmsen, displaying high involvement from the start and providing relevant academic feedback throughout the process.

# Abstract

Amsterdam's public water utility Waternet set the ambitious goal to become climate neutral in 2020 – i.e. zero net greenhouse gas (GHG) emissions in 2020 – thereby acknowledging the necessity of mitigating climate change. To become climate neutral, Waternet will need to achieve a reduction of GHG-emissions of approximately 97.2 kton/year. Setting this goal puts them at the forefront of public utilities moving towards more sustainable practices. In order to reach the ambitions, a mitigation policy plan up to 2020 will be devised. The aim of this research was to explore mitigation measures for GHG-emission reduction. The main focus of mitigation measures is on the Amsterdam watercycle, since it offers much potential for innovative GHG mitigation, such as thermal energy, chemical energy and resource recovery.

Out of twenty-six available measures, four reduction measures and six compensation measures were evaluated. By means of a multi-criteria analysis and marginal abatement cost curves, insights were gained on climate impact, cost-effectiveness, service delivery, and Waternet's influence and autonomy in realization of the mitigation measures.

Of the evaluated measures, wind energy production and shower water heat recovery have the highest potential for the reduction of GHG-emissions, respectively 37.3 kton/yr and 28.7 kton/yr. The total package of ten mitigation options could lead to a GHG-emission reduction of 88.1 kton/yr. The remaining 9.1 kton/year can be compensated by other watercycle reduction and compensation measures which requires further research, or by the purchase of green electricity and/or carbon credits. In conclusion, Waternet can achieve its goal of climate neutrality in 2020 by implementing the package of researched mitigation measures with a minimal procurement of carbon credits and/or green electricity.

*Key concepts:* climate neutrality, public utility, water sector, mitigation measures, MAC-curves, MCA

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# 1. Introduction

## 1.1. Climate change

Since the last decades, evidence for anthropogenic climate change[1] has grown (IPPC, 2001, 2007). The most notable effect of climate change is temperature increase as a result of an increase greenhouse gas effect. The greenhouse effect is a naturally occurring principle that ensures liveable temperatures on earth, through reflecting infrared radiation from the sun. Due to increased human induced greenhouse gas (GHG) emissions[2], this effect is strengthened. Anthropogenic GHGs originate from diverse human activities; one of the main sources of GHGs stems from energy-related activities (such as fossil fuel burning) resulting in CO2 emissions. Other important GHGs such as CH4 (methane) and N20 (nitrous oxide) stem from a variety of sources such as land use changes, fertilization, waste streams, "fugitive emissions from chemical processes, and fossil fuel production, transmission and combustion" (Fernandez et al., 2005, p. 28).

To measure the impact on climate change, the global warming potential of the different GHG emissions (the 6 Kyoto protocol gasses: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6)) can be described. CO2 has a global warming potential (GWP) of 1. The emissions that are less present in terms of volume but with a more powerful global warming potential are CH4 (GWP 23) and N20 (GWP 296), considering a lifetime of 100 years according to carbon accounting methods of the IPPC (IPPC, 2001). In this manner, GHG emissions can be translated in to CO2 equivalents (CO2 eq.)[3].

It is important to understand that climate change and global warming are a worldwide problem; although emissions find their origin locally, particles are equally dispersed over the earth's atmosphere, resulting in worldwide effects. The effects of climate change and the increased greenhouse effect are difficult to estimate although, through the increased use of climate models, climate scientists are increasingly better able to estimate the regional effects. Amongst others, precipitation patterns are changing, droughts will occur more often and sea levels are rising. These effects, often climate forcings in itself, result in radical changes in ecosystems around the world that most likely result in significant impacts on local communities. As the last assessment report of IPPC (2007) puts it: anthropogenic warming could lead to impacts that are abrupt or irreversible, depending upon rate and magnitude of the change. The interconnectedness of the system and high potential impact over the coming century asks for immediate action to reduce GHG emissions. Different scenarios have been created by the IPPC to indicate possible temperature rises and the necessary stabilization rate of carbon in the atmosphere (in ppm[4]).

As a result of the highly dispersed effects and causes of climate change, and high levels of uncertainty and unknown feedbacks, mitigating climate change has become a tremendously complex policy field. From a policy perspective, there are different strategies to deal with climate change: mitigation of the harmful impacts of climate change through a net reduction of human induced GHGs (climate change mitigation), and adapting to the effects of climate change by taking measures to deal with increased levels of precipitation for example (climate change adaptation). Climate change adaptation is not a topic discussed in this study.

In order to stabilize carbon emissions and achieve of equilibrium concentrations, agreement has to be sought by many different countries regarding amongst others the height of stabilization levels and the necessary policy measures should be taken. The most important policy tool utilized by the United Nations is the Kyoto Protocol (UN, 1997), which poses binding agreements as regards reduction of GHG emissions. The UN is in the middle of renewing the protocol but unfortunately

[1] Aside from climate change attributable to anthropogenic (or human) influences, many different naturally occurring climate forcings also result in variability of the climate. Examples thereof are plate tectonics, volcanic eruptions, variations in the earth's orbit and naturally occurring climate oscillations (e.g. El Nino) (Middelkoop, 2011). Furthermore, a complex system of feedback loops is at work which causes high interrelatedness of the different forcings.

[2] IPCC distinguishes the following GHGs: CO2, CH4, water vapour, N20, HFCs, PFCs and SF6 (IPPC, of which the last three gasses are not naturally occurring and are solely human induced (EPA, 2002).

3 In the remainder of this research, the terms GHG emissions and CO2 eq. Emissions are used interchangeably.

4 Particles per million

some of the most important emitters (USA, China and Canada) do not intend to ratify the protocol. The Netherlands ratified the current Kyoto Protocol for the period of 2008-2012 to reduce emissions by 6% as compared to 1990 levels. To put this ambition into context, the IPPC (2007) estimates that in order to remain within a border of 2-degree temperature rise, worldwide emission reductions of 50-85% in 2050 are required, compared to 1990.
Although modestly, the Dutch water sector also contributes to emitting GHGs. Frijns et al (2008) estimated this contribution at 0.8% of the total Dutch emissions, with the majority of emissions attributed to heavy industries like energy and cement.

## 1.2. GHG emissions in the watersector

The emissions in the watersector occur through the processes and tasks necessary to manage the water system, mainly to produce drinking water and to process waste water. Next to indirect emissions from the required energy, multiple sources of direct GHG emissions (CH4, N20, business travel, gas use) can be identified. Emissions of the GHGs CH4 and N2O occur mainly in waste water treatment plants (WWTPs) (Kampschreur et al., 2010). Lastly, indirect emissions occur from amongst others the procurement of life cycle emissions of chemicals and employee commuting.
Widely used, the GHG protocol aids in identifying the emissions and order them in three scopes: direct emissions (scope 1), indirect emissions from procured energy (scope 2) and other indirect GHG emissions (scope 3) (GHG protocol, 2004).

### 1.2.1. Zooming in: GHG emissions of Waternet

To categorize the sources of emissions at Waternet, it is important to understand Waternet as organization, with the main tasks its executes. Formally, Waternet Waternet is the operational and administrative body, ensuring different tasks assigned by the city of Amsterdam and Waterboard Amstel, Gooi en Vecht (hereafter: AGV) (see Table 1).

Table 1: Overview of divisions, processes and tasks, and the assigning authorities in the watercycle of Waternet

| Divisions | Processes and tasks | Assigning Authority |
|---|---|---|
| Drinking water (DW) | DW-production | Municipality |
| | DW-distribution | Municipality |
| Waste water (WW) | WW-collection & distribution (sewering) | Municipality |
| | WW-purification/treatment | AGV |
| Water system (WS) | Managing surface water (including canals) levels and water quality | AGV, Municipality |
| | Managing ground water levels and water quality | Municipality, AGV |
| | Operation bridges/sluices | AGV |

Instantiated in 2006, Waternet is considered the first watercycle[5] company in the Netherlands. Different laws, such as the sewerage law, the water act and the drinking water law, legally determine these tasks (personal communication Kapteyn, 2011).

[5] In this context, the terminology of watercycle is used to indicate the integrated management of the municipal and waterboard watertasks (coined by Waternet), as opposed to the scientific interpretation of the watercycle as hydrological process describing the transport of water on, below and above the earth's surface.


Figure 1: Visualization of the relationship between Waternet and its assigning authorities (de Haan, 2008)

Waternet's legal status is a foundation, a private law entity, but as its two main assigners are public organizations, it is a public authority foundation (personal communication Kapteyn, 2011). Waternet's executive director, ir. Roelof Kruize, is provided full mandate, as well as the mandate to transfer partial mandate to the rest of the organization. Both authorities, and not Waternet, remain fully responsible for the sound execution of the tasks. Waternet employs around 1700 people, and is not only involved with the planning, policy and design for the diverse pallet of water tasks, but explicitly chooses to insource the executive tasks as well (Waternet, 2005). From Waternet's key tasks and processes, the most important sources of emissions can be identified and categorized in the three scopes taxonomy proposed by GHG protocol (2004) (Table 2).

Table 2: Overview of the different sources of emissions classified in three scopes classification (GHG protocol, 2004)

| Scope | Emission Source | Description | Sources recognized by Waternet |
|---|---|---|---|
| 1 | Direct GHG emissions | "Direct emissions coming from sources owned or controlled by the organization" (GHG protocol, 2004, p. 27) | Use of gas in own installation, business travel, process emissions ($CO_2$, $CH_4$, $N_2O$) |
| 2 | Indirect GHG emissions: Procured energy | "Emissions from the generation of purchased electricity, steam, or district heating/cooling that is consumer in their owned or controlled equipment or operations" (GHG protocol, 2004, p.29) | Total purchased electricity |
| 3 | Other indirect GHG emissions | Indirect emissions, as identified by Waternet. | Employee commuter travel, purchased materials and chemicals (e.g. $FeSO_4$, $FeCl_3$) |

In line with the reality of climate change, there is a need to mitigate GHG emissions.[6]

[6] Except from the contribution to mitigating climate change, many other reasons could be mentioned why the reduction of GHG emissions is of importance to the watersector. For example, the need to become less dependent on fossil fuels due to other environmental impacts related to the use of fossil fuels such as air pollution and acid precipitation (Dincer, 2000).

## 1.3. Mitigating GHG emissions in the Amsterdam water sector

Widely acknowledged, the water sector can reduce its own emissions by increasing the resource- and energy efficiency of its processes, or by developing renewable energy to green its electricity supply. But above all, thermal and chemical energy can be gained from the many processes in the watercycle management (Frijns et al., 2008; Mol et al., 2010; van der Hoek, 2012; Blom et al., 2010; etc.). For example, Mol et al. (2010) and van der Hoek (2010), point towards a mitigation potential of thermal energy recovery from the watercycle sources drinking water, surface water and waste water in Amsterdam of almost 150 kton/yr. In this light of innovative GHG mitigation possibilities, Waternet has recognized its own role in contributing to climate change mitigation and explicitly seeks innovations within its watercycle management tasks to become climate neutral in 2020 (amongst others van der Hoek, 2010; 2012).

### 1.3.1. Zooming in: climate neutrality for Waternet

The definition used by Waternet to establish a target for climate neutrality is that of zero net GHG emissions in 2020 (Van der Hoek, 2010). Waternet aims at reducing the emissions that stem forth from the operational processes and activities, as defined under scope 1, 2 and 3. This ambition can be achieved through effectuating (a combination of) essentially two options. First of all, by reducing one's own scope 1, 2, and 3 emissions through for example reductions in emissions and/or substitution materials by less carbon intensive materials. Secondly, by compensating for one's own emissions through the realization of emission reduction (personal communication Cozijnse, 2012; Thompson, 2012; Genee, 2012). A clear distinction between the two types of mitigation measures is that in the first type, Waternet's own emissions are actually reduced (from now on: reduction measures) whereas the latter type only compensates for Waternet's own emissions without actual reduction effects for Waternet's emissions (from here on: compensation measures). The difference is sketched by the illustration below (Figure 2).

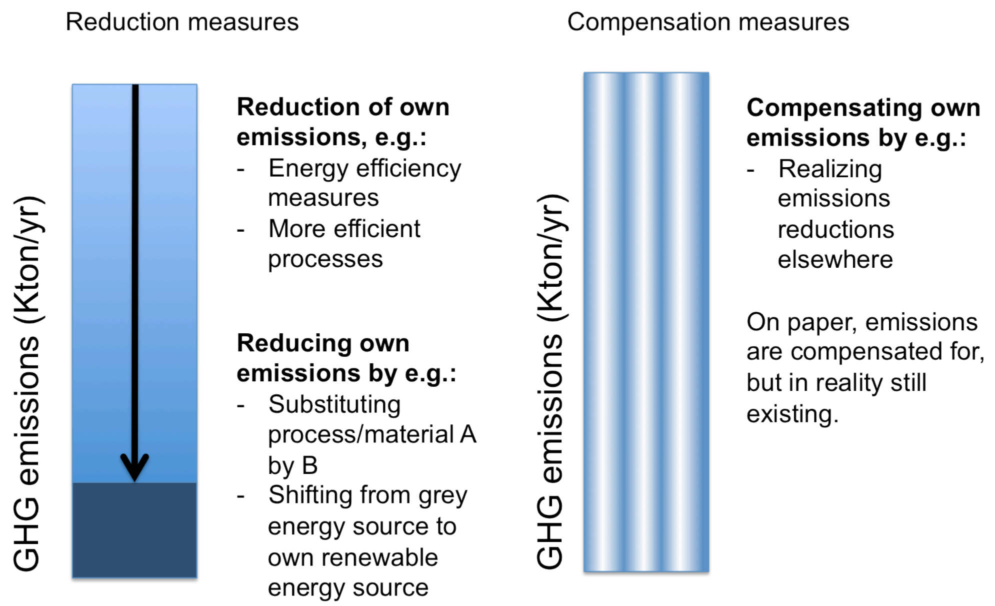


Figure 2: Difference between reduction and compensation measures

Although no formal guidelines exist in how to achieve a goal as climate neutrality (personal communication Cozijnse, 2012; Thompson, 2012; Genee 2012), this research is inspired by the Trias Energetica[7] principle to indicate the order of the mitigation options. It is assumed that Waternet first reduces its own emissions as much as possible (linked to "permanent increase in energy efficiency" and "augmented use of renewables to substitute grey electricity emissions"),

[7] The principle of Trias Energetica, then known as Trias Energica, was first coined by Lysen (1996) to propose an integral energy strategy: the first step being: "permanent increase in energy efficiency", secondly "augmented use of renewables" and thirdly "cleaner use of remaining fossil fuels" (p. 1).

only after which the remaining emissions will be compensated for ("cleaner use of remaining fossil fuels" is translated into achieving emissions reductions elsewhere by compensation).

## 1.4. Research goals and research question

Three knowledge gaps for Waternet have been distinguished.

The first knowledge gap that has been identified is that Waternet has no clear overview of possible mitigation measures

- **Subgoal 1:** Identify mitigation options (reduction and compensation measures).

The second knowledge gap is that, next to the fact that Waternet has limited knowledge regarding the potential mitigation options, it lacks the methodology to value and compare the mitigation options in order to select the best options for the mitigation policy plan.

- **Subgoal 2:** Develop and employ a methodology to value and compare mitigation options to select mitigation options to substantiate Waternet's mitigation policy plan.

The final identified knowledge gap concerns Waternet's lack of understanding of the impact of the mitigation measures on the attainment of the climate neutral goal and the required financial means.

- **Subgoal 3:** Provide an overview of the impact of the mitigation measures on the mitigation goal and of the required financial means.

Synthesizing the above stated knowledge gaps and subgoals, it becomes clear that Waternet has an ambition to contribute to mitigate climate change but lacks a coherent mitigation policy plan to achieve climate neutrality.

- **Research goal:** This research will result in a constructive exploration of the mitigation options Waternet can take to substantiate its mitigation policy in order to achieve climate neutrality in 2020.

To set up a research that will provide Waternet with the required information to design a effective mitigation policy plan, that will ensure the set goals will be met the following research question is posed:

*Which mitigation options does Waternet have to mitigate GHG emissions, and will implementation of these measures suffice to realize its ambition regarding climate neutrality?*

By answering this research question, this research shows multiple folded relevancy, addressing the challenge of Waternet to achieve climate neutrality, while at the same time contributing to different knowledge gaps in academic literature.

## 1.5. Relevance research

By design, this research is an academic case study for Waternet, in which case specific as well as academic information is combined to provide the most up-to-date knowledge in the field. The author hereby combines available knowledge within Waternet with potential studies from academic literature, resulting in in-depth knowledge on the mitigation options available for water utilities and for Waternet in particular. Many of these mitigation options are not or hardly described in academic literature.

A second element in this research is the development a methodology to substantiate the climate neutral ambition by mitigation measures. The evaluation of mitigation options is facilitated by de inclusion of a Multi-Criteria Framework (MCF). From the discipline of energy studies, an tool Marginal Abatement Cost Curves (MAC curves) is derived to visually support the decision making process. The results gathered in this research are directly translatable to the decision making process, hence displaying high practical relevancy.

Next to the direct relevance for Waternet, this research addresses several knowledge gaps in academic literature. It is important to understand the role of cities. The need for low carbon service delivery especially in urban areas is high. As urban expansion will continue, 1 in 10 people on earth will live in cities in 2025 and 80% of GHG emissions is stemming from cities and their residents (Spiegelhalter & Arch, 2010). Hence it is essential to embed carbon neutral concepts in cities' metabolism[8]. Fossil resources depletion, scarcity and conflicts lead to insecurity about the availability of energy in the future (Dincer, 2000), as well as price volatility of fossil fuels (Duffle et al., 2004). Will organizations such as Waternet be able to deliver the services at acceptable societal costs? Continuous innovation in planning and organization of services is required, by consciously embedding resource-, energy, and carbon efficiency concepts in all processes, infrastructure and tasks.

One can discern the governance implications of these tasks and challenges. To achieve continuous innovation, organizations such as Waternet necessitate sound strategies and policies. Many organizations have set, or will set, similar ambitions to contribute to the transition to a low carbon society. Furthermore, clear governmental and/or academic guidelines and directions are required to support organizations in this quest. A clear knowledge gap is formed by the fact that no such guidelines exist. At the moment, only private carbon auditors provide guidelines to mitigation planning, which are difficultly deemed objective. By studying Waternet as a case, the propositions made for ranking mitigation options to achieve a goal as climate neutrality could be generalized to apply to other water utilities and organizations. This research could contribute to a new field in academic literature on voluntary GHG mitigation policies for mainly public (utility) organizations in the Netherlands and abroad. By developing adequate tools to support the exploration and ranking of mitigation options, more organizations will be able to effectuate actual GHGs emissions savings.

For the watersector specifically, the introduction of the methodology of Marginal Abatement Cost Curves (MAC curves), conventionally used in top-down policy studies to analyze and visually represent the mitigation potential of a sector or a country, assures a novelty[9]. Its applicability to the water sector is hypothesized as highly relevant, since Stuker (personal communication, 2011) indicates that an organization such as Waternet is particularly searching for such a tool to support the strategic decision making process.

From the above-described relevancies, distinct links with the research undertaken by the Copernicus Institute of Sustainable Development, the research group linked to the Faculty of Geosciences, become visible. By addressing relevant governance challenges faced by public organizations aiming to contribute to climate change mitigation, this research makes a link with the "environmental governance for sustainability" group. By researching mitigation options from the watersector and utilizing MAC curves this research also links to the "energy and resources" group.

## 1.6. Reading guide

The research is presented in five chapters and an extensive appendix. The next chapter (chapter 2) describes the methods used to identify and evaluate the mitigation measures. Chapter 3 describes the mitigation measures and the results of each mitigation option on the multi-criteria framework and marginal abatement cost curve. Additionally, the impact of the mitigation measures on the goal of climate neutrality is determined and the required financial means are presented.
In the discussion (chapter 4), the results of the study are interpreted in the light of the background and the study's strengths and weaknesses are indicated, aside from presenting suggestions for further research. The research will close by a conclusion and recommendations for Waternet (chapter 5). In the appendix one finds references, consulted experts as well as relevant background information and methods. In the main text, references are made to the appropriate appendices.

[8] Urban metabolism is a term first coined by Wolman (1965) in 'The metabolism of cities', Scientific American, 213(3), 179-190.
[9] The author will give an oral presentation on the applicability of the MAC-curves methodology for the watersector at the International Water Association world congress on Water Climate and Energy, held in Dublin, May 2012.

# 2. Methods

## 2.1. Research framework

The underlying methodological foundations of this research originate from Hoogerwerf's theory of policy construction (Hoogerwerf, 1992), also referred to as policy engineering or evidence based policy making (EBPM) (Geul, 2005). EBPM is often applied to complex societal issues on a national scale. This theory is a highly rational approach to policy making, focusing on (scientific) evidence of 'what works' in order to achieve a certain policy goal. The central driving force of EBPM is focus on effectiveness and efficiency (Trinder, 2000, p. 19 through Matston & Warts, 2003).

By systematically (metaphorically speaking: like an engineer) listing the organization's wishes, understanding the background of the problem, inventorying the possible means to come to a final goal and researching the trajectory of implementation and costs (Geul, 2005, p. 92), EBPM results in a coherent policy plan. Important backbones of the policy plan are the already discussed policy problem of climate change, the policy cause of GHG emissions and hence the policy goal as set by Waternet to become climate neutral.

Inspired by the EBPM theory and Geul (2005), the following steps will be undertaken to provide Waternet with relevant research to coherent policy plan on achieving climate neutrality.

**Step 1:** The first step in this research is to quantify the policy goal of climate neutrality by constructing an emissions baseline for Waternet, to be able to rationally reduce the emissions by introducing the mitigation options.

**Step 2:** The next step is inventorying the possible mitigation measures that Waternet can take to address the policy problem.

**Step 3:** In the third step, the mitigation options will be compared and valued by means of a multi-criteria framework and a visually supporting method to highlight the cost-effectiveness of GHG mitigation: marginal abatement costs curves (MAC-curves).

**Step 4:** Finally, the measures will be selected on the basis of the MCA and the MAC curve to achieve the policy goal. Furthermore, the impact of the mitigation measures on the emissions baseline and the financial means required will be discussed. For Waternet, this forms the basis of constructing their policy plan.

## 2.2. Policy goal and baseline

The baseline of Waternet, in which a projection has been made for the GHG emissions in 2020, is depicted in figure 4. This shows that the climate neutrality goal of Waternet will require an approximately 97.2 kton/yr GHG emission reduction by 2020. Currently, Waternet claims to have already achieved over fifty percent of its climate neutral goal, suggesting a sound progress (van der Hoek, 2012). It should however be noted that this fifty percent reduction of its emissions is a result of a compensation measure that does not physically reduce Waternet's own emissions: currently Waternet procures hundred percent green electricity, hereby compensating for the scope 2 emissions from electricity procurement. For multiple reasons, it is decided to leave this out of the established baseline. Most importantly, it gives a distorted picture of the possibilities to reduce GHG emissions: any energy efficiency measure seems to have no impact, because all emissions from scope 2 seem to have disappeared already.

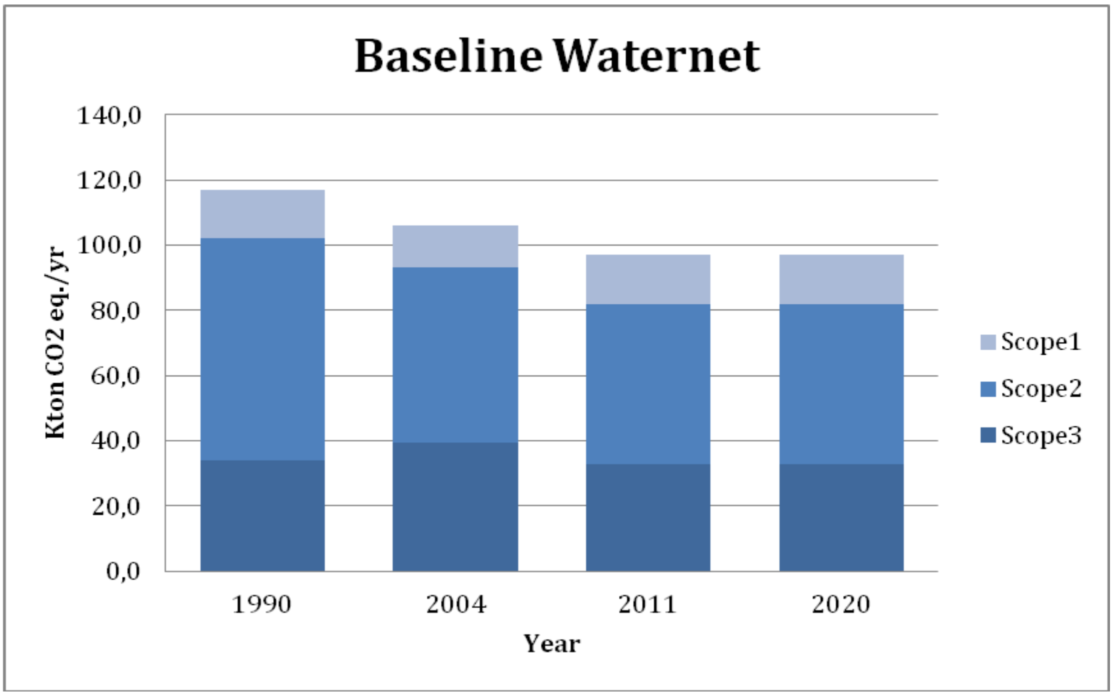


Figure 3: Baseline scenario $CO_2$ eq./yr emissions of Waternet

The baseline was established by collecting data from spread sheets provided by, and personal communication, with Janse (2012) for the base year 1990 and the years 2004 and 2011. The three scopes classification is used to systematically organize the data. A frozen technology baseline is constructed, not taking into account potential reductions in emissions as a result of technological improvement. It is assumed that no volume changes occur[10] and hence, the emissions of 2011 are ought to be similar in 2020 if no policy measures are taken.

## 2.3. Researching mitigation measures

### 2.3.1. Identifying mitigation measures

Following Waternet's wish, the mitigation options should either act upon the main tasks in the watercycle, or should utilize the potential of the watercycle sources (waste water, drinking water and surface water) for the gain of thermal and chemical energy. Besides mitigation potential within the watercycle management tasks, Waternet acknowledges the watercycle mitigation potential inside households and buildings ('behind the meter') also as source for GHG mitigation measures (personal communication, Stuker; Mol, 2012). To conclude Waternet's wish for the identification of mitigation measures, renewable energy that can be realized on Waternet's facilities is also preliminarily included.

The mitigation potential (avoided CO2 eq. emissions/year) of each mitigation measure investigated in this research provides a realistic picture for Waternet: the deployment potential is depicted, in contrast to a technical potential[11].

In order to get a complete overview of the mitigation possibilities in and from the water cycle, as main source a policy report issued by the Dutch Watercycle Research Institute STOWA commissioned by the Dutch (former) ministry of VROM on the climate neutral watercycle was taken (Frijns et al., 2010). Additional measures were identified by means of expert interviews at Waternet. The long list of mitigation options with referral to criteria based upon which the measures were rejected can be found in appendix 9.1. In order to increase the feasibility of the research, an initial screening of the mitigation options took place to reduce the long list to a short list of options. For this selection, the following preliminary screening criteria were employed (Table 3).

[10] An extensive literature review on trends in the water sector could not reveal volume changes.

[11] The difference between the technical potential and the deployment potential is that in the technical potential, only the projected demand a certain technology can meet is depicted and forms hereby an overestimation of the application of the technology to the market (Harmsen, 2011). The deployment potential takes stock turn over and market growth of new technologies into account.

Table 3: selection criteria for short list of mitigation measures.

| Criteria | | Reasoning behind criteria |
|---|---|---|
| 1 | Mitigation options should be physical (technological, infrastructural) measures | Predefined by Waternet in research assignment. |
| 2 | Mitigation options should be realizable on the short term (until 2020) | Otherwise, the mitigation options cannot contribute to the 2020 and 2025 targets. |
| 3 | Mitigation options should not yet exist in Waternet's facilities/portfolio. | If already existing, the mitigation potential is already fulfilled. |
| 4 | Sufficient data should be available to research the mitigation options. | Data availability threatens the feasibility of the research. |

### 2.3.2. Evaluating mitigation options: MCA analysis and MAC curve

In order to compare and valuate the impact of the different mitigation options a Multi-Criteria Framework is devised to perform a Multi-Criteria Analysis (MCA). Additionally, in order to support the selection process of mitigation measures, the method of marginal abatement cost curves (MAC-curves) has been employed in order to provide for a clear, visual overview the cost-effectiveness and the mitigation potential of each mitigation option. This method will be discussed in 3.4.2.

Multi-criteria frameworks are widely used in decision-making processes and policy drafting (Geul, 2005). It aids by optimizing the choice between different policy instruments, or in this case, mitigation measures. Table 4 below shows the assessment criteria used in the MCA which are derived from semi-structured interviews and research into policy documents of Waternet (Waternet, 2011) regarding its climate policies and organizational core values.

Table 4: assessment criteria used in the multi-criteria framework

| Assessment criteria | | | | |
|---|---|---|---|---|
| **Number** | **Criterion** | **Category** | **Indicator** | **Rating** |
| 1 | Contribution to mitigation goal | Environmental | GHG reduction potential (ton CO2 eq./year) | High: GHG mitigation > 10 kton/yr; Medium: GHG mitigation 1-10 kton/yr; Low: GHG mitigation <1 kton/yr. |
| 2 | Cost-effectiveness | Economic | Pay back period, mitigation costs (€/ton CO2 eq. mitigated) | High: PBP<5 years & negative specific costs; Medium: PBP 5-10 years & negative specific costs; Low: PBP>20years & positive specific costs. |
| 3 | Service delivery | Service | Qualitative estimation of increase in service delivery and unburdening of measure | Rated low, medium or high |
| 4 | Autonomy and influence Waternet | Influence | Qualitative estimation based on power and interest of each stakeholder | Rated low, medium or high |

Now follows a discussion of the methods used to score each of the mitigation measures on each criterion. The specific assumptions made for each mitigation measure to be scored on the criteria, factsheet are constructed to which will be referred in text.

**Criterion 1: Contribution to mitigation goal**
Criterion 1 is assessed by the mitigation potential of each option in terms of avoided GHG emissions in CO2 eq./year. In order to investigate this criterion, interviews and an extensive literature study are performed. When required, appropriate sources for emission factors will be indicated.

**Criterion 2: Cost-effectiveness**
Criterion 2 encompasses multiple financial aspects. For Waternet, mainly the pay back period of a mitigation measure as well as the cost-effectiveness of GHG abatement are important indicators to measure this criterion (personal communication Struker, 2012). To account for sensitivity of the results on this criterion, two cost-levels were constructed. In this way, energy price increases and price decreases of investments for mitigation measures are taken into consideration – if applicable.

To calculate the simple pay back period, the following formula is employed (Blok, 2008):

$$Simple\, pay\, back\, period = \frac{I}{B - C}$$

Where:

- I = total investment costs (€)[12]
- B = total benefits (€/yr)
- C = total costs (€/yr)

To calculate the specific abatement costs (in € per ton CO2 eq. abated), the following formula is utilized (Blok, 2008):

$$c_{specCO2} = \frac{\alpha \cdot \Delta I + \Delta C - \Delta B}{\Delta M_{CO2}}$$

Where:

- Cspec, CO2 = Specific CO2 mitigation costs (€/ton CO2)
- α * I = annualized capital costs (€)
- B = annual benefits (€/yr)
- ΔMCO2 = annual amount of avoided CO2 emissions (ton CO2 eq.)

Where α is calculated as follows (Blok, 2008):

$$\alpha = \frac{r}{1 - (1 + r)^{-L})}$$

Where:

- α = capital recovery factor
- r = discount rate
- L = Lifetime

**MAC-curves**

To support the selection process of mitigation measures, the methodology of Marginal Abatement cost-Curves (MAC-curves) is employed. MAC-curves are clear, easy to understand graphs displaying which (technological) measures reduce carbon emissions in the most cost-efficient way (Kesicki, 2011). This allows decision makers to see in one glance what the yearly costs are to abate a set amount of CO2 emissions. To construct a MAC curve, the specific costs of GHG abatement (€/ton CO2, as calculated according to formula in the method for criterion 2) is displayed with the cumulative CO2 savings (in ton or kton CO2) of all researched options.

[12] Total investment costs excluding costs for installing, execution, design, public tender etc.

**Criterion 3: Service delivery**
Waternet highly values service delivery, which is defined two-folded. Firstly, Waternet aims to deliver a reliable[13] execution of its (municipal) water tasks (Waternet, 2012). Secondly, Waternet finds it important to deliver (new) services that unburden[14] Waternet's clients. Throughout this research it is assumed that all mitigation options will results in reliable service delivery and hence never undermine a reliable execution of the water tasks. For this reason, only the second aim of service unburdening will be measures. Hereto, an answer will be provided to the following questions: is the (new) service contributing to customer unburdening? Through expert interviews, literature review and educated guesses, the mitigation measures will be scored low, medium or high on this criterion.

**Criterion 4: Autonomy and influence on realization**
The extent to which Waternet is able to exercise control over the realization of the mitigation options is highly valued by Waternet (personal communication Jacobs; Kruize, 2011). To investigate autonomy and influence of Waternet to realize the mitigation options the number of involved stakeholders and the role they play is of utmost important, as stakeholders, involved in or affected by the project form "an important factor in determining its success or failure" (Brugha & Varvasovszky 2000, p. 243). Therefore, the method of stakeholder analysis (Bryson, 2004) is employed to understand the involved stakeholders and their role. The level of power and influence stakeholders maintain determines the role they play: 'subjects', 'crowd', 'players' or 'context setters'. This in turn determines the level of autonomy and influence of Waternet in realizing the mitigation options can be determined.

The level of power a certain stakeholder can exert is qualitatively determined by understanding the specific means (such as financial and legal means including ownership), and influence (mainly political) a stakeholder possesses, and the ability to mobilize (or deliberately not mobilize) these resources. The level of power is indexed by low, medium, and high power. The interest of a stakeholder is in this case defined as the value and importance a certain stakeholder attaches to the realization of the mitigation measure (defined in terms low, medium and/or high). To investigate the interest of a stakeholder, a qualitative appraisal is performed by estimating the value and importance of a stakeholder for the mitigation measure realization based on educated guess of the author. From the analysis of power and interest, the role of stakeholder is identified by positioning them on the grid as shown below in Figure 4 (next page).

[13] Defined as: "consistently good in quality or performance" (Oxford Reference Online, 2012).
[14] Defined as: "bring or provide aid or assistance to" (Oxford Reference Online, 2012).

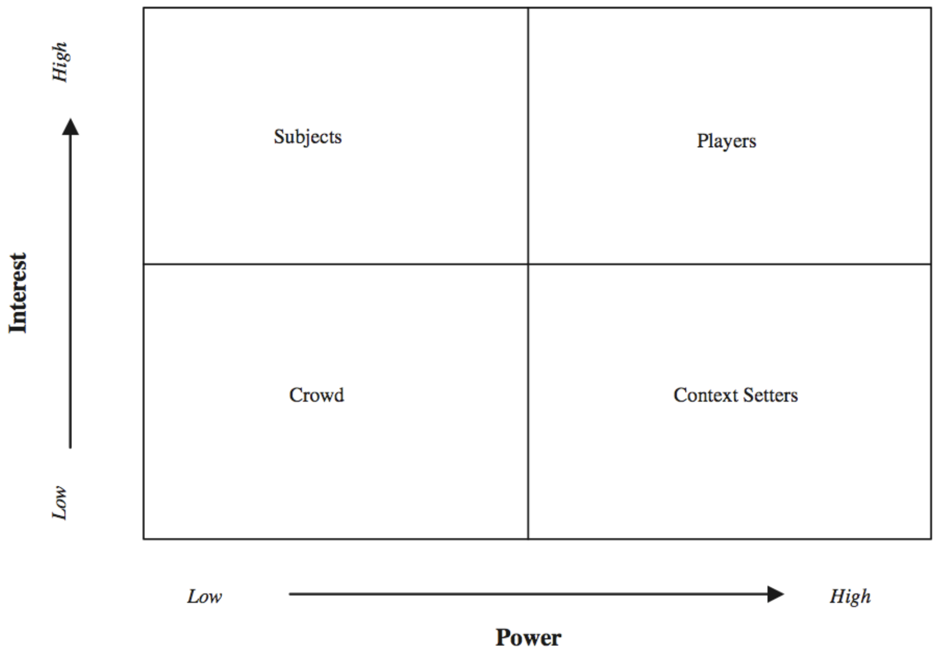


Figure 4: Role of stakeholder in terms of power versus interest (Bryson 2004, p.30)

Waternet has high autonomy and influence when stakeholders are involved that are identified as 'subjects' (high interest, low power) or 'crowd' (low interest, low power). On the other hand, Waternet's autonomy and influence on the realization of mitigation measures decreases when 'players' (high interest, high power) and context setters (low interest, high power) are involved. These become strong opponents or proponents of Waternet's plans. This group of stakeholders, together with the context setters requires hence the most proactive strategy of Waternet to ensure it has high autonomy and influence.

# 3. Mitigation measures

Several mitigation options are identified that enact upon the policy cause of GHG mitigation. To illustrate how the mitigation measures relate to the addressing the policy cause and eventually contribute to achieving the policy goal, a final model is constructed (see Figure 5).

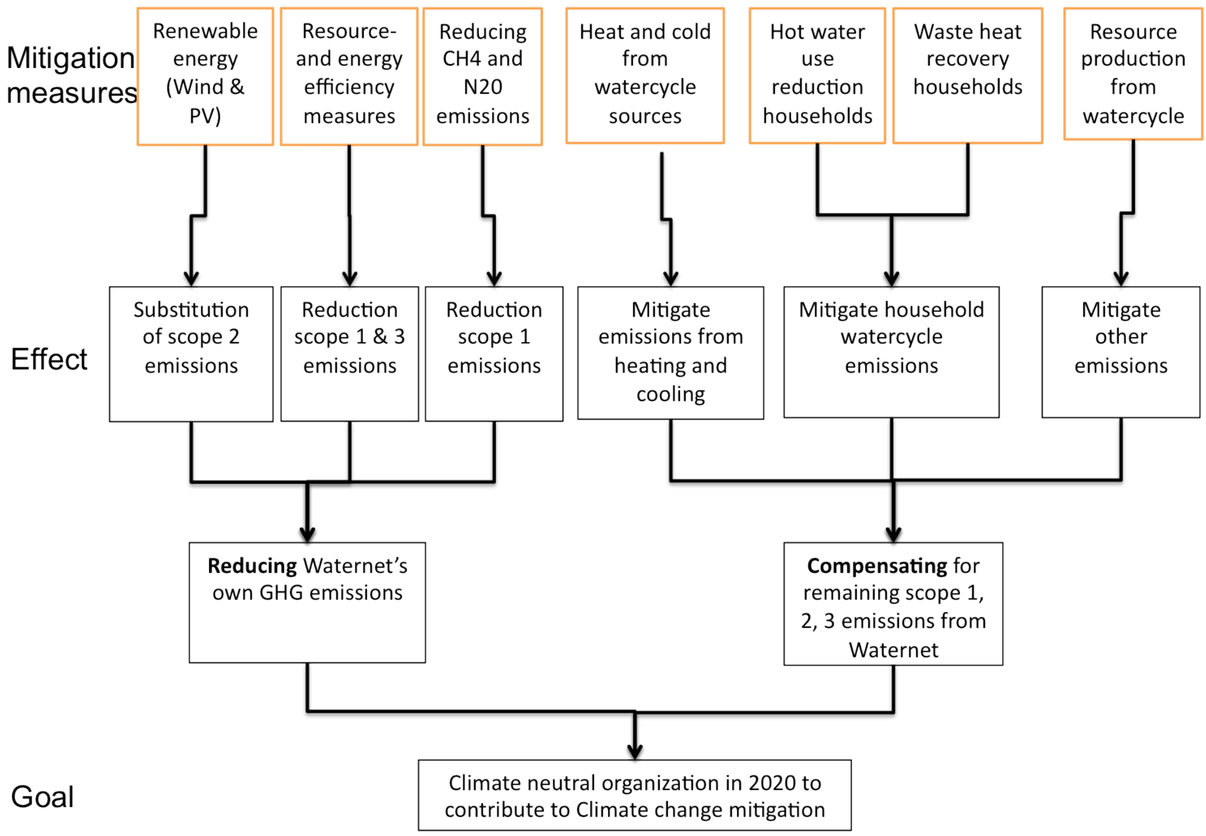


Figure 5: Model displaying the mitigation measures and their relation to the policy goal

The next sections will introduce the reader further in to the reduction and compensation measures and provide the score on each of the criteria. Additional performed research, background information, and the assumptions taken for each measure can be found in the factsheets to which will be referred.

## 3.1. Reduction measures

The reduction measures that were selected from the long list can be found in Table 5 below:

Table 5: Overview of identified reduction measures

| Mitigation measure | Effect of mitigation measure |
|---|---|
| **Reducing Waternet's own emissions** | |
| Cluster of resource- and energy efficiency measures at Waternet's waste water facilities (REEM cluster) | Reduction of Waternet's scope 1 and 3 emissions |
| Reducing CH4 and N2O emissions at Waternet's waste water facilities | Reduction of Waternet's scope 1 emissions |
| Renewable energy production (PV) | Substituting Waternet's scope 2 emissions |
| Renewable energy production (wind energy) | Substituting Waternet's scope 2 emissions |

### 3.1.1. Cluster of resource- and energy efficiency measures at waste water facilities (REEM cluster)

In the wastewater facilities of Waternet, Waternet intends to take a range of measures to reduce scope 1, 2 and 3 emissions (personal communication Piekema, 2012). Researching the individual measures was not deemed feasible in this research, and therefore all measures that can be taken up to 2020 are clustered: *cluster of resource- and energy efficiency measures at waste water facilities (REEM cluster)*. The individual measures are diverse; on the different waste water facilities measures are implemented which reduce energy use, or enable the utilization of waste streams of heat and resources to gain secondary benefits. These measures are highly specialized, but to name a few: increased regulation of retuning slib flow[15], utilizing heat buffering capacity of sludge destruction tank, and replacement of ceramic bubble aeration to membrane bubble aeration.

> **Appendix B.3 factsheet on the REEM cluster:**
>
> An expert estimation by Piekema (2012) has resulted in an overview of the intended effects of this cluster of measures that can be found in appendix B.3.1. For the assumptions and calculations on the financial data, see appendix B.3.2.

- **Contribution to mitigation goal: MEDIUM.** In terms of avoided GHG ($CO_2$ eq.) emissions, this cluster of measures results in a 3.7 kton/year reduction.
- **Cost-effectiveness: HIGH.** The REEM cluster appears highly cost-effective with a pay back period of 0-5 years and with specific mitigation costs of -124 €/ton $CO_2$. No distinction has been made between price levels of 2011 or 2020, as no estimation could be made on changes in prices of procurement of chemicals and steam.
- **Service delivery: LOW.** This cluster of measures ensures higher efficiency of Waternet's core processes in the waste water division. Here with it is assumed to provide a reliable service to Waternet's clients, but no (new) services are delivered that specifically unburdens its clients. Consequently, service delivery is rated low for the REEM cluster.
- **Influence and autonomy Waternet: HIGH.** Waternet has high influence and autonomy on the realization of the package of measures, due to the fact that it has full ownership over its own facilities. No other stakeholders are identified.

### 3.1.2. Reducing CH4 and N2O emissions at Waternet's waste water facilities

Through taking measures at Waternet's waste water facilities, it is possible to reduce the direct emissions stemming from the waste water treatment process, notably $CH_4$ (methane) and N20 (nitrous oxide) (personal communication Piekema, 2012).

> **Appendix B.4: a factsheet on reducing CH4 and N20 emissions:**
>
> The assumptions used to calculate the impact on the mitigation goal, see appendix B.4.1. For all financial data and calculations, see appendix B.4.2.

- **Contribution to mitigation goal: MEDIUM.** Reducing direct emissions from waste water facilities results in a medium contribution to the mitigation goal of 4.8 kton/year
- **Cost-effectiveness: LOW.** The measures necessary to reduce $CH_4$ an N20 direct emissions are low in cost-effectiveness, with a long pay back period (>20 years) and specific costs of 8 €/ton $CO_2$.

[15] in Dutch: "retourslib debiet regelen", implemented on Waternet's facilities West-2 and Westpoort-1.

- **Service delivery: LOW.** As this measures does not offer a (new) service to Waternet's clients and consequently not unburdens Waternet's clients, service delivery is rated low.

- **Influence and autonomy Waternet: HIGH.** Waternet has high influence and autonomy on the realization of the package of measures, due to the fact that it has full ownership over its own facilities. No other stakeholders are identified.

### 3.1.3. Renewable energy production: PV

Waternet intends to provide some of its facilities' roofs with solar panels, consisting of photovoltaic (PV) cells (personal communication van der Meer, 2011). It plans to install 6,000kWp between 2011 and 2020, producing 6,000,000 kWhe per year. It is assumed in this research that all electricity will be utilized directly by Waternet's facilities. Therefore, the benefits lie in the avoidance of grey electricity procurement. The reference electricity price is the wholesale procurement price Waternet pays for electricity (personal communication Knibbe, 2012).

**Appendix B.5: a factsheet on PV:**

For more specific details on the PV installation, see appendix B.5.1. The assumptions used to calculate the impact on the mitigation goal, see appendix B.5.2. For all financial data and calculations, see appendix B.5.3.

- **Contribution to mitigation goal: MEDIUM.** The projected capacity of solar results in a medium carbon mitigation effect of 3.4 kton/yr.

- **Cost-effectiveness: LOW.** Solar energy is low on cost-effectiveness, showing long payback periods and positive specific costs in 2011 (50 €/ton $CO_2$). In 2020, and most likely before that time, solar energy is expected to become more cost-effective with specific costs of -86 €/ton $CO_2$. With subsidies, PV is cost-effective already.

- **Service delivery: LOW.** As this measures does not offer a (new) service to Waternet's clients and consequently not unburdens Waternet's clients, service delivery is rated low.

- **Influence and autonomy Waternet: HIGH.** Waternet has high influence and autonomy on the realization of the PV, due to the fact that it has full ownership over it's own facilities. No other stakeholders are identified.

### 3.1.4. Renewable energy production: wind energy

An often-encountered difficulty with onshore wind energy production is the availability of suitable land. Waternet has multiple facilities that assumedly allow for the placement of wind turbines (personal communication van der Meer, 2011). Waternet intends to install 10 turbines of 3 MW each, in total resulting into 30 MW installed capacity in 2020.

**Appendix B.6: a factsheet on wind energy:**

For more specific details on the wind energy installation, see appendix B.6.1. The assumptions used to calculate the impact on the mitigation goal, see appendix B.6.2. For all financial data and calculations, see appendix B.6.3.

- **Contribution to mitigation goal: HIGH.** The substantial planned wind capacity (30MW) results in high GHG emissions avoidance of 37 kton/year.

- **Cost-effectiveness: LOW.** Results are comparable to solar energy (45 €/ton $CO_2$), and follow a similar line of explanation for the low cost-effectiveness. With subsidies, wind energy is cost-effective.

- **Service delivery: LOW.** As this measures does not offer a (new) service to Waternet's clients and consequently not unburdens Waternet's clients, service delivery is rated low.

- **Influence and autonomy Waternet: MEDIUM.** Wind energy requires more space and is much more prominent in the natural landscape than for example solar energy. Two important stakeholders come into play: the province and surrounding inhabitants. Placed on the stakeholder grid, both can be regarded as 'players'; having high power and interest. For the province, the power lies in the fact that they have legal power: permitting Waternet to build windmills or not. Their interest is high due to the governance task as described in spatial plans. Windmills are (in)famous examples of the NIMBY (not-in-my-backyard)-effect. People in general highly value renewable energy, such as wind energy, as long as they do not have the face the negative aspects close to their personal lives (Ek, 2005; Wolsink, 2000 through Graham et al., 2009). Therefore, construction proposals for wind mills and wind farm often meet significant resistance and Waternet's influence and autonomy on the realization thereof is deemed 'medium'.

## 3.2. Compensation measures

Compensation measures identified from the long list are found in Table 6 below. It is important to note that the reduction of GHG emissions and the financial benefits of this measure are located at the side of the customer for most of the compensation measures. The point of view utilized in this research is that of Waternet as main investor and receiver of the benefits and GHG emission reduction, through financial constructions and formal contracts.

Table 6: Overview of identified compensation measures[16]

| Mitigation measure | Effect of mitigation measure |
|---|---|
| **Compensating for Waternet's own emissions** | |
| Heat recovery from surface water, drinking water and waste water | Reducing customer's emissions from heating |
| Cold recovery from surface water and drinking water | Reducing customer's emissions from cooling |
| Heat recovery from shower water | Reducing household emissions |
| Reduction of hot water use for showering | Reducing household emissions |
| Resource production from the watercycle: struvite | Reducing customer's emissions from fertilizer use |
| Resource production from the watercycle: biogas | Reducing customer's emissions from energy or travel[17] |

### 3.2.1. Heat and cold recovery from surface water, drinking water and waste water

The watercycle sources of drinking water pipelines, waste water sewers and surface water[18] can provide sustainable heat and cold, as literature and expert guesses suggest (Frijns, 2008; personal communication Mol, 2011; personal communication Scholten, 2012). The heat recovered from these sources is of low quality (18-21° Celsius); the recovered cold is ±5-7° Celsius.

For this research, it is not so much of importance what the theoretical heat and cold supply of these sources is. On the contrary, to investigate the potential CO2 reduction, we need to reason from the demand side to investigate the deployment potential of heat and cold recovery. Therefore a demand study for heat and cold in Amsterdam has been performed. From the results of this study, different potential customers for watercycle heat and cold could be identified.

[16] Full allocation of the achieved emissions reductions elsewhere to Waternet is assumed. In reality this is a delicate issue which will be further elaborated upon in the discussion.
[17] Depending on the purpose of the biogas
[18] Including deep lakes and Amsterdam's canals

- Regeneration of Aquifer Thermal Energy Storage systems (ATES systems): utilizing heat and cold recovered from the watercycle sources for the regeneration of ATES systems. These systems are often in disbalances, requiring additional heat or cold to effectively store sustainable heat and cold in underground aquifer layers to supply sustainable heating and cooling to houses.

- Direct delivery of heat and cold: often in combination with ATES systems, this heat and cold can be used to cool/heat households and utility buildings (data centers, hospital, offices).

**Appendix B.7: a factsheet on heat and cold recovery from the watercycle**

Due to data unavailability and time constraints, only the regeneration of ATES systems as potential customers was researched. To understand more of the functioning of ATES systems and ATES regeneration by means of recovered heat and cold from the watercycle, appendix B.7.1 provides a factsheet. The investigation performed to understand the demand for heat and cold for ATES regeneration can be found in appendix B.7.2. Appendix B.7.3 provides the assumptions made to come to the avoided CO2 emissions. For the financial data used to come to the cost effectiveness of ATES regeneration, see appendix B.7.4.

- **Contribution to mitigation goal: MEDIUM.** Cold recovery with 1.9 kton/year and heat recovery with 3.0 kton/yr are scored medium as to their mitigation potential.

- **Cost-effectiveness: HIGH.** The different watercycle sources show different levels of cost-effectiveness. Heat recovery for ATES regeneration from surface and drinking water score both high on cost-effectiveness. Heat recovery for ATES regeneration from wastewater however is a highly costly measure, for both the 2011 and 2020 cost levels. Cold recovery for ATES regeneration appears to be highly cost-effective for both sources (surface and drinking water). All except heat recovery from waste water show a low pay back period (<5 years). This results to conclude that overall, the cost-effectiveness of this measure is high.

- **Service delivery: LOW.** In this research it is assumed that heat and cold recovery for ATES systems does delivery a new service to Waternet's clients directly. As a consequence of this, it does not unburden Waternet's clients and service delivery is rated low.

- **Influence and autonomy Waternet: LOW.** Over 100 different owners can be identified as separate stakeholders to realize the deployment potential of the watercycle in this respect. As Waternet is the supplying party, its power in realizing the ATES regenerations is much lower than the power of the ATES system owners, who are the customers. Either they can be identified as 'players' or as 'context setters' depending on their interest in sustainability. For these stakeholders, multiple options are available to regenerate their ATES systems; through reducing the use of heat and cold (in which case no is regeneration necessary) or through connecting to non-sustainable regeneration sources such as boilers and cooling machines. Additionally, some of the ATES system owners already regenerate their ATES conventionally, which enlarges the barrier to switch to sustainable regeneration at potentially higher costs). Due to the significant power ascribed to heat and cold customers, Waternet's level of autonomy and influence is regarded low.

### 3.2.2. Heat recovery waste water in households

Much acknowledged is the potential of heat recovery from shower water in households and other buildings (personal communication Sukkar, 2012; Mol, 2011). A drain waste heat recovery system (DWHR system) is a system that recovers heat from shower water by means of a heat exchanger. Shower waste water contains high quality heat. On average, the shower water temperature is 40° Celsius, and the temperature after utilization 35° Celsius. Furthermore, showering is often a daily activity and hence a constant use of the DWHR system is guaranteed throughout the year (Blom et al., 2010). Optimally, the recovered heat is utilized both to directly pre-heat the cold water for the shower as well as the water flowing to the boiler or the central heating system. The heat is used directly in this way and no buffer or storage system needs to be installed.

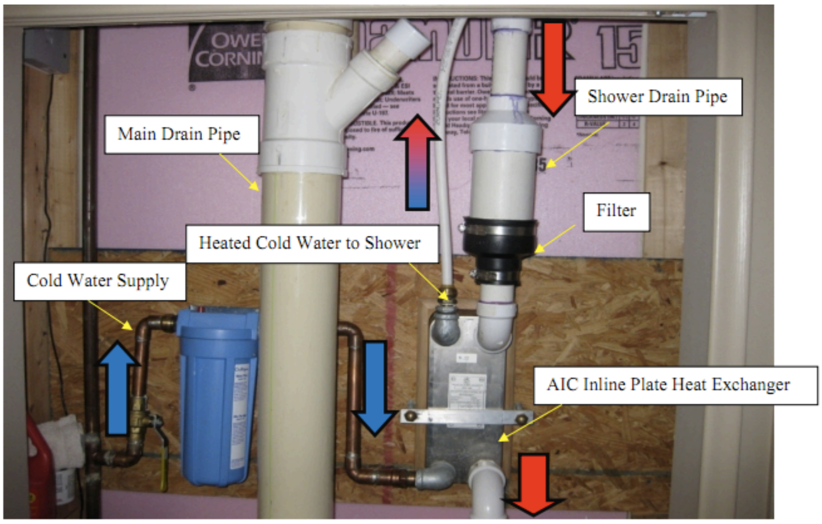


Figure 6: DWHR system (Bartkowiak et al., 2009).

Different types of heat exchangers can be distinguished: horizontal, vertical and forced. Both horizontal and vertical heat exchangers make use of gravitational forces to achieve a flow sufficient enough for optimal functioning of the heat exchanger. The latter option is usually installed in larger showering facilities, such as in sport centers, and requires pump to force the water through a heat exchanger (Blom et al., 2010).

**Appendix B.8: a factsheet Drain Waste Heat Recovery System**

A demand side study has been performed to understand the demand for DWHR systems in Amsterdam until 2020, to recover heat from shower water: see appendix B.8.1. For the calculation of the avoided CO2 eq. emissions, see appendix B.8.2. The financial assumptions can be found in appendix B.8.3.

- **Contribution to mitigation goal: HIGH.** With a deployment potential of 27.8 kton/yr from 2020, this compensation measure can significantly contribute to the mitigation goal.

- **Cost-effectiveness: HIGH.** Drain waste heat recovery system for Amsterdam households appears to be highly cost-effective, with specific costs well below -200€/ton CO2 and a pay back period between 0-5 years.

- **Service delivery: HIGH.** This compensation measure delivers a new service to Waternet's clients. Through the installation of a drain waste heat recovery system, Waternet's clients are able to save energy, avoid CO2 emissions and save costs; without reducing the client's level of comfort (milieucentraal.nl, 2012). Herewith, this innovation clearly unburdens the clients.

- **Influence and autonomy Waternet: LOW.** In the case of the drain waste heat recovery system and the low flow showerhead, similar low levels of autonomy and influence for Waternet could be identified. The interest for Waternet is high (realizing its ambition), but inhabitants might face barriers and hence (deliberately) have low interest. As they hold ownership over their household equipment, they behold high power; if they do not desire a DWHR, Waternet cannot force it upon them.

### 3.2.3. Hot water use reduction in households

Another potential reduction in the household watercycle, is through reducing the amount of hot water used. A low flow shower head (LFSH) is a shower head which reduces the flow of water, without reducing the level of comfort (Milieucentraal.nl, 2012). GHG reductions by LFSHs principally come from the lesser water that has to be heated: a LFSH has a lower flow than a regular or a comfort douche.

**Appendix B.9: a factsheet Low Flow Shower Head**

The demand side study to investigate the deployment potential for Low Flow Shower Heads in Amsterdam is related to the demands side study performed for DWHR systems. Additional details are found in appendix B.9.1. For the calculation of the avoided CO2 eq. emissions, see appendix B.9.2. The financial assumptions can be found in appendix B.9.3.

Figure 7: low flow shower head

- **Contribution to mitigation goal: MEDIUM.** With 2.9 kton/year, the contribution to the mitigation goal is moderate, but not insignificant.
- **Cost-effectiveness: HIGH:** Due to the low investment costs, low flow shower heads for Amsterdam households also appear to be highly cost-effective, with specific costs well below -200€/ton CO2 and a pay back period between 0-5 years.
- **Service delivery: HIGH.** Following the same line of reasoning as for the drain waste heat recovery systems, the low flow shower head scores high on service delivery.
- **Influence and autonomy Waternet: LOW.** Following the same line of reasoning as for the drain waste heat recovery systems, Waternet holds little influence and autonomy in the realization of the low flow shower heads in Amsterdam households.

### 3.2.4. Resource production from the watercycle: biogas

Through a novel watercycle innovation, a sludge destruction installation, Waternet will produce 3 million nm3 of biogas from its waste water facilities per year. This biogas can be transformed in electricity and heat at the neighbouring waste-to energy plant (Afval Energie Bedrijf (AEB)), or it can be used to fuel sustainable transport in the city of Amsterdam. As this biogas will be sold to external partners, the GHG emissions mitigation is allocated to Waternet as act of compensation of Waternet's own emissions.

**Appendix B.10: a factsheet biogas production**

For the calculation of the avoided CO2 eq. emissions, see appendix B.10.1. The financial assumptions can be found in appendix B.10.2.

- **Contribution to mitigation goal: MEDIUM.** Biogas production appears to result in a low impact of GHG emissions reduction: 3.6 kton/yr.
- **Cost-effectiveness: LOW.** According the financial data, biogas production scores low on cost-effectiveness, with pay back periods over 20 years and specific mitigation costs of over 14 €/ton CO2.
- **Service delivery: LOW.** As this measures does not offer a (new) service to Waternet's clients[19] and consequently not unburdens Waternet's clients, service delivery is rated low.

[19] Theoretically speaking it can occur that a Waternet client will buy biogas produced by Waternet. However, in this research it is assumed that Waternet's clients do not form the intended market.

- **Influence and autonomy Waternet: HIGH.** Regarding the production of biogas, Waternet has high autonomy and influence. Waternet has full ownership over its own facilities and can construct its sludge destructor. The market for biogas is currently limited, and hence most customers can be identified as stakeholders with high interest and low power: 'subjects'. Aside of the customer, an important stakeholder for Waternet for biogas production is the waste-to-energy plant located nearby one of Waternet's waste water facilities (RWZI West[20]). AEB can in this sense be regarded as a 'player' with high interest and high power, but it is highly likely to be a proponent player as the AEB and Waternet share the same executive director.

### 3.2.5. Resource production from the watercycle: struvite

Another watercycle innovation is the production of struvite at Waternet's waste water plants. Struvite ($MgNH_4PO_4$, or Magnesium-Ammonium-Phosphate) is a side effect of de-phosphating waste water (SNB, 2012).
This innovative process was discovered recently as a result of increasing nuisances in the purification process (AGV, 2011b). Through amongst others the addition of the $MgCl_2$, nuisance of the waste water purification processes are reduced, additional sludge is removed and struvite is recovered, which in turn can be utilized as fertilizer. Aside from these benefits, large investments have to be made to construct the struvite reactor.

The main benefits of the struvite reactor can be quantified as $CO_2$ eq. reductions through increase electricity production at the waste-to-energy plant through delivery of additional sludge, and the avoided $CO_2$ eq. emissions if struvite replaces traditional NPK fertilizers[21].
Struvite production requires the additional chemical $MgCl_2$ (magnesium chloride), aside of personnel and maintenance costs.

**Appendix B.11: factsheet struvite production**

For the calculation of the avoided $CO_2$ eq. emissions, see appendix B.11.1. The financial assumptions can be found in appendix B.11.2.

- **Contribution to mitigation goal: MEDIUM.** Struvite production results in a medium impact of GHG emissions reduction: 1.9 kton/yr.

- **Cost-effectiveness: HIGH.** The cost-effectiveness of struvite production can be regarded as high, with a pay back period below 5 years and negative specific mitigation costs (-166 €/ton $CO_2$). The investment demanded for the struvite reactor is high, but the cost-savings on the long term as well, not even taken into account potential profits from struvite sale as fertilizer.

- **Service delivery: LOW.** Following the same line of reasoning as for biogas production, this compensation measures scores low on service delivery.

- **Influence and autonomy Waternet: HIGH.** Following the same line of reasoning as for biogas production, struvite production scores high on influence and autonomy for Waternet.

[20] RWZI is the Dutch abbreviation for Waste Water Treatment Plant (WWTP)

[21] As struvite is regarded as a slower operating fertilizer, a factor of 0.75 is taken to compare to traditional fertilizers (personal communication Piekema, 2012). In this case, the reference fertilizer is a swedish produced NPK fertilzer (Davis & Haglund, 1999).

## 3.3. Summary of results Multi Criteria Analysis

To be able to compare the mitigation measures amongst each other, the scores per criterion are summarized in Table 7 for the reduction measures and Table 8 for the compensation measures.

Table 7: Results multi-criteria analysis for reduction measures

| **Reduction measure** | **Criterion 1: Carbon mitigation** | | **Criterion 2: Cost effectiveness** | **Criterion 3: service delivery** | **Criterion 4: autonomy and influence Waternet** |
|---|---|---|---|---|---|
| **Reducing Waternet's own emissions** | | | | | |
| Cluster of resource- and energy efficiency measures at Waternet's waste water facilities | Medium | 1.4 kton/year | High | Low | High |
| Reducing CH4 and N2O emissions at Waternet's waste water facilities | Medium | 4.8 kton/year | Low | Low | High |
| Renewable energy production (PV) | Medium | 3.4 kton/year | Low | Low | Medium |
| Renewable energy production (wind energy) | High | 37.3 kton/year | Low | Low | Low |

Table 8: Results multi-criteria analysis for compensation measures

| **Compensation measure** | **Criterion 1: Carbon mitigation** | | **Criterion 2: Cost effectiveness** | **Criterion 3: service delivery** | **Criterion 4: autonomy and influence Waternet** |
|---|---|---|---|---|---|
| **Compensating for Waternet's own emissions** | | | | | |
| Cold recovery from surface water | Medium | 1.9 kton/year | High | Low | Low |
| Cold recovery from drinking water | Medium | 1.9 kton/year | High | Low | Low |
| Heat recovery from drinking water | Medium | 3.0 kton/year | High | Low | Low |
| Heat recovery from surface water | Medium | 3.0 kton/year | High | Low | Low |
| Heat recovery from waste water | Medium | 3.0 kton/year | Low | Low | Low |
| Heat recovery from shower water | High | 27.8 kton/year | High | High | Low |
| Reduction of hot water use for showering | Medium | 2.9 kton/year | High | High | Low |
| Resource production from the watercycle: biogas | Medium | 3.6 kton/year | Low | Low | High |
| Resource production from the watercycle: struvite | Medium | 1.9 kton/year | High | Low | High |

## 3.4. Marginal abatement cost curves[22]

Waternet CO2 eq. reduction deployment potential 2020 (cost level 2011)

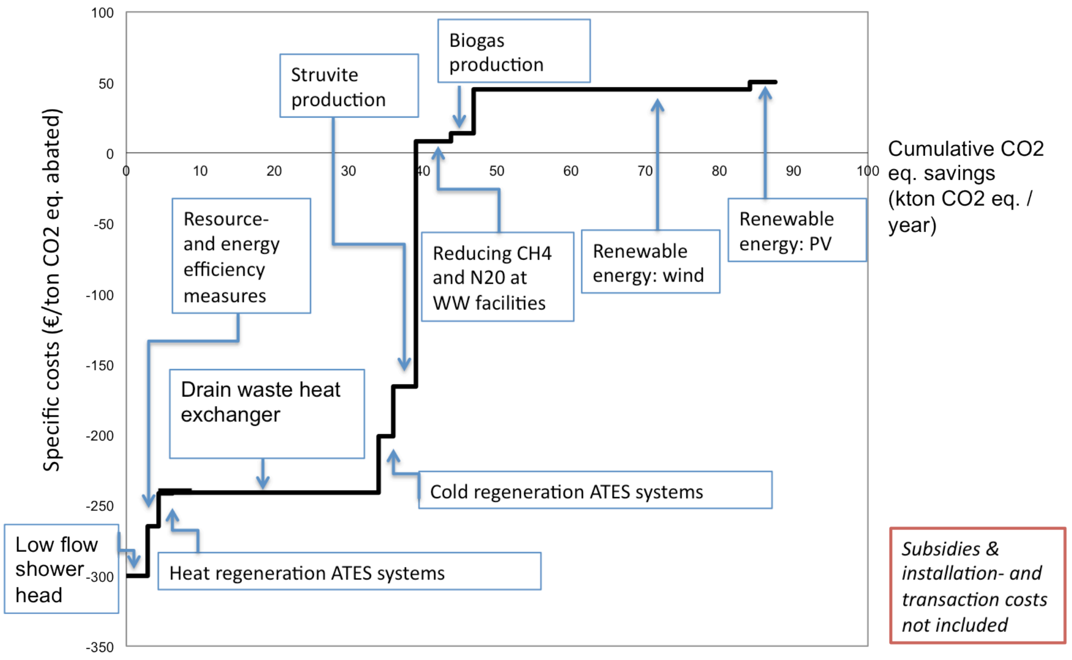


Figure 8: Marginal abatement cost curve displaying the deployment potential for 2020 with cost level 2011

Waternet CO2 eq. reduction deployment potential 2020 (cost level 2020)

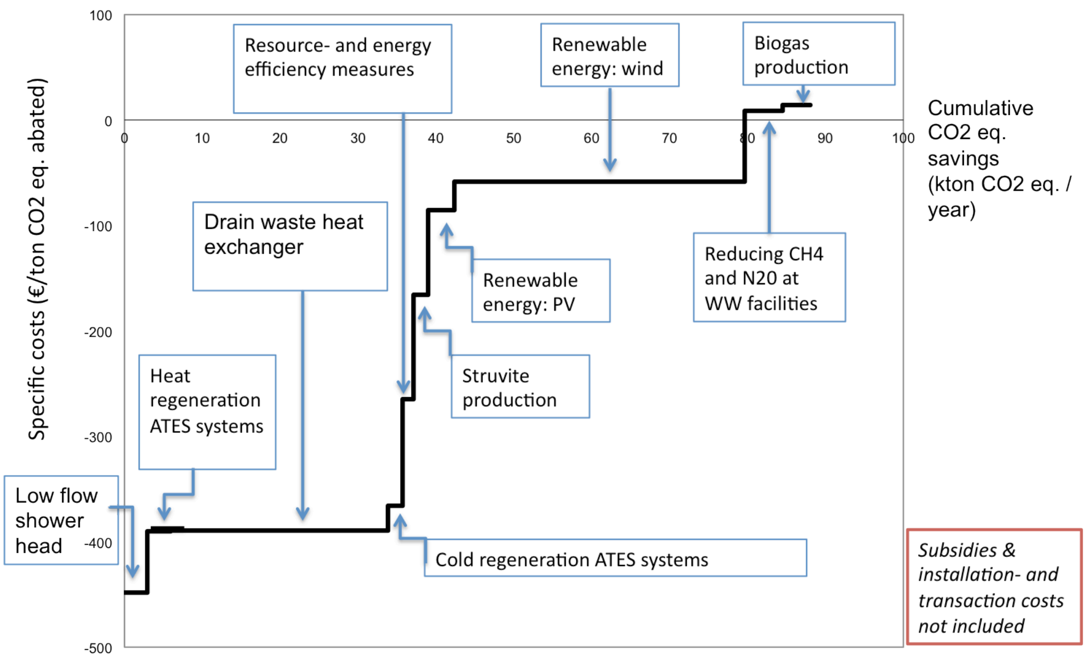


Figure 9: Marginal abatement cost curve displaying the deployment potential for 2020 with cost level 2020

22 The measures heat and cold recovery for ATES regeneration are separately indicated and only the regeneration by means of surface water is depicted in the MAC-curve as this has the highest cost-effectiveness of the watercycle sources. For detailed scoring of these measures in combination with the other watercycle sources, see tables 7 & 8 and factsheet 6 in the appendix.

The results of each mitigation measures as described in the tables above and the cost curves for the cost levels of 2011 and 2020 show the following.

A substantial part of the total mitigation measures package is formed by the mitigation options *wind energy production* and *heat recovery from shower water*, which have the highest potential for GHG reduction, respectively 37.3 kton/year and 27.8 kton/year. Hereafter follow the measures with a medium impact of between 1-10 kton/per year such as the *hot water use reduction in households, heat and cold recovery from watercycle*, *resource production from the watercycle: struvite and biogas*, *the REEM cluster*, and *reducing CH4 and N20 emissions.*

Regarding the criterion of cost effectiveness it should first of all be noticed some significant changes in the cost-effectiveness are found between the two cost levels: especially the renewable energy production by means of PV and wind become cost-effective. *Biogas production* and the *reducing CH4 and N20 emissions* measures remain unchanged at low cost-effectiveness.

In particular, *heat and cold recovery from watercycle*, as well as *heat recovery from shower water* and *hot water use reduction in households* are highly cost effective with specific mitigation costs of well below -200 €/ton CO2. Notably, exactly these two household innovations score high on the criterion of service delivery, having the potential of delivering a new service unburdening Waternet's clients. All other mitigation measures score negatively on this criterion.

Most measures score low on the level of influence and autonomy Waternet's has over its realization. Measures that enact upon Waternet's own facilities, such as the *REEM cluster*, *reducing CH4 and N2O emissions,* and *renewable energy production: solar energy* and *resource production from the watercycle: struvite and biogas* production yield most influence and autonomy for Waternet. Lower impact of this criterion is noticeable for the measures which are characterized by presence of stakeholders with high power and interest, such as *renewable energy production: wind energy*. Especially low score the measures involving many individual stakeholders, such as the heat and cold *heat and cold recovery from watercycle* or the watercycle innovations in the household: *heat recovery from shower water* and *hot water use reduction in households.*

## 3.5. Impact of mitigation measures

If we sum the mitigation impact of each measure, it follows that the total of avoided emissions by means of both the reduction and compensation measures is not sufficient to reach the policy goal. Hence, no selection of mitigation measures on the basis of the score on the four criteria and the MAC-curve is made; all mitigation measures researched should substantiate the mitigation policy plan. Assuming that Waternet follow the logical steps of mitigation inspired by the Trias Energetica, Waternet first implements the reduction measures, after which follow the compensation measures. This yields the following impact on the emission baseline (Figure 10).

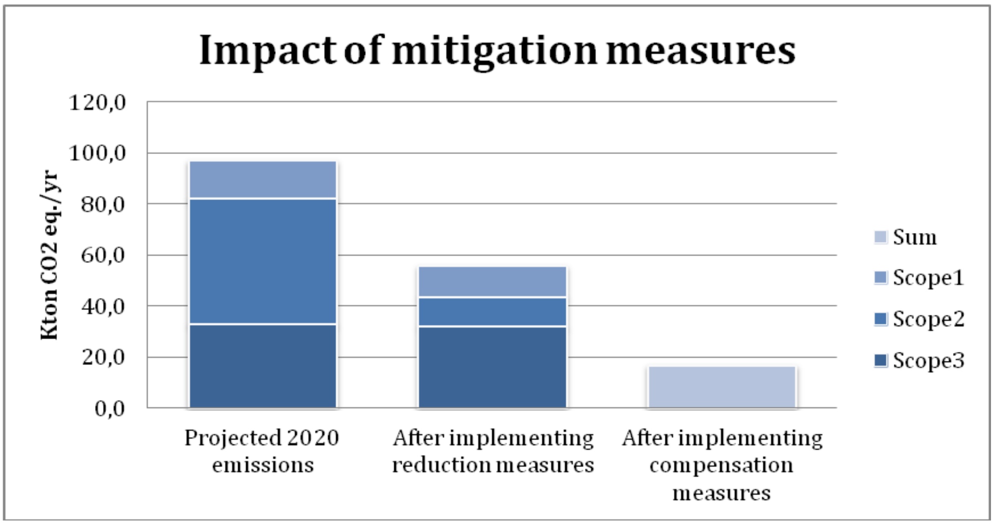


Figure 10: Emission baseline after implementing the reduction and compensation measures

The remaining sum of GHG emissions (~9.1 kton/year) after implementing first the reduction and secondly the compensation measures, requires conventional compensation means (carbon credits and/or green electricity procurement), or additional reduction and compensation measures form the watercycle, in order for Waternet to achieve the ambition of achieving climate neutrality in 2020.

## 3.6. Financial means required

To realize the policy package, financial means are required. As appeared from the results of each mitigation measure on the MCA, most mitigation measures display a pay back period between on average 0 and 10 years, except for *wind energy, solar energy* and *biogas production*. The lifetime of most measures is more than 25 years, hence most mitigation measures show a positive return on investments. The incomplete package of mitigation measures in total costs approximately € 90 million. For summary of the financial costs and benefits for the reduction measures, see Table 9, and for an overview for the compensation measures, see Table 10. Depending on the choice for additional reduction and/or compensation measures, extra financial investments are required. To give an indication; at the expected long term market price of carbon credits on the ETS market of € 20 per ton (Ecofys, 2010), the compensation of 9.1 kton requires a yearly investment, without yearly benefits, of € 182,000.

Table 9: Overview of financial costs and benefits for reduction measures

| | Cluster resource- and energy efficiency measures | Reduction of CH4 and N20 emissions | Renewable energy (PV) | Renewable energy (Wind) | Total (all reduction measures) |
|---|---|---|---|---|---|
| Investment costs (€) | €300,000 | €500,000 | €7,380,000 | €40,500,000 | €48,680,000 |
| Yearly costs (€/yr) | €0 | €0 | €102,000 | €1,483,800 | €1,585,800 |
| Yearly benefits (€/yr) | €400,000 | €10,000 | € -169,800 | € -1,669,800 | € -1,429,600 |

Table 10: Overview of financial costs and benefits for compensation measures

| | Cold recovery (surface water) | Heat recovery (surface water) | Heat recovery from shower water (2020 cost levels) | Hot water use reduction households (2020 costs levels) | Production struvite | Production biogas | Total (all reduction measures) |
|---|---|---|---|---|---|---|---|
| Investment costs (€) | €840,000 | €780,000 | €37,000,000 | €1,900,000 | €2,700,000 | €5,000,000 | €48,220,000 |
| Yearly costs (€/yr) | €25,000 | €23,000 | €0 | €0 | €350,000 | €950,000 | €1,348,000 |
| Yearly benefits (€/yr) | €740,000 | €1,100,000 | €14,000,000 | €1,500,000 | €932,000 | €1,400,000 | €19,672,000 |

# 4. Discussion

In this research, out of twenty-six mitigation measures that could potentially contribute towards reaching Waternet's goal of climate neutrality ten measures were selected for further evaluation based on preset criteria. These measures can be divided into two categories: reduction measures and compensation measures.

Reduction measures include:

1. Energy- and resource efficiency cluster
2. Reducing CH4 and N20 emissions
3. Solar energy production
4. Wind energy production

Compensation measures include:

5. Heat Recovery from watercycle sources
6. Cold Recovery from watercycle sources
7. Heat recovery from shower water in households
8. Hot water use reductions in households
9. Biogas production
10. Struvite production

The most striking findings will be discussed and explained below; some measures are discussed in combination or left out of the discussion if no explanation is required.

## Mitigation Options

### Renewable energy (PV and solar energy)

An important drawback for the development of renewable energy as reduction measure is the low cost-effectiveness of PV and wind energy at current cost levels. These results can be explained by two reasons: first of all, no subsidies (such as SDE[23] plus) or tax benefits (EIA[24]) are taken in to account since subsidy applicability is not ensured due to changing government policy. If however, subsidies or tax benefits will become available in the period 2011-2020, both wind and solar energy become more cost-effective with specific costs of 0€/ton CO2 or lower. Additionaly, it is important to note that especially PV experiences a steep price difference and hence even without subsidy will likely to be cost effective in near time. A second reason for the low cost-effectiveness is that Waternet's electricity procurement price is significantly lower than that of individual consumers (the difference between 0.071€/kWh for Waternet and 0.22€/kWh for end-users), and hence, only limited - if at all - profits are made by the renewable energy production. On top of that, no price increase can be assumed due to specific long term contracts closed with the supplying parties. Nevertheless, substantial arguments could be provided to realize wind and solar energy, such as becoming independent from fossil fuels and the protection against energy price volatility. Perhaps more interesting, is the fact that the Union of Waterboards (UvW) and the Dutch Ministry have signed a long term agreement[25] which explicitly agrees upon 40% share of renewable energy in 2020 in the total electricity consumption.

### Heat and cold recovery from the watercycle: ATES regeneration

From the introductory background research, this mitigation measures seemed promising in terms of mitigation impact. As Mol et al. (2010) and van der Hoek (2010) indicated, the mitigation potential of thermal energy recovery from the Amsterdam watercycle sources drinking water, surface water and waste water amounts to almost 150 kton/yr. The deployment potential found in this research only results in a GHG emission reduction of ~3 kton/year for heat recovery and ~2 kton/yr for cold recovery; a factor 30 lower. This extreme difference can be explained by multiple reasons: first of all, Mol et al. (2010) and van der Hoek (2010) utilized a theoretical potential as opposed to the deployment potential utilized in this study. The latter approach sketches a more realistic market perspective. A second explaining stems from the limitation of this study that no other demanding parties for the recovered heat and cold from the watercycle could be researched, due to data availability and time constraints. The deployment potential for heat and cold recovery from the watercycle could be substantially larger, and more in the direction of the theoretical

[23] Stimulering Duurzame Energieproductie

[24] Energie Investeringsaftrek

[25] "Klimaatakkoord Unie van Waterschappen en het Rijk" (Klimaatakkoord – Unie en Rijk, 2010)

potential, than depicted in this research. Considering for example the fact that large demand for cooling of utilities such as data centres, which could be (partially) supplied by cold recovered from the watercycle (personal communication Mol, Scholten, 2012), the deployment potential in reality might be much higher.

Additional concerns regarding the researched potential of this mitigation measure should be highlighted. Various assumptions were made that could not be supported by practical experience or scientific data. First of all, the demand for heat and cold regeneration of ATES systems is drawn from a monitoring set of data, which is threatened by statistical reliability due to the unequal distribution of the sample. The applicability to the situation of Amsterdam could hence be doubted. Furthermore, the assumption is made that each ATES systems requiring regeneration lies in the proximity required to realize a connection to the watercycle source. No proof from practise is supporting this hypothesis. Lastly, it is assumed that 50% of the owners/managers of the assumed ATES systems that are out of balance in the direction of heat or cold requirements, is cooperating with Waternet to realize the mitigation option. Again, no scientific or practical data has been found to support this assumption and in reality, this number might be higher or lower. All in all, it should be clear that the topic of heat and recovery from the watercycle requires additional research: first of all to research other demanding parties than ATES regeneration systems, and secondly to verify the ATES regeneration data and assumptions.

Regarding the cost-effectiveness of heat and cold regeneration, an important difference was found: heat recovery from waste water is significantly more costly than heat and cold recovery from the other watercycle sources. This prominent difference lies primarily in investment costs per kW for the regeneration system. Heat recovery from waste water requires investing in a sewage with integrated heat exchanger which is more than a factor 10 more costly than regeneration systems for surface and drinking water.

Interesting to note is that heat and cold recovery can significantly enhance the quality of task execution of Waternet. Cold and heat recovery in many instances lead to positive side effect; in surface water for example thermal energy recovery results in significant improvements of water quality (Scholten, 2011; Bearzatto et al, 2011; personal communication Bakker, 2011). Cold recovery in winter and heat recovery in summer from drinking water leads to changes in drinking water temperature that lead to more pleasant water temperatures for drinking (personal communication Mol, 2011).

### Household watercycle innovations

The results of this research point towards the possibility to reduce significant amounts of GHG emissions in the household watercycle due to relatively simple application of a drain waste heat recovery system and/or a low flow showerhead. As limiting factor was identified that Waternet has low influence and autonomy over the realization of this mitigation measure. In reality however, Waternet possesses a strong tool: the potential customer base is already customer of Waternet. Utilizing Waternet's client database and financial constructions such as leasing out the appliance increases the influence and autonomy of Waternet in the realization. Next to that, Waternet could be a powerful actor in overcoming the traditional problem of split incentive; in which for examples housing corporations neglect to invest in energy efficiency measures, as the house occupant will be the one benefiting from the reduced energy costs. For Waternet, there may be a barrier to intervene as is often referred to as "behind the meter". Given the significant benefits for both Waternet and its clients however, the traditional thinking within the system borders can be breached. Interesting to highlight is the trend visible in other areas of service delivery, to think outside the existing box. Unilever for example, with its sustainability living plan (Unilever, 2012), is not only considering the footprint of the production of its products, but is specifically mapping out the impact of the products over its life cycle – from production to use to disposal. As acknowledged by Unilever, this is oftentimes where the real impact can be made.

The specific results on the evaluation of each of the mitigation measures, aside from being relevant for Waternet's case, are generalizable to other water utilities in the Netherlands, and even abroad. This generalization is potentially restricted by two factors: firstly that the specific heat and cold demands, as well as the potential for the DWHR and LFSH are often location specific. Secondly, certain mitigation measures might already be in place at other water utilities, hence contesting the novelty.

## General limitations

Although the author has done her utmost to ensure the quality of the presented research, it still suffers from a number of limitations which are described below.

The research boundaries have created a narrow scope for the identification of the applicable mitigation measures for Waternet. It could be argued that additional research into potential reduction and compensation measures will most likely yield a higher sum GHG emissions reduction. By posing stringent selection criteria, a number of measures have not been evaluated. Some measures were not included because they cannot be realized before 2020, effectively surpassing the scope of this research. Others where excluded on the basis of predetermined boundaries in this research assignment, such as the first criterion that measures should be physical measures. Some of these excluded measures, notably 'soft' – non physical – mitigation measures could result in high mitigation effects. For example communication strategies and financial support schemes stimulating Waternet's employees into pro-environmental behaviour.

For Waternet, it is paramount that the implementation of a specific mitigation measure will not endanger Waternet's ability to perform its core tasks (personal communication Kruize, 2011). Therefore, this would have been an important selection criterion for mitigation measures. However, since no information was available on this subject, it was assumed for all measures that they do not confer risks for Waternet in this matter.

It is assumed in this research that the emission reductions achieved by the realization of the mitigation options, and in particular compensation options, are allocated to Waternet. In reality, there is no legal definition of climate neutrality, nor are there rules or guidelines how such neutrality should be achieved.
The most important aspect of compensation is that the mitigation measures should always provide for additional CO2 reductions. If the reductions would have taken place in any case, no additionality is guaranteed and hence the reductions should not be allocated. To make sure that Waternet can rightfully allocate the emissions reductions, the following development should be carefully watched: it is currently impossible to buy or generate emission credits domestically in the Netherlands. However, changing Dutch and EU regulations might allow 'domestic offsetting' in the future. According to Thompson (personal communication, 2012), this will take at least two more years and on top of that, it seems to be no priority of the European Commission.
A critical note should be placed to the current practice of Waternet in which emissions reductions are allocated to Waternet without any formal underpinnings. A specific case is that of the Ouderkerkplas, for which Nuon was given permission of Waternet to recover cold to supply surrounding utility buildings. In this case, Waternet is allocating the emissions reduction to compensate for its remaining GHG emissions, whereas no clear agreements have been made with the developing parties and it is therefore highly possible that this is a situation of double counting.

Regarding the attribution of financial benefits Waternet's perspective was assumed: to calculate the cost-effectiveness of the measures, Waternet is assumed to be the party bearing the investment costs, the O&M costs and benefiting from the financial savings. In reality, this requires smart cooperation forms with for example house owners and ATES system owners.

A final limitation that applies to all mitigation measures researched is that of realistic reflection of investment costs, energy prices and discount rates. It should be noted that the costs (investment costs, O&M costs and benefits) do not accurately reflect the actual situation; the main limitation is that the installation costs have been excluded from this research. This limitation emerged from data unavailability to correctly estimate the investment costs for all mitigation measures and hence to provide honest comparisons between measures, all installation costs were excluded. As some experts suggest, these investment costs might amount up to 50-70% of the installation costs depending on the type of installation (Personal communication Piekema, 2012). The energy prices assumed in this research for gas and electricity are surrounded by uncertainties. Energy price forecasting is a highly delicate issue which could influence the yearly financial benefits of many of the mitigation measures researched. On the other hand, the results showed that the effect of 2020 costs levels as opposed to 2011 costs levels yielded no significant changes in the cost-effectiveness of the mitigation measures, hence this effect is estimated to be relatively insignificant. The assumed discount rate in this research of 6% is assumed to be a social discount rate and hence appropriate for this research.

## Relevance

Despite these limitations, the results of this study have a direct relevance for Waternet. The evaluation of specific mitigation measures, has shown significant differences between them in terms of mitigation potential, cost-effectiveness, service delivery and possibility of realization. These data will enable Waternet to make sound decisions on which mitigation measures should be included in the policy plan. The proposed methodology of amongst others the marginal abatement cost curves is already deemed applicable: experts within Waternet from other divisions have already posed interest on its utilization to investigate their division's mitigation potential (personal communication, Struker 2012).

Furthermore, a significant knowledge gap in academic literature has been identified for public organizations and utilities in particular, as to how and by which means an organization can contribute to climate change mitigation. This research specifically gathered data on achieving the ambition of climate neutrality for the case of Waternet, and yields result that could be interpreted by other Dutch water utilities and municipalities to investigate their watercycle potential. Furthermore the methodology used can be translated to other situations and could prove instrumental for the reliable investigation of mitigation measures.

Concluding, this research shows the feasibility of attaining ambitious mitigation goals without giving in to the easiness of offsetting one's carbon by means of green electricity and carbon procurement[26], but instead aiming at real and lasting innovations in the watercycle. Consequently, could work as a precedent for other Dutch utilities to investigate their mitigation potential, possibly inspiring them to define and achieve their own mitigation ambitions.

[26] Multiple issues can be identified as to why realizing reduction measures and compensation measures in the watercycle is preferential over procurement of green electricity and carbon procurement. First of all, the additionality of green electricity or carbon offsetting is not always guaranteed (personal communication Harmsen, 2011). Secondly, green electricity procurement, as mentioned before, is often a disincentive for energy efficiency measures. Next to that, yearly returning investments have to be made that do not provide for a structural solution for Waternet, nor for the city of Amsterdam. Innovating in the watercycle requires larger upfront investments but, can in most instances result in cost-effective measures and contribute to the transition towards a low carbon city of Amsterdam, as was shown by this research.

# 5. Conclusion & recommendations

## 5.1. Conclusion

The results of the presented research suggest that Waternet can achieve their goal of climate neutrality in 2020 by implementing the package of researched mitigation measures - albeit with a minimal procurement of carbon credits and/or green electricity.

Of the evaluated measures, *wind energy production* and *shower water heat recovery options* have the highest potential for GHG reduction, respectively 37.3 kton/year and 27.8 kton/year. The total package of ten mitigation options could lead to a GHG reduction of 88.1 kton/year, whereas the climate neutrality goal of Waternet requires a reduction of approximately 97.2 kton/year. Since the selected mitigation measures for the policy plan do not suffice for the achievement of the policy goal, additional compensation measures are required for a remaining 9.1 kton/year. Evaluation of other options from the watercycle, not covered in this research, might prove instrumental for further reductions. The remaining gap in GHG emissions after implementation of all mitigation options can be covered by the purchase of green electricity or carbon credits.

To realize climate neutrality for Waternet, using the proposed package of nine mitigation options supplemented with carbon credits, an investment of at least € 91 million euro until 2020 is required for implementation of the package, on top of which a yearly carbon credit purchase of € 182K is required from 2020 onwards.

Important factors for successful implementation of the package are cost-effectiveness and the influence that Waternet can exert on other stakeholders to realize the measure. When the pay back period and the specific costs of CO2 eq. mitigation of individual measures are assessed, the measures *heat recovery from watercycle source, cold recovery from watercycle sources, shower water heat recovery in households* and *reduction of hot water use in households* are cost-effective. In addition, last two measures have the benefit of offering Waternet clients a means to reduce household gas consumption, thus offering an unburdening service. *Wind and solar energy*, as well as *biogas production* are at current price levels not cost-effective mitigation options, but have the potential to become so in near time and if subsidies are available their cost-effectiveness increases strongly.

Waternet has most influence and autonomy over the realization of the measures in the *energy- and resource efficiency cluster* and *the reducing CH4 and N2O emission measure*, as well as *solar energy* and *biogas and struvite production*. For the other evaluated mitigation measures, the influence of Waternet in the possible implementation is limited, so realization might be complicated in light of opposing interests of other stakeholders.

## 5.2. Recommendations

- **Realization**

It is advisable to realize the proposed mitigation measures as soon as possible: many mitigation measures require realization between now and 2020. What is noticeable from the results of the first two mitigation measures – the *energy- and resource efficiency cluster* and *the reducing CH4 and N2O emission measure* – is that Waternet has specifically high autonomy and influence over the measures at the facilities over which it has full ownership and little other stakeholders are involved. This applies also for the realization of *solar energy, biogas and struvite production*. It would be highly advisable to prioritize the realization of these measures. Additionally, most of these measures require time significant amounts of time to prepare – the permit process for wind energy could last 5-7 years. Starting now, on a small scale with pilots for example, allows the organization also to learn how to scale it up. It is strongly recommended to develop project plans now, to be able to roll out when a beneficial subsidy is available or when grid parity is reached for Waternet.

For all other mitigation measures (mainly the compensation measures) for which Waternet, in its current position, has little influence and autonomy, Waternet could choose to institutionalize a separate organization. One of the possibilities is to erect a project development organization in the form of a daughter-company of Waternet or a public private partnership in which Waternet will be able to realize the watercycle innovations such as heat and cold recover from surface, drinking and waste water in a commercial way.

- **Further research**

As indicate above already, several individual measures require additional research. In particular, the deployment potential of *heat and cold recovery from the watercycle*. Further research into the excluded mitigation measures to achieve the ambition of climate neutrality, could prevent Waternet from reaching out for the conventional methods to compensate one's emissions: carbon credit purchase and green electricity procurement. Especially relevant could be to broaden the scope of mitigation measures from non-technical and infrastructural also towards 'soft' mitigation measures. As indicated before, it was assumed for all measures that they do not confer risks for Waternet in this matter. If any measure is to be implemented, it would be sound practice to perform additional research on this topic.

- **Extending scope and influence**

This research possibly provided the first step for Waternet in continuing to look beyond its own footprint, by investigating the reduction potential of the watercycle in Waternet's client's households. In this regard, Waternet could further investigate the potential mitigation impact it can achieve by stimulating its clients 'behind the meter' to reduce emissions related to the watercycle. Other emissions as a result of water use behind the meter (toilet flushing, appliances that use hot water etc.) could for example become part of the scope 3 "indirect emissions". In line with this previous thought, Waternet could consider to also consolidate other scope 3 emissions such as from contracted. One way to reduce the impact of these scope 3 emissions would be to introduce the *CO2 Prestatie Ladder*, as introduced by ProRail (SKAO, 2012). This tool allows large executing organization such as Waternet to pressure contractors to integrate energy-, carbon-, and resource efficiencies in the tenders.

- **Communication and lobbying**

In order to realize the mitigation policy plan as proposed in this research, Waternet could communicate clearly and engage in the process of political lobby in order to realize its plan. First of all, regarding the topic of carbon allocation, Waternet could lobby for the possibility of domestic offsetting in order to allow for the official acquisition of carbon credits for the achieved GHG reductions elsewhere. Until domestic offsetting becomes a realistic possibility, it is advisable to Waternet to make sure to enter in to formal arrangements with the stakeholders with whom it realizes the compensation measures (households, housing corporations etc.) to carefully allocate and divide the achieved emissions reductions.

Additionally, it is of utmost important to find political support for its plans given the fact that Waternet's main assigning authorities are democratic institutions: the municipality of Amsterdam and Waterboard Amstel, Gooi & Vecht. Clearly communicating the policy problem, the policy causes and the potential solutions, such as proposed in the form of mitigation options in this research, can be of assistance in this lobby process. Furthermore, Waternet could draft a budget allowing for the execution of innovative research and test pilots to experiment with the sound realization of the mitigation projects. To support the lobby process, Waternet can point towards contributes to the climate goals of the city of Amsterdam (40% CO2 reduction as opposed to 1990 levels in 2025) (Klimaatbureau Amsterdam, 2010) in relation to the remaining task of the municipality of 3,863 kton, Waternet can contribute ± 88,1 kton, which translate in a ~2% contribution to the city's overall climate goal. Internal lobby may also be required. Waternet is a large organization, governed by a conventional style of line management. Mitigation policy plans drafted in the Strategic Center could find internal support of important line managers, advisors and key players. This requires, similarly as described, above clear and transparent communication about the rationales and intentions behind the mitigation policy.

Last but not least, Waternet is advised to communicate its mitigation plans and climate ambitions externally as well. From the perspective of Waternet's reputation, communicating its achieved mitigation reductions shows that the watercycle as management concept can bring about innovative and resource-, energy, and carbon- reducing opportunities. Additionally, being a public organization that is serious about the public cause, Waternet can lead by example and hereby inspire citizens and other organizations to not just offset its carbon emissions but to undertake innovations in a pro-active manner.

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## A.2. Consulted Experts

Table 11: Overview of consulted experts; referenced to in text by '(personal communication, year)'

| Consulted experts | | | | |
|---|---|---|---|---|
| **Name** | **Function** | **Organization** | **Date** | **Topic** |
| Bakker, Wiebe | Policy advisor | Waternet | Nov-11 | Water quality improvement |
| Bosch, Arne | Manager drinking water division | Waternet | Nov-11 | DW measures |
| Bosman, Frodo | Manager climate & energy bureau | Gemeente Amsterdam | Nov-11 | Amsterdam climate policies |
| Cozijnsen, Jos | Consultant | Cozijnsen consultancy; emissierechten.nl | Feb-12 | Emissions rights and domestic offsetting |
| Dulfer, Wiegert | Executive AGV | AGV | Nov-11 | Assessment criteria |
| Frijns, Jos | Senior scientific researcher | KWR water research | Oct-11 | Mitigation measures |
| Genee, Sanne | Consultant | Climate Neutral Group | Feb-12 | Emissions rights and domestic offsetting |
| Hartog, Paulien | Strategic advisor | Waternet | Dec-11 | Role Waternet |
| Heemstra, Wido van | Advisor | Agentschap NL | Feb-12 | Emissions rights and domestic offsetting |
| Huits, Peter | Permission provider | Provincie NH | Jan-12 | ATES (regeneration) |
| Jacobs, Eilard | Strategic advisor | Waternet | Regularly | Role Waternet, Allocation emission reductions |
| Janse, Theo | Advisor hydrology & ecology | Waternet | Regularly | Waternet's footprint |
| Kapteyn, Hans | Senior policy advisor legal issues | Waternet | Nov-11 | legal status Waternet |
| Klaversma, Enna | Advisor watertechnology | Waternet | Jan-12 | Emission factors |
| Knibbe, Adriaan | Energy coordinator | Waternet | Feb-12 | Energy use & pricing Waternet |
| Kruize, Roelof | General executive | Waternet | Oct-11 | Assessment criteria |
| Lambrechts, Marlies | Senior advisor energy & climate | Gemeente Amsterdam | Jan-12 | ATES (regeneration) |
| Meer, Jos van der | Advisor projectmanagement | Waternet | Oct-11 | PV & wind |
| Mol, Stefan | Advisor energy & water | Waternet | Regularly | ATES regeneration, mitigation measures |
| Oerlemans, Mari | General manager | Hydreco - Brabant Water | Dec-11 | Realization projects |
| Piekema, Peter | Senior advisor waste water treatment | Waternet | Regularly | Biogas production |
| Scholten, Barry | Specialist energy storage | IF Technology | Feb-12 | ATES (regeneration) |
| Struker, André | Strategic advisor | Waternet | Regularly | Allocation emission reductions |
| Sukkar, Rada | Consultant | Tauw | Nov-11 | Heat and cold recovery potential |
| Swaan, Dennis | Advisor | Kroohn Delhy | Nov-11 | Riothermia - waste heat exchanger sewage |
| Thompson, Eva | Policy advisor emissions trading | Ministerie I&M | Mar-12 | Emissions rights and domestic offsetting |
| Tuenter, Hans | Specialist | If Technology | Feb-12 | ATES (regeneration) |
| Vink, Wijnand | Specialist geothermal energy systems | IF Technology | Feb-12 | ATES (regeneration) |
| Zijlema, Peter | Advisor | Agentschap NL | Feb-12 | Emissions rights and domestic offsetting |

# B. Appendix

## B.1. Long list mitigation options

Table 12: Selection criteria used to come filter out the short list from the long list

| | Criteria |
|---|---|
| 1 | Mitigation options should be 'hard' (technological, infrastructural) measures: technologies, infrastructural mitigation options |
| 2 | Mitigation options should be realizable on the short term (until 2020) |
| 3 | Mitigation options should not yet be fully implemented in Waternet's facilities/portfolio. |
| 4 | Sufficient data should be available to research the mitigation options. |

Table 13: Long list of mitigation measures identified from literature and expert interviews

| Category | Number | Mitigation Measure | Source | Opted? | Comments |
|---|---|---|---|---|---|
| Water cycle | 1 | Alignment sewering system and waste water treatment facility | Frijns et al., 2008 | Disregarded by criteria 4 | |
| | 2 | Rainwater use toilet flushing | Frijns et al., 2008 | Disregarded by criteria 2 | Realizable on middle to long term 15-20 years (Frijns et al., 2008) |
| | 3 | Reduction warm water use (e.g. Through low flow shower head) | Frijns et al., 2008 | Opted | |
| | 4 | Heat recovery waste water households | Frijns et al., 2008 | Opted | |
| | 5 | Heat and cold recovery from waste water, surface water, drinking water | Frijns et al., 2008; Stefan Mol; IF technology | Opted | |
| | 6 | Separate urine/black water collection system | Frijns et al., 2008 | Disregarded by criteria 2 | Realizable on middle to long term 15-20 years (Frijns et al., 2008) |
| | 7 | Recovery of resources/nutrients from waste water | Frijns et al., 2008 | Opted | Realizable on middle to long term 15-20 years (Frijns et al., 2008) |
| | 8 | Renewable energy production (PV, wind energy) | Personal communication van der Meer | Opted | |
| Drinking water division | 9 | Energy efficient production (e.g. New membrane concepts) | Frijns et al., 2008 | Disregarded by criteria 4 | |
| | 10 | Optimal distribution (e.g. Through modelpredictors, lower pressure) | Frijns et al., 2008 | Disregarded by criteria 4 | |
| | 11 | Reduction of procurement chemicals | Personal communication, Piekema | Disregarded by criteria 4 | |
| | 12 | Methane extraction | Frijns et al., 2008 | Disregarded by criteria 4 | |

| | | | | | |
|---|---|---|---|---|---|
| Waste water division (including sewering) | 13 | Optimizing biological processes | Frijns et al., 2008 | Opted: clustered into one package of resource- and energy efficiency measures | |
| | 14 | Optimal adjustments | Frijns et al., 2008 | | |
| | 15 | Optimizing efficiencies | Frijns et al., 2008 | | |
| | 16 | Low-energy concepts (e.g. Fermentation) | Frijns et al., 2008 | | |
| | 17 | Reducing N2O emissions | Frijns et al., 2008 | | |
| | 18 | Reduction of procurement chemicals | Personal communication, Piekema | | |
| | 19 | Co-digestion | Frijns et al., 2008 | Opted | |
| | 20 | Coincineration sludge | Frijns et al., 2008 | | |
| | 21 | Reducing amount of waste water (e.g. By means of separate collection systems) | Frijns et al., 2008 | Disregarded by criteria 2 | |
| | 22 | Optimizing transport waste water (e.g. By means of real-time control) | Frijns et al., 2008 | Disregarded by criteria 4 | |
| Water system | 23 | Reducing natural emissions of peat areas through alternative water level management (peilbeheer) | Waternet/other sources | Disregarded by criteria 1, 2 | Although this measure has a high potential, it is a highly debated and politically sensitive topic; requires changes in national and provincial land use policies |
| | 24 | Centralized softening water | Frijns et al., 2008 | Disregarded by criteria 3 | |
| | 25 | Aquifer thermal energy storage (ATES) | Frijns et al., 2008 | Opted, clustered with measure 4 | |
| | 26 | Green electricity procurement | Frijns et al., 2008 | Disregarded by criteria 1,3 | |

## B.2. Factsheet energy price assumptions

Table 14: General energy prices assumptions made in this research

| Assumption | Data | Unit | Source |
|---|---|---|---|
| **Energy Prices** | | | |
| Electricity price Waternet (excl. Taxes) | 0.071 | €/kWh | Personal communication Knibbe, 2012 |
| Gasprize (excluding fixed right costs) | 0.63 | €/m³ | CBS, 2011 |
| Electricity price end users | 0.22 | €/kWh | CBS, 2011 |
| Energy price increase | 4% | yr | CBS, 2011 |

## B.3. Factsheet cluster of resource- and energy efficiency measures[27]

### B.3.1. Impact on mitigation goal

Table 15: Effects of the cluster of resource- and energy efficiency measures at Waternet's waste water facilities with appropriate emissions factors and translation to avoided CO2 eq. emissions

| Effect | Data | Unit | Emission factor | Unit | Source emission factor | Avoided CO2 eq. emissions (ton/year) | | Effect |
|---|---|---|---|---|---|---|---|---|
| **Energy** | | | | | | | | |
| Reduction gas use | 30,000 | Nm3/yr | 0.00192 | ton CO2/m3 | Personal communication Swaan, 2011 | 58 | ton CO2 eq./yr | Reduction scope 1 |
| Reduction electricity use | 2,000 | MWh/yr | 0.000565 | ton CO2/kWh | van der Ree et al., 2011 | 1,130 | ton CO2 eq./yr | Reduction scope 2 |
| **Reduction use chemicals** | | | | | | | | |
| FeClSO4 (41% solution) | 800 | ton/yr | 0.0779 | kg CO2/solution | SimaPro | 62 | ton CO2 eq./yr | Reduction scope 3 |
| NaAlO2 (21% solution) | 400 | ton/yr | 0.2625 | kg CO2/solution | SimaPro | 105 | ton CO2 eq./yr | Reduction scope 3 |
| Al(OH)Cl2 (31% solution) | 200 | ton/yr | 0.2046 | kg CO2/solution | SimaPro | 41 | ton CO2 eq./yr | Reduction scope 3 |

### B.3.2. Financial data

Table 16: Utilized investment data for the resources and energy efficiency cluster

| Assumption | Data | Unit | Source |
|---|---|---|---|
| **Investment data** | | | |
| Total investment costs | 300,000 | € | Personal communication Piekema, 2011 |
| Total O&M costs | 0 | € | Personal communication Piekema, 2011 |
| Total benefits | 400,000 | € | Personal communication Piekema, 2011 |
| Lifetime | 15 | years | Personal communication Piekema, 2011 |
| Discount rate | 6% | | Personal communication Piekema, 2011 |

[27] All data is provided by Piekema (personal communication, 2012).

## B.4. Reducing CH4 and N20 emissions at Waternet's waste water facilities

### B.4.1. Impact on mitigation goal

Table 17: Effects of the measures taken to reduce CH4 and N20 direct emissions from Waternet's waste water facilities

| Effect | Data | Unit | Emission factor | Unit | Source emission factor | CO2 reduction (ton/year) | | Effect |
|---|---|---|---|---|---|---|---|---|
| **Reduction direct emissions** | | | | | | | | |
| Reduction emission CH4 (methane) | 196 | ton/yr | 23 | GWP | IPPC TAR SYR, 2001 | 4,500 | ton CO2 eq./yr | Reduction scope 1 |
| Reduction emission N20 | 1 | ton/yr | 296 | GWP | IPPC TAR SYR, 2001 | 300 | ton CO2 eq./yr | Reduction scope 1 |

### B.4.2. Financial data

Table 18: Investment data

| Assumption | Data | Unit | Source |
|---|---|---|---|
| **Investment data** | | | |
| Total investment costs | 500,000 | € | Personal communication Piekema, 2011 |
| Total O&M costs | 0 | € | Personal communication Piekema, 2011 |
| Total benefits (from biogas production methane) | 10,000 | € | Personal communication Piekema, 2011 |
| Lifetime | 15 | years | Personal communication Piekema, 2011 |
| Discount rate | 6% | | Personal communication Piekema, 2011 |

# B.5. Factsheet Solar Energy (PV)

## B.5.1. Additional information

Table 19: Utilized general assumptions on solar installation

| Assumption | Data | Unit | Source |
|---|---|---|---|
| | | Solar installation data | |
| Total capacity | 6,000 | kWp | Personal communication van der Meer 2011 |
| Load hours | 1,000 | hours/year | Lensink et al., 2011 |
| Total produced electricity | 6,000,000 | kWh/year | Calculation |
| Life time | 25 | years | Lensink et al., 2011 |
| Discount rate | 6% | | Assumption |

## B.5.2. Impact on mitigation goal

**Calculating CO2 emission savings**

$$Avoided\ CO2\ emissions = (E.F.\ conventional\ energy - E.F.\ solar\ energy) \cdot E_{Produced}$$

Where:
- Avoided CO2 emissions = avoided CO2 emissions as a result of solar energy compared to conventional energy mix (CO2 eq./year)
- E.F. conventional energy = emission factor of conventional energy mix in the Netherlands (ton eq. CO2/kWh)
- E.F. solar energy = emission factor of solar energy (ton CO2 eq./kWh)
- $E_{produced}$ = total produced electricity (kWh/yr)

**Assumed emission factors:**
- Conventional energy = 0.565 kg CO2/kWh
- Solar energy = 0 ton CO2/kWh[28]

## B.5.3. Financial data

Table 20: Financial assumptions and calculations for solar energy

| Assumption | Data | Unit | Source |
|---|---|---|---|
| | | Investment data (cost level 2011) | |
| Total investment costs | 7,380,000 | € | Lensink et al., 2011 |
| Total O&M costs | 102,000 | €/year | Lensink et al., 2011 |
| Subsidy, Energie Investerings Aftrek (EIA) | | Not included | |
| Price solar energy | 0.099 | €/kWh | Calculation |
| (Reference) price conventional energy | 0.07 | €/kWh | Personal communication Knibbe, 2011 |

[28] No life cycle emissions are taken in to account in the calculation of emission factors for solar and wind energy.

| | | | |
|---|---|---|---|
| Yearly benefits | -169,800 | €/year | Calculation |
| **Investment data (cost level 2020)** | | | |
| Price decrease | 35% | in 2020 | EPIA, 2012 |
| Total investment costs | 4,797,000 | € | Lensink et al., 2011; calculation on basis of price decrease |
| Total O&M costs | 102,000 | €/year | Lensink et al., 2011; calculation on basis of price decrease |
| Subsidy, EIA | Not included | | |
| Price solar energy | 0.06 | €/kWh | Calculation |
| (Reference) price conventional energy | 0.11 | €/kWh | Personal communication Knibbe, 2011; calculation on basis of 4% yearly energy price increase |
| Yearly benefits | 290,010 | €/year | Calculation |

**Calculating yearly benefits**

$$Yearly\ benefits = (Price\ conventional\ energy - Price\ solar\ energy) \cdot E_{Produced}$$

Where:
- Yearly benefits = financial benefits from solar energy (€/yr)
- Price conventional energy = price paid by Waternet (€/kWh)
- Price solar energy = production price electricity by means of solar energy (PV cells) (€/kWh)
- $E_{produced}$ = total produced electricity (kWh/yr)

**Calculating price solar energy**

To calculate the price of solar energy for cost levels 2011 and 2020, the following formula is used:

$$Price_{energy} = \frac{\alpha \cdot I + C}{E_{produced}}$$

Where:
- $Price_{energy}$ = production price electricity by means of solar energy (PV cells) (€/kWh)
- α = capital recovery factor (see methods section for formula)
- I = total investment costs (€)[29]
- C = Total operation and maintenance (O&M) costs (€/yr)
- $E_{produced}$ = total produced electricity (kWh/yr)

[29] Total investment costs excluding costs for installing, execution, design, public tender etc.

## B.6. Factsheet Wind Energy

### B.6.1. Additional information

Table 21: Utilized general assumptions on wind energy installation

| Assumption | Data | Unit | Source |
| --- | --- | --- | --- |
| **Wind installation data** | | | |
| Number of turbines | 10 | # | Personal communication van der Meer 2011 |
| Total capacity | 30 | MW | Personal communication van der Meer 2011 |
| Load hours | 2,200 | hours/year | Lensink et al., 2011 |
| Total produced electricity | 66,000,000 | kWh/year | Calculation |
| Life time | 25 | years | Lensink et al., 2011 |
| Discount rate | 6% | | Assumption |

### B.6.2. Impact on mitigation goal

**Calculating CO2 emission savings:**

$$Avoided\ CO2\ emissions = (E.F.\ conventional\ energy - E.F.\ wind\ energy) \cdot E_{Produced}$$

Where:

- Avoided CO2 emissions = avoided CO2 emissions as a result of solar energy compared to conventional energy mix (CO2 eq./year)
- E.F. conventional energy = emission factor of conventional energy mix in the Netherlands (ton eq. CO2/kWh)
- E.F. wind energy = emission factor of wind energy (ton CO2 eq./kWh)
- $E_{produced}$ = total produced electricity (kWh/yr)

**Assumed emission factors:**

- Conventional energy = 0.565 kg CO2/kWh
- Wind energy = 0 ton CO2/kWh[30]

### B.6.3. Financial data

Table 22: Financial assumptions and calculations for wind energy

| Assumption | Data | Unit | Source |
| --- | --- | --- | --- |
| **Investment data (cost level 2011)** | | | |
| Total investment costs | 40,500,000 | € | Lensink et al., 2011 |
| Total O&M costs | 1,483,800 | €/yr | Lensink et al., 2011 |
| Subsidy, EIA | Not included | | |
| Price wind energy | 0.096 | €/kWh | Calculation |
| (Reference) price conventional energy | 0.07 | €/kWh | Personal communication Knibbe, 2011 |
| Yearly benefits | -1,669,800 | €/year | Calculation |

[30] No life cycle emissions are taken in to account in the calculation of emission factors for solar and wind energy.

| Investment data (cost level 2020) | | | |
|---|---|---|---|
| Price decrease investment | 10% | in 2020 | EWEA (2012) |
| Total investment costs | 32,400,000 | € | Lensink et al., 2011; calculation on basis of price decrease |
| Total O&M costs | 1,436,400 | €/yr | Lensink et al., 2011; calculation on basis of price decrease |
| Subsidy, EIA | Not included | | |
| Price wind energy | 0.086 | €/kWh | Calculation |
| (Reference) price conventional energy | 0.12 | €/kWh | Personal communication Knibbe, 2011; calculation on basis of 4% yearly energy price increase |
| Yearly benefits | 2,181,000 | €/year | Calculation |

**Calculating yearly benefits:**

$$Yearly\ benefits = (Price\ conventional\ energy - Price\ wind\ energy)\ \cdot\ E_{Produced}$$

Where:

- Yearly benefits = financial benefits from solar energy (€/yr)
- Price conventional energy = price paid by Waternet (€/kWh)
- Price solar energy = production price electricity by means of wind energy (wind turbines) (€/kWh)
- $E_{produced}$ = total produced electricity (kWh/yr)

**Calculating price wind energy:**

$$Price_{energy} = \frac{\alpha \cdot I + C}{E_{produced}}$$

Where:

- $Price_{energy}$ = production price electricity by means of wind turbines (€/kWh)
- α = capital recovery factor
- I = total investment costs (€)[31]
- C = Total operation and maintenance (O&M) costs (€/yr)
- $E_{produced}$ = total produced electricity (kWh/yr)

[31] Total investment costs excluding costs for installing, execution, design, public tender etc.

## B.7. Factsheet ATES regeneration from watercycle sources

### B.7.1. ATES regeneration by heat and cold from watercycle sources

Regeneration systems for Aquifer Thermal Energy Storage (ATES) systems consist largely speaking of a heat exchanger, a pump to circulate the water and connecting infrastructure to the ATES sources. Different types of heat exchanger can be utilized; for waste water for example, one can choose for a separate heat exchanger that should be installed in an existing sewer or one can opt for a integrated heat exchanger in the sewer. The latter has a higher durability, but the costs are also much higher. Heat and cold from drinking water can be recovered by for example a rerouted pipe in which a plate heat exchanger is installed. For surface water, the system should also consist of a filtering system to avoid clogging of the heat exchanger.

Drinking water and surface water regeneration systems can recover cold in the winter and can deliver heat in the summer (Personal communication Mol, 2011). A waste water regeneration system can deliver heat throughout the year as the source of heat is not influence by seasonal fluctuations but instead finds it origin in hot water utilized in households connected to the sewer. The heat recovered from these sources is of low quality (18-21°C), equal to the heat stored in the ATES. By means of the release system in the house or utility, which includes a heat pump, the temperature is upgraded to useable temperatures for heating systems (low temperature heating system requires ± 40°C and conventional heating systems require ±60°C). The recovered cold is ±5-7°C and matches the temperature of the cold water already stored in the ATES. This cold can be utilized through distribution systems such as ventilation of cold air to cool houses or utilities.

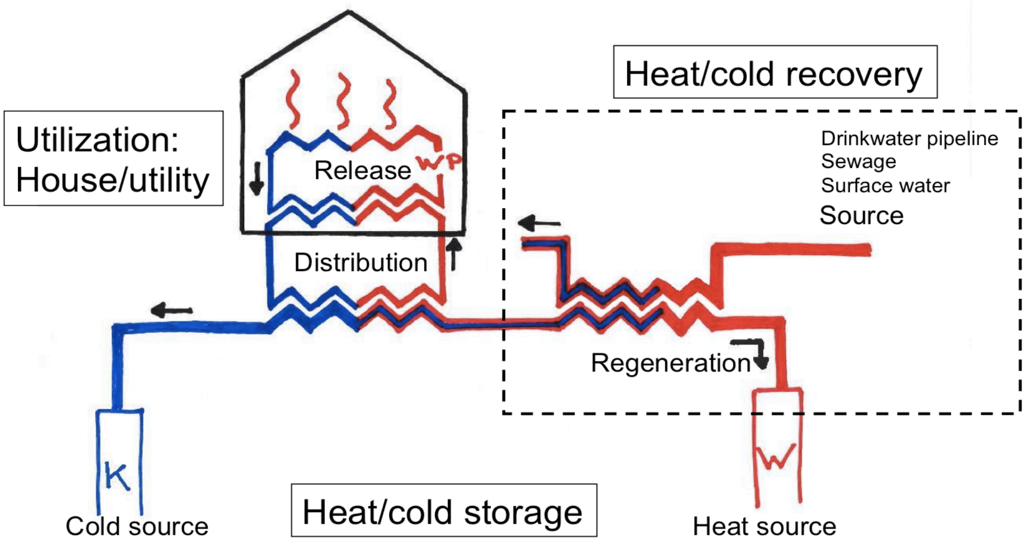


Figure 11: schematic representation of ATES regeneration demarcation (dotted box) (Mol, 2012)

To illustrate this specific mitigation option, figure 7 sketches the outlay of an ATES system. Only the part of heat and cold recovery from the three sources of the watercycle (waste water, drinking water, surface water) to regenerate an existing ATES falls within the system boundaries. The connection to the ATES is included, but not the ATES system it self, nor the release and distribution of heat/cold for utilization.

The recovered cold can be used directly for cooling purposes through a heat exchanger. The heat however is of a low quality and therefore needs to be 'upgraded' to higher useable temperatures. This might differ per customer, as some houses, mainly new and highly renovated houses, have a low temperature heating system requiring a temperature of around 35-45°C. Existing housing stock however requires 65°C for warm tapwater, for the prevention of legionella, and for heating purposes.

The sources drinking water and surface water are mainly influenced by seasonal fluctuations which means that the sources become hotter in summer and colder in winter. The cooling however is mostly required in summer and the heat most in winter. This implies that cold and heat storage (Acquifer Thermal Energy Storage, or ATES system) has to be utilized to exploit the potential. For deep lakes, also part of the category of surface water, this does not hold true because the temperature of the water deep down in the lake is 5-7°C throughout the year. The heat from waste water could technically also be recovered throughout the year.

All potential heat demand is summarized to come to an understanding of the deployment potential for heat recovery from the watercycle. As all three sources of the watercycle (waste water, surface water and drinking water) can provide heat, three different investment data are given[32].

### B.7.2. Demand for heat and cold in Amsterdam

The sustainable heat and cold recovered from the watercycle could also be employed directly, or in combination with Aquifer Thermal Energy Storage (ATES) systems. Examples hereof are datacenters that usually only have a large cold demand; swimming pools which have a large heat demand which can be supplied by heat from the waste water sewerage. Also, feasibility studies have been performed of new housing projects which will be heated by heat of waste water sewerage without ATES systems included. As the heat is of a low quality it needs to be 'upgraded' to higher useable temperatures. This might differ per customer, as some houses, mainly new and highly renovated houses, have a low temperature heating system requiring a temperature of around 35-45C. Existing housing stock however requires 65°C for warm tapwater, for the prevention of legionella, and for heating purposes.

Aside from the broad market of utility buildings and new and high renovation houses, the market of ATES regeneration has been identified. In the dense area of Amsterdam in which Waternet operates, an important source for sustainable heat and cold are ATES systems. These system are often (deliberately dimensioned) out of balance, hence requiring extra heat or cold to increase their effective functioning[33] (personal communication Scholten, 2012). Conventional solutions to address the problem of disbalance are amongst others gas fired boilers, cooling machines or dry coolers. More and more alternative and sustainable techniques come available, such as heat regeneration through street sun collectors, sunboilers, and concepts such as energy roofs.

**Quantification of heat and cold regeneration demand**

To further quantify the demand for heat and cold regeneration, estimation has been made of the number of ATES systems out of balance and of the magnitude of the disbalance. This data follow from calculations from IF technology, on the basis of a non-representative sample of 56 ATES systems in the Netherlands[34] (personal communication Vink, 2012). Of this sample, 19% of the ATES systems were in balance, with less that 10% shortage of either heat or cold. 56% ATES systems showed more than 10% excess heat delivery yearly, resulting in a net extra heat demand, for which the average was 190 MWh/year. Approximately 25% of the ATES systems of this sample showed an excess cold delivery, requiring extra cold with an average of 472 MWh/year. Matching this data with the number of current and estimated future ATES systems in Amsterdam allows us to understand the deployment potential for heat and cold regeneration from the watercycle for Amsterdam ATES systems.

The number of current and future ATES systems in Amsterdam has been estimated. It is assumed that over 233 ATES systems will require extra sustainable heat and cold up to 2020. Furthermore, it assumed that ~ 50% of the ATES systems owners will in reality be regenerating their ATES systems with sustainable heat and cold from the watercycle.

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[32] In practice the choice for a certain source will depend on the specific location of the heat/cold requiring ATES system and what the closest watercycle option is.

[33] Some experts suggest that the number of ATES systems that functions properly in reality is minimal – nation wide (personal communication Harmsen, 2012)

[34] For the municipality of Amsterdam or the province of Noord Holland monitoring data to establish the disbalance of ATES systems is scarcely available (Personal communication Huits, 2012). Currently, the municipality is performing a monitoring and evaluation study with IF technology for Amsterdam ATES systems (Personal communication Lambrechts, 2012). The sample used is non-representative for two reasons: first of all, it does not include a well-distributed population of ATES locations and secondly, different sizes and types of buildings are present in the sample. This creates a not equally distributed population, which reduces the external validity and reliability of the data. As this was the only available monitoring data, it is utilized nevertheless.

Table 23: Estimation of number of ATES systems in Amsterdam up to 2020

| Number of ATES systems in Amsterdam | | |
|---|---|---|
| Description | Value | Source: |
| # ATES systems realized up to 2011 in Amsterdam | 100[35] | Agentschap NL, 2012 |
| # ATES systems realized 2011-2020 in Amsterdam | 133[36] | Calculation |
| Total # of realized ATES systems up to 2020 | 233 | Calculation |

As the heat and cold supply to ATES systems for regeneration is regarded as a compensation measure for Waternet, it is interesting to combine the total potential of all systems that can be regenerated up to 2020. The summed disbalance of ATES systems in terms of heat demand is ± 12,000 MWh/year and the summed disbalance of ATES systems in terms of cold demand is 14,000 MWh/year[37]. Knowing this energy demand, it is possible to estimate the summed required regeneration capacity; to recover the necessary amount of heat, a total capacity of 7 MW should be available through waste water, drinking water or surface water sources. The necessary cold demand requires 6 MW of installation for cold recovery from drinking water and surface water sources.

### B.7.3. Impact on mitigation goal

In order to investigating the avoided energy use it is important to calculate CO2 savings and the financial benefits from the ATES regeneration system. Therefore, both heat and cold regeneration systems are compared with a reference system to regenerate respectively with gas boiler (for heat) and with a compression cool machine (for cold). The efficiency of a gas boiler is estimated at $\eta$ 0.84[38] and the coefficient of performance (COP) of an electric cooling device is estimated at COP 4 (CSH, 2012).

**Calculating avoided emissions for cold regeneration of ATES systems:**

$$Avoided\ emissions = \frac{Regeneration\ demand}{COP} \cdot E.F.electricity$$

Where:

- Regeneration demand = total required cold to regenerate all estimated ATES systems (in MWh)
- Avoided emissions = avoided emissions of cold regeneration compared to conventional cold regeneration with compression cool machine (ton CO2 eq./yr)
- COP = coefficient of performance compression cool machine
- E.F. electricity = emission factor electricity (ton CO2 eq. /MWhe)

Assumptions:

- COP compression cool machine = 4

[35] In total, up tot 2011, 266 permissions have been requested at the province of Noord Holland. An estimation on the basis of an ATES map issued by the province of Noord Holland suggest a realization rate of 38%.
[36] According to Taskforce WKO (2009), the national yearly growth rate for ATES systems is 12%. Projecting this statistic on the number of permits issued yearly and establishing a growth curve, leads to the assumptions that in total 354 permits will be requested in the period of 2011-2020. Of this, 38% (133 ATES systems) will according to this line of reasoning be realized.
[37] In this research it is assumed that the total required heat is provided by a watercycle source. In reality, this depends on the location and suitability of the source (flow and heat content (personal communication Mol, 2011).
[38] It is assumed that in 2020, half of the stock of boilers will be of an old type (efficiency 67%, Blom et al., 2004) and that the other half will be a highly efficient boiler (efficiency 100%, close to the theoretical efficiency of 107%). This results in an averaged efficiency of 84%.

- E.f. electricity = 0.565 ton CO2 eq./MWhe

**Calculating avoided emissions for heat regeneration of ATES systems:**

$$Avoided\ emissions = \frac{Regeneration\ demand}{\eta_{gas\ boiler}} \cdot E.F.\ natural\ gas$$

Where:

- Regeneration demand = total required heat to regenerate all estimated ATES systems (in GJ)
- Avoided emissions = avoided emissions of heat regeneration compared to conventional heat regeneration by means of a gas fired boiler
- $\eta$ = efficiency gas boiler
- E.F. natural gas = emission factor natural gas (ton CO2 eq./GJ)

Assumptions:

- $\eta$ = 0.84
- E.f. natural gas = 0.0567 ton CO2 eq./GJ

### B.7.4. Financial data

In order to calculate the cost-effectiveness of the cold and heat regeneration from sources in the watercycle, investment costs per kW have been estimated by researching different case studies and feasibility studies available[39].

To come to the costs for heat regeneration from waste water, an estimation of the total investment costs for a heat regeneration system has been made on the basis of discussions with installation company Kroon Dehly (personal communication Swaan, 2011) for a specific case in the Watergraafsmeer area in Amsterdam: the James Watt straat. Waternet plans to install a waste heat recovering sewer in this street to regenerate two existing ATES systems; total investment costs amount to ±575,000 € for a total capacity of 217kW.

The installation costs for heat and cold regeneration system from drinking water follows from two cases in the working area of Waternet. For a housing project in Diemen (De Sniep), a feasibility study has been performed by van der Meer et al., 2010, estimating an investment of 525,000-910,000€ for a system with a capacity of ±3,600 kW. Additionally, a recently developed plan is to provide large parts of the Schiphol area by sustainable cooling through cold recovered from drinking water. The total installation will cost ±30,000,000 € and will have a capacity of ±38,000 kW (Personal communication Mol, 2012).

To come to the reference costs per kW installed capacity for surface water, no feasibility or case study was available to come to a comparative calculation.  Therefore, the reference investment costs as utilized by IF technology are used: 125€/kW for heat/cold recovery from surface water (Personal communication Scholten, 2012).

In total, this leads to the following financial data for ATES regeneration:

Table 24: Financial assumptions for ATES regeneration from three different watercycle sources

| Financial data | | | |
|---|---|---|---|
| Description | Data | Margin | Source: |
| Heat regeneration from waste water | 2,700 €/kW | | Meijer et al., 2011; personal communication Swaan, 2011 |

[39] The system boundaries for heat and cold regeneration as described in figure 7 are maintained, meaning that it is assumed that all heat and cold is delivered into a new or existing ATES system, which is not included in the estimated investment costs, nor is the distribution or release system included in the investment costs. The investment costs consist of the material costs including a plate/sewer heat exchanger, a pumping system and connecting infrastructure, excluding costs for design, installation, taxes, public tender etc. Additionally, heat loss in the system due to transport of heat and cold is not taken in to account.

| | | | |
|---|---|---|---|
| Heat and cold regeneration from drinking water | 500 €/kW | +/-60% | Averaged project data Diemen de Sniep & Schiphol |
| Heat and cold regeneration from surface water | 125 €/kW | | Personal communication Scholten, 2012 |
| Lifetime (L) | 25[40] year | | Greeve et al., 2010 |
| Discount rate | 6% | | General assumption |
| Maintenance cost as percentage of investment costs | 3% | | van der Meer et al., 2010 (Sniep) |

[40] As the systems consist of different elements: a heat exchanger's lifetime is estimated at 30 years; pumps and other technical equipment have an estimated life time of 10 years (Greeve et al., 2010). Therefore, an average lifetime of 25 years is assumed in order to ease the calculation.

## B.8. Factsheet Drain waste heat recovery systems

### B.8.1. Investigation deployment potential Amsterdam DWHR

Natural renovation moments are ideal to install DWHRs in buildings (houses, utilities etc.). The total of natural installation moments is calculated by summing different sources of data. With natural installation moment it is meant that the DWHR system can be installed easily due to the naturally occurring (bathroom) renovations in existing houses or new build of houses. It is assumed that the average yearly number of new build houses in Amsterdam is 4781 houses. This is an estimation based on the average number of new built houses in Amsterdam over the past five years (Amsterdam.nl – statistics). Although significant changes in the (macro-) economical climate might affect this number, this trend is not taken in to account. Additionally, it is assumed that housing corporations perform around 2200 house renovations that would allow for the possibility to implement a shower heat exchanger. It is also assumed that private house owners (43% of the total number of houses in Amsterdam) will perform a renovation once every 25 years, in which in 50% of the cases the piping infrastructure is renovated, and it is assumed that again in 50% of these instances, a possibility exists to install a shower heat exchanger. Lastly, 2000 DWHR systems are assumed to be installed by hotels, governments, sporting facilities etc. With natural installation moment it is meant that the DWHR system can be installed easily due to the naturally occurring (bathroom) renovations in existing houses or new build of houses. This leads to the final assumption that there are approximately 9500 natural installation moments per year in Amsterdam.

### B.8.2. Impact on mitigation goal

To calculate the avoided CO2 emissions and hence the impact on the mitigation goal, the savings as a results of the DWHR systems need to be calculated. Therefore, the following assumptions are made:

Table 25: Assumptions and calculations of the savings of drain waste heat recovery systems on total gas use

| Savings due to drain waste heat recovery system (per system) | | | |
|---|---|---|---|
| Average gas use household Amsterdam | 1,150 | m³ gas/yr | CBS, 2011 |
| Gas use for showering and bathing (reference) | 265 | m³ gas/yr | Calculation |
| Energy savings due to DWHR system | 62% | | Technea, 2012 |
| Savings DWHR on total gas use | 164 | m3/year | Calculation |

**Calculating avoided emissions:**

$$Avoided\ emissions = natural\ gas\ savings\ \cdot\ heat\ value\ \cdot\ E.F.\ natural\ gas$$

Where:

- Avoided emissions = avoided emissions of heat regeneration compared to conventional heat regeneration by means of a gas fired boiler
- Natural gas savings = natural gas savings as result of DWHR (in m3/year)
- Heat value = heat value of natural gas (in GJ/m3)
- E.F. natural gas = emission factor natural gas (ton CO2 eq./GJ)

### B.8.3. Financial data

Table 26: Financial assumptions and calculations for drain waste heat recovery systems

| Assumption | Data | Unit | Source |
|---|---|---|---|
| **Investment data** | | | |
| Investment costs per system | 385 | € | Technea, 2012 |
| Total investment costs all years all systems | 37,000,000 | € | Calculation |
| Yearly O&M costs | 0 | € | Technea, 2012 |
| Yearly benefits (2011) | 980,000 | € | Calculation |
| Yearly benefits (2020) | 14,000,000 | € | Calculation |
| Lifetime | 25 | year | Technea, 2012 |
| Discount rate | 6% | | Assumption |

**Calculating yearly benefits:**

$$Yearly\ benefit = gas\ savings\ \cdot\ gas\ price$$

Where:

- Yearly benefits = financial benefits per year as a result of DWHR use (€/year)
- Gas savings = gas savings as a result of DWHR use (m3/year)
- Gas price = price of natural gas in respective year (€/m3)

## B.9. Factsheet Low flow shower head

### B.9.1. Investigation deployment potential Amsterdam LFSH

The deployment potential for the low flow shower head is based on the same assumptions as for the customer base for the DWHR system. The difference is however that currently, the penetration rate for LFSHs is 50% (Foekema & van Thiel, 2011). According to an estimated calculation of the potential renovation moments of bathing rooms in Amsterdam, approximately 4750 LFSHs could be installed each year. Note that replacing a shower head is easy, so the actual implementation is not necessarily limited to natural renovation moments. The average shower duration has relatively stabilized, and hence will not be regarded as a rebound effect[41] on the warm water savings grace to the LFSH.

### B.9.2. Impact on mitigation goal

Table 27: Assumptions and calculations of the savings of low flow shower heads on total gas use

| Assumption | Data | Unit | Source |
|---|---|---|---|
| **Savings due to low flow shower head** | | | |
| Average gas use household Amsterdam | 1,150 | $m^3$ gas/yr | CBS, 2011 |
| Gas use for showering and bathing (reference) | 265 | $m^3$ gas/yr | Calculation |
| Water use (reference shower head) | 8.5 | l/s | Foekema & van Thiel, 2011 |
| Water use (low flow shower head) | 7.4 | l/s | Foekema & van Thiel, 2011 |
| Gas use for showering and bathing (LFSH) | 230 | $m^3$ gas/yr | Calculation |
| Gas consumption savings as result of LFSH | 34.6 | m3/yr | Calculation |

**Calculating avoided emissions:**

$$Avoided\ emissions = natural\ gas\ savings \cdot heat\ value \cdot E.F.\ natural\ gas$$

Where:
Avoided emissions = avoided emissions of heat regeneration compared to conventional heat regeneration by means of a gas fired boiler
Natural gas savings = natural gas savings as result of LFSH (in m3/year)
Heat value = heat value of natural gas (in GJ/m3)
E.F. natural gas = emission factor natural gas (ton CO2 eq./GJ)

### B.9.3. Financial data

Table 28: Financial assumptions and calculations for low flow shower heads

| Assumption | Data | Unit | Source |
|---|---|---|---|
| **Investment data** | | | |
| Investment costs per system | 40 | € | Milieucentraal, 2012 |
| Total investment costs all years all systems | 1,900,000 | € | Calculation |
| Total O&M costs | 0 | € | Milieucentraal, 2012 |
| Yearly benefits (2011) | 100,000 | € | Calculation |
| Yearly benefits (2020) | 1,500,000 | € | Calculation |
| Lifetime | 25 | year | Milieucentraal, 2012 |
| Discount rate | 6% | | Assumption |

[41] In this situation, the rebound effect would entail that the positive environmental effect is diminished or eliminated due to increase in comfort, such as longer showers.

**Calculating yearly benefits:**

$$Yearly\ benefit = gas\ savings\ \cdot\ gas\ price$$

Where:
Yearly benefits = financial benefits per year as a result of LFSH use (€/year)
Gas savings = gas savings as a result of LFSH use (m3/year)
Gas price = price of natural gas in respective year (€/m3)

## B.10. Factsheet biogas production

### B.10.1. Impact on mitigation goal

Waternet is currently finalizing a proposal and hence rough assumptions are made and specific details regarding the function of the sludge destruction installation for the production of biogas lack. No calculations are made to estimate the impact on the mitigation goal or the financial yearly benefits as all estimations are provided by Piekema (personal communication, 2012).

Table 29: Assumptions utilized for resources production: biogas

| Effect | Data | Unit | Emission factor | Unit | Source emission factor | Avoided CO2 eq. emissions (ton/year) | | Effect |
|---|---|---|---|---|---|---|---|---|
| Effects | | | | | | | | |
| Reduction heat use | 2,500 | MWhe/yr | 0.000565 | ton CO2/kWh | van der Ree et al., 2011 | 1,453 | ton CO2 eq./yr | Reduction scope 1 |
| Production biogas | 3,000,000 | Nm3/yr | 0.0015 | ton CO2/m3 biogas | Personal communication Piekema, 2012 | 4,500 | ton CO2 eq./yr | Compensation measure |
| Co-incineration sludge | 2,000 | MWhe/yr | 0.000565 | ton CO2/kWh | van der Ree et al., 2011 | 1,130 | ton CO2 eq./yr | Compensation measure |
| Increased use of steam | 6,000 | MWhe/yr | 0.000565 | ton CO2/kWh | van der Ree et al., 2011 | 3,486- | ton CO2 eq./yr | Increase scope 1 |

### B.10.2. Financial data

The yearly O&M costs are composed of additional steam, aside from other O&M costs such as extra personnel and maintenance costs (Personal communication Piekema, 2011).

Table 30: Financial assumptions biogas production

| Data | | Source |
|---|---|---|
| Total installation costs | € 5,000,000 | Personal communication Piekema, 2011 |
| Yearly O&M costs | € 950,000 | Personal communication Piekema, 2011 |
| Yearly benefits | € 1,400,000 | Personal communication Piekema, 2011 |
| Lifetime | 15 years | Personal communication Piekema, 2011 |
| Discount rate | 6% | General assumption |

## B.11. Factsheet struvite production

### B.11.1. Impact on mitigation goal

No calculations are made to estimate the impact on the mitigation goal or the financial yearly benefits as all estimations are provided by Piekema (personal communication, 2012).

Table 31: Assumptions utilized for resource production: Struvite

| Effect | Data | Unit | Emission factor | Unit | Source emission factor | CO2 reduction (ton/year) | | Effect |
|---|---|---|---|---|---|---|---|---|
| **Reduction direct emissions** | | | | | | | | |
| Production struvite | 900 | ton/yr | 0.0018 | ton CO2 eq per kg product NPK | Davis & Haglund (1999), through Wood&Co wie, 2004 | 1,215 | ton CO2 eq./yr | Compensation measure |
| Co-incineration sludge | 500 | MWhe/yr | 0.000565 | ton CO2/kWh | van der Ree et al., 2011 | 283 | ton CO2 eq./yr | Compensation measure |
| MgCl2 (32% solution) | 3,000- | ton/yr | 0.10144 | kg CO2/solution | SimaPro | 304- | ton CO2 eq./yr | Increase scope 3 |
| Polymeer (42% solution) | 60 | ton/yr | 0.8946 | kg CO2/solution | SimaPro | 54 | ton CO2 eq./yr | Reduction scope 3 |
| FeCl3 (40% solution) | 1,800 | ton/yr | 0.352 | kg CO2/solution | SimaPro | 634 | ton CO2 eq./yr | Reduction scope 3 |

### B.11.2. Financial data

Table 32: Financial assumptions struvite production

| Data | | Source |
|---|---|---|
| Total installation costs | €2,700,000 | Estimation based on personal communication Piekema, 2011 |
| Yearly O&M costs | € 350,000 | AGV, 2011 |
| Yearly benefits | € 932,000 | AGV, 2011 |
| Lifetime | 15 years | Estimation based on personal communication Piekema, 2011 |
| Discount rate | 6% | General assumption |