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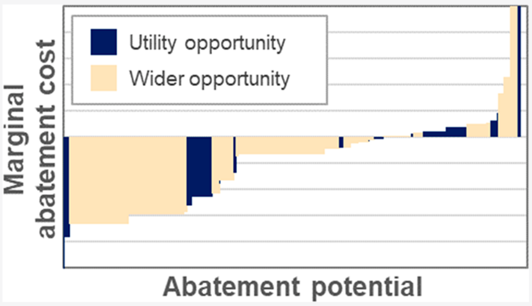

ABSTRACT: The provision of urban water and wastewater services contributes to greenhouse gas (GHG) emissions. Urban water supply and wastewater utilities can potentially achieve low-carbon or carbon-neutral operation through many "utility opportunities". Outside the jurisdiction of water utilities, many water-related "wider opportunities" can also contribute to GHG emissions abatement for cities. This study aims to explore the GHG emissions abatement potential, cost effectiveness, and enabling factors of implementing wider opportunities in cities. Using Amsterdam as a case study, we developed a marginal abatement cost curve to compare the abatement potential and cost effectiveness of both utility and wider opportunities. The results show that many wider opportunities related to thermal energy, water end use, and life cycle are cost-effective with significant abatement potential, compared to utility opportunities. This case study and emerging worldwide examples show that the water industry has a role to play to support wider water-related opportunities in cities. This vision can be supported by developing mechanisms to credit utilities for wider opportunity initiatives, building inter- and intrasectoral partnerships for utilities, accounting for scope 3 emissions of utilities, and being open to extend utilities' role beyond water and wastewater services providers.

INTRODUCTION

The provision of urban water and wastewater services contributes to greenhouse gas (GHG) emissions directly and indirectly from energy use,[1] reservoir methane emissions,[2] wastewater treatment and sludge disposal,[3] and chemicals use and infrastructure construction.[4] Several urban water supply and wastewater utilities worldwide (e.g., Amsterdam, Melbourne, New York) are setting GHG emissions reduction or carbon neutrality goals to contribute to climate change mitigation.[5]

For urban water supply and wastewater utilities (collectively referred to as water utilities in this study), low-carbon or carbon-neutral operation can be achieved through improving operational energy efficiency, generating electricity onsite from renewable sources, biogas valorization, capturing fugitive emissions, optimizing treatment processes, and purchasing carbon offsets. Significant research effort has been devoted to these utility opportunities, such as research on understanding and controlling methane and nitrous oxide emissions at wastewater treatment plants,[6,7] integrating renewable energy sources in water and wastewater utilities,[8] and maximizing energy recovery from sewage sludge.[9] Some of these opportunities also lead to operational cost savings and advance other urban water goals such as resource recovery.[10]

Outside the jurisdiction of water utilities, many wider water-related opportunities can also contribute to GHG emissions abatement for cities. In water end use, significant GHG emissions abatement can be achieved through hot-water-related opportunities such as shifting from electric water heating to gas or solar water heating,[11] water demand management in showers, and heat recovery.[12] Thermal energy recovery from drinking water for industrial cooling use has been demonstrated.[13] Taking a life cycle perspective, opportunities such as using materials with lower carbon footprint,[14] exporting biogas,[15] and recycling nutrients from wastewater[16] help reduce emissions indirectly.

Economic criteria are a dominant aspect in the policy discussion of climate change mitigation.[17] For example, the Australian state of Victoria sets out the water sector's emissions reduction obligations (47% reduction over business-as-usual) to be achieved by 2025 with one of the priorities to "*pursue actions and targets at the lowest possible cost, seeking to minimise the impact on water customer bills*".[18] While many utility and wider water-related opportunities are being researched, they are mostly being studied in silo on the technical aspects. Few studies took a systems perspective to contrast these water-related opportunities on their GHG emissions abatement potential and economic performance. Fagan et al.[19] developed

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Table 1. GHG Emissions Abatement Opportunities

utility opportunities		wider opportunities	
ID	opportunity	ID	opportunity
S1-1	sludge drying with solar energy or residual heat	S3-1	use of calcite instead of garnet sand in drinking water softening
S1-2	CO_2 emissions from combustion plants are reduced by Building Management System	S3-2	use of a 5MW aquifer thermal energy storage in a data center
S1-3	sealing sludge digestion tanks	S3-3	use of surface water as a solar energy collector to regenerate aquifer thermal energy storage systems
S1-4	flue gas treatment of combined power-heat generators	S3-4	struvite recovery from wastewater
S1-5	burning of N_2O from the waterline in the furnace of the Amsterdam Waste-to-Energy plant	S3-5	use of thermal energy (heat) from wastewater to regenerate aquifer thermal energy storage systems
S1-6	burning of CH_4 from the waterline in the furnace of the Amsterdam Waste-to-Energy plant	S3-6	use of 20,000 shower heat exchangers in households
S1-7	optimization of the nitrification in the wastewater treatment plants to reduce N_2O emissions	S3-7	use of thermal energy (heat) from drinking water to regenerate aquifer thermal energy storage systems
S1-8	sealing sewers and use of recovered CH_4	S3-8	use of calcite garnets from drinking water softening
S2-1	side stream dosing of ozone in drinking water plants	S3-9	use of thermal energy (cold) from surface to regenerate aquifer thermal energy storage systems
S2-2	supply of drinking water to water distributor by frequency-controlled pumps	S3-10	use of CO_2 from the biogas upgrading process in drinking water treatment
S2-3	building of 5 3MW wind turbines	S3-11	use of thermal energy (cold) from drinking water to regenerate aquifer thermal energy storage systems
S2-4	shutting down water conditioning at Loenderveen drinking water pretreatment plant	S3-12	use of thermal energy (cold) from industrial water to regenerate aquifer thermal energy storage systems
S2-5	installation of 100,000 solar panels	S3-13	biogas production from glycol containing wastewater from Schiphol airport
S2-6	15 additional measures 2014 in the long term energy saving program	S3-14	sludge destruction and expansion of the biogas upgrading process at the Amsterdam West wastewater treatment plant
S2-7	7 additional measures 2016 in the long term energy saving program	S3-15	use of thermal energy (cold) from wastewater
S2-8	6 additional measures 2015 in the long term energy saving program	S3-16	use of thermal energy (heat) from drinking water to regenerate aquifer thermal energy storage systems
S2-9	5 additional measures 2013 in the long term energy saving program	S3-17	regeneration of an aquifer thermal energy storage at Schiphol airport with industrial water
S2-10	400 solar panels for heat production digestion and cooling panels	S3-18	supply of industrial water without dune passage
S2-11	more efficient aeration at WWTPs	S3-19	use of thermal energy from a drinking water transport main to recover an aquifer thermal energy storage
S2-12	production of drinking water and industrial water from wastewater effluent	S3-20	use lime instead of sodium hydroxide in drinking water softening
S2-13	shut down water circulation between drinking water reservoirs	S3-21	sustainable purchase of chemicals
S2-14	use of direct current instead of alternating current	S3-22	use of thermal energy (heat) from rainwater for room heating
S2-15	direct treatment of drinking water without dune passage	S3-23	regeneration of activated carbon onsite
S2-16	replacement of small polder sewers by large polder sewers	S3-24	use of grinders in households and production of CH_4
S2-17	replacement of small sewage pumping stations by large sewage pumping stations	S3-25	use of iron containing membrane concentrate instead of $FeCl_3$ in wastewater treatment plants

a dynamic modeling framework to assess life cycle environmental impacts and cost-effectiveness of different policy, design, planning, and management options in urban water systems. Larsen[20] compared thermal energy recovery opportunities at the wastewater treatment scale and at the household scale. Lam et al.[21] used average Australian data to compare a limited set of utility and nonutility opportunities for their water-related energy use reduction potential and cost-effectiveness.

This study aims to explore the GHG emissions abatement potential, cost effectiveness, and enabling factors of implementing water-related wider opportunities in cities, in addition to the typical utility opportunities considered by water utilities. Using Amsterdam as a case study, we utilized an inventory of 50 utility and wider opportunities from the local water utility to develop a marginal abatement cost curve to compare the GHG emissions abatement potential and marginal abatement cost of these opportunities. The inventory includes opportunities on energy efficiency, process modifications, renewable energy generation, resources recovery, thermal energy recovery, household water-related management, and using alternative materials with lower carbon footprint. Hypothesizing that the water industry has a role to play to support wider water-related opportunities in cities, we discuss, based on this case study and emerging worldwide examples, the potential opportunities and enabling factors to achieve this vision.

■ MATERIALS AND METHODS

Case Study. In Amsterdam, *Waternet* is the public water utility responsible for potable water treatment and supply, wastewater collection and treatment, surface water management, groundwater management, control of the canals, and flood protection. The City of Amsterdam set climate goals on 55% reduction in GHG emissions in 2030 compared to 1990 and 95% reduction in GHG emissions in 2050 compared to 1990.[22] Owned by the City of Amsterdam and the regional water authority "Amstel, Gooi en Vecht", *Waternet* also set an ambitious carbon neutral goal.[23] *Waternet* is one of several water utilities worldwide that set specific targets for GHG emissions abatement and carbon neutrality operation.[5] This case study is especially relevant to water utilities exploring the

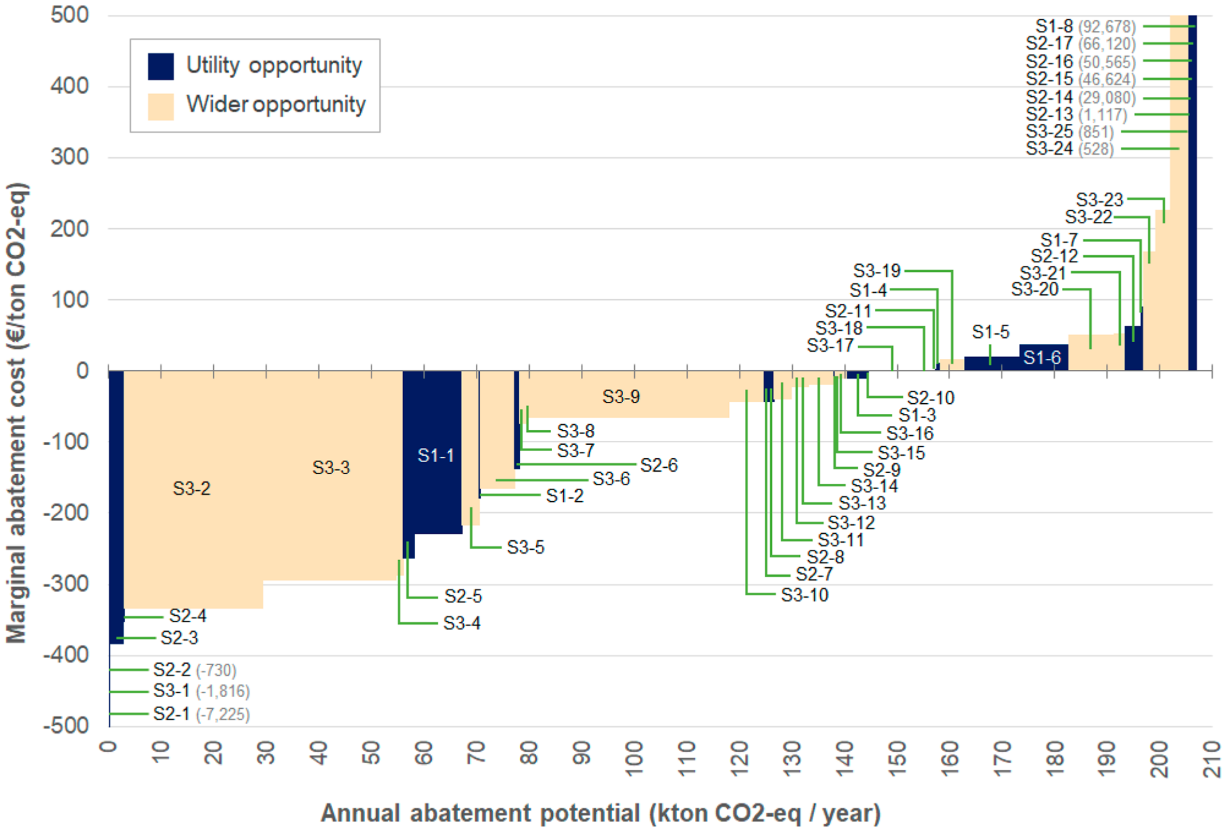

Figure 1. Marginal abatement cost curve of 50 abatement opportunities. For opportunities with marginal abatement costs less than −500 €/ton CO_2-eq or greater than 500 €/ton CO_2-eq, their marginal abatement costs are shown in brackets.

pathways to achieve low-carbon or carbon-neutral operation. The discussion also draws on examples from other countries.

Marginal Abatement Cost Curve. Marginal abatement cost curve has become a popular policy tool in assessing and communicating the economics of climate change mitigation opportunities.[17,24] A growing body of research is exploring the use of this cost curve approach for supporting energy and GHG management in urban water systems[21,25−27] and water efficiency management.[28−30] In the applications of GHG emissions management, the approach visualizes the marginal abatement costs (net cost per unit of GHG emissions abated, e.g., €/ton CO_2-eq) and abatement potentials (annual or total abatement potential, e.g., kton CO_2-eq/year) of different opportunities and prioritizes opportunities based on their marginal abatement costs. The marginal abatement cost of an opportunity can be expressed as the annualized net cost over the annual abatement potential. In this study, the annualized net costs of various opportunities consider capital investment cost, interest, linear depreciation, maintenance cost, energy (cost/revenue), other operating cost, and other revenue.

Inventory Data. The inventory of abatement opportunities used in this study was built by *Waternet*.[31] In 2015, an internal workshop was first organized for participants to brainstorm GHG emissions abatement opportunities and to roughly estimate their GHG emissions abatement potential. These opportunities were further evaluated in detail for their GHG emissions abatement potential, economic costs, and realization periods. Detailed cost calculations, the RoyalHaskoning-DHV cost calculator, and expert judgment were used to estimate capital costs and operational costs of all opportunities. An interest rate of 5% and a linear depreciation were assumed. The assessment period was from 2012 to 2050. Previous internal and external GHG emissions studies on *Waternet*'s system and expert judgment at *Waternet* were used to estimate GHG emissions abatement potential of all opportunities. For a given opportunity, its total annual expense is the sum of annualized capital expenditure (CAPEX) and annualized operating expenditure (OPEX). Its marginal abatement cost is its total annual expense over its annual GHG emissions abatement potential. Further details of all opportunities are provided in the Supporting Information (Tables S1, S2, and S3).

When an opportunity is initialized by *Waternet*, the GHG emissions abatement is credited to *Waternet*. In this study, opportunities within the jurisdiction of *Waternet* are referred to as "utility opportunities" (S1 and S2 in Table 1). They are directly related to the operation of *Waternet* and can be directly influenced by *Waternet*. Opportunities on which *Waternet* has no direct influence and/or has to cooperate with others are termed as "wider opportunities" (S3 in Table 1). They concern the emissions caused by chemicals, raw materials, and services used by *Waternet* by the suppliers of these goods and the emissions due to the use of products and services sold by *Waternet*. These are more difficult to be influenced (only indirectly) by *Waternet*.

■ RESULTS

Overall Abatement Curve. The 50 abatement opportunities are prioritized based on their marginal abatement costs from the most cost-effective (left) to the least cost-effective (right) in the marginal abatement cost curve (Figure 1). Each bar represents an opportunity. The area of a bar is the

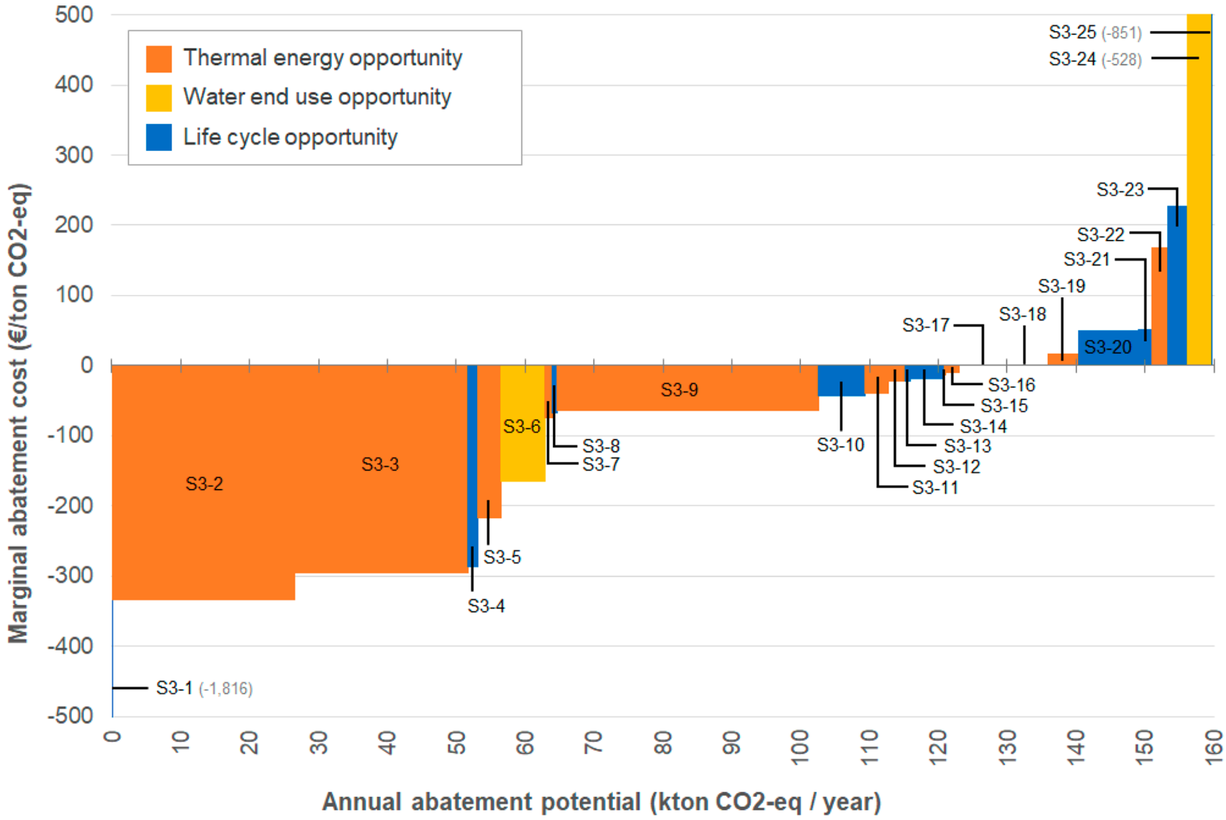

Figure 2. Marginal abatement cost curve of 25 wider opportunities, categorizing into thermal energy, water end use, and life cycle. For opportunities with marginal abatement costs less than −500 €/ton CO_2-eq or greater than 500 €/ton CO_2-eq, their marginal abatement costs are shown in brackets.

annualized net cost of an opportunity. The width of a bar corresponds to the abatement potential (kton CO_2-eq/year), while the height of a bar is the marginal abatement cost (i.e., the cost per unit of emissions abated, €/ton CO_2-eq). A negative marginal abatement cost means a net cost savings. The 25 utility opportunities that can be directly influenced by the water utility are shown in dark color, while the remaining 25 wider opportunities are in light color.

The bigger cost-effective utility opportunities (in term of annual abatement potential) are building of five 3MW wind turbines (S2-3), installation of 100,000 solar panels (S2-5), and sludge drying with solar energy or residual heat (S1-1). The bigger cost-effective wider opportunities are use of 5 MW aquifer thermal energy storage in a data center (S3-2) and use of surface water as a solar energy collector to regenerate aquifer thermal energy storage systems (S3-3). The total abatement potential of cost-effective wider opportunities (123 kton CO_2-eq/year) is far more substantial than that of utility opportunities (21 kton CO_2-eq/year).

As an example, to achieve a reduction target of 40 kton CO_2-eq in the least cost manner, the water utility has to implement 17 opportunities if only limited to utility opportunities (i.e., from S2-1 until S1-6, skipping light-colored wider opportunities in Figure 1). Some of these opportunities are not cost-effective (i.e., positive marginal abatement costs). Alternatively, if all categories of opportunities can be implemented, the water utility only needs 7 opportunities to reach the reduction target (i.e., from S2-1 until S3-3).

Abatement Curve for Wider Opportunities. The 25 wider opportunities (from the full marginal abatement cost curve in Figure 1) are further categorized as thermal energy, water end use, and life cycle (Figure 2). These are opportunities beyond typical measures implemented at water utilities. Thermal energy opportunities are about recovering, supplying, and storing sensible heat and cold. Water end use opportunities are initiatives implemented at water users. Life cycle opportunities are any other measures (at the water utility) that lead to emissions reduction at sources not owned or controlled by the water utility (e.g., supply chain of materials).

Thermal energy opportunities have the greatest cost-effective abatement potential (S3-2: use of a 5MW aquifer thermal energy storage in a data center, S3-3: use of surface water as a solar energy collector to regenerate aquifer thermal energy storage systems, S3-9: use of thermal energy (cold) from surface water to regenerate aquifer thermal energy storage systems). Two of the bigger cost-effective life cycle opportunities are the use of CO_2 from the biogas upgrading process in drinking water treatment (S3-10) and sludge destruction and expansion of the biogas upgrading process at the Amsterdam West wastewater treatment plant (S3-14).

Limitations. There are several limitations on the inventory of water-related opportunities used for developing the marginal abatement cost curve. First, the inventory was not intended to be exhaustive, especially for water end use opportunities that water utilities currently have little economic incentive to implement them. Second, *Waternet* has started GHG emissions management long before the development of the inventory, so opportunities with greater abatement potential and cost-effectiveness might have already been implemented and are not included in the inventory. For other water utilities, their inventories would depend on their status of GHG emissions management and other local contexts. Third, uncertainties (e.g., future energy-mix, interest rate, opportunity lifespan, future energy price, GHG emissions abatement potential estimates, cost impacts of future technological improvements) were not evaluated. Detailed economic and environmental analysis of individual opportunities under different future scenarios is needed to evaluate their feasibility, to better estimate the cost and abatement potential, and to understand the sensitivity of modeling various opportunities. The inventory just provides a brief overview on what opportunities are possible.

A sensitivity analysis was performed on the marginal abatement costs of the four most significant opportunities by economic performance. The sensitivity analysis (detailed in the Supporting Information) shows that while certain input parameters can significantly influence the marginal abatement costs of wider opportunities (e.g., energy prices on thermal energy-related opportunities), there is still a high confidence in the general conclusion of this study that some wider opportunities are potentially more cost-effective (i.e., with attractive marginal abatement costs) than some utility opportunities. Therefore, it is worth the effort for water utilities to explore wider opportunities and to identify those that are cost-effective to them.

The limitations of marginal abatement cost curve approach are well documented.[17,24] In the context of this study, the approach just provides one perspective on GHG emissions management of urban water systems. In practice, the prioritization of implementing opportunities is based not only on the marginal abatement cost (i.e., cost-effectiveness) but also on other factors such as initial investment cost, future cost uncertainty, implementation time horizon, operational risk, performance uncertainty, and resource recovery targets. For *Waternet*, aspects such as legislations, restrictions, and subsidies also play an important role.

■ DISCUSSION

Water-Related Opportunities beyond Water and Wastewater Utilities. While the prioritized opportunities in the marginal abatement cost analysis are specific to the water utility evaluated, this study demonstrates that many wider water-related opportunities are potentially cost-effective and have substantial GHG abatement potential for the society. It is worth the effort for water utilities to explore wider opportunities and to identify those that are cost-effective to them. We discuss three categories of these wider opportunities—thermal energy, water end use, and life cycle. Their GHG abatement potential and cost effectiveness are also evident from examples worldwide.

Thermal Energy Opportunities. A significant amount of energy can potentially be recovered from the water cycle.[32] In municipal wastewater, available thermal heat energy is a few times more than the chemical energy contained in organic matter, which is often partially recovered as biogas.[33,34] This heat energy can be recovered by heat exchangers (where the temperature gradient is higher, e.g., households) or heat pumps (where wastewater temperature is considerably lower, e.g., wastewater treatment plants). In the water supply side, cold recovery from surface water and drinking water is feasible,[32] without the fouling and clogging issues as in wastewater heat recovery.[35] In both heat and cold recovery opportunities, a significant barrier for their implementation is the spatial and temporal mismatch between recovered energy supply and its demand.[35,36] This can potentially be addressed by the use of aquifer thermal energy storage (ATES), in which sensible heat and cold is stored in the subsurface through injection and withdrawal of groundwater.[32,37] This enables interseasonal energy storage (i.e., cooling for summer, heating for winter). While many thermal energy recovery opportunities are at water utilities, supplying or storing the recovered energy are beyond the core business of water utilities.

Waternet has conducted extensive research to evaluate the potential of different thermal energy recovery opportunities, especially on performing economic analysis,[31] conducting pilot studies,[38] and understanding the microbial risks of cold recovery from drinking water distribution systems.[39] Many of the assessed thermal energy recovery opportunities are economically viable (Figure 2), especially when combining with ATES systems which are abundant in The Netherlands.[32]

Heat recovery from sewer and influent and effluent of wastewater treatment plants has been in practice in a number of European countries.[35,40] In addition, some studies in Asia and Northern America have demonstrated that wastewater thermal energy recovery for heating and/or cooling is cost competitive and has GHG emissions abatement potential.[41−43] On the other hand, energy recovery from drinking water for cooling is a relatively new opportunity with little evaluation on its cost effectiveness.[13,44]

Water End Use Opportunities. Many water-related opportunities for GHG emissions abatement are present in water end use. In urban water systems, households have significant abatement opportunities because household water-related energy use is many times more than the energy use in the water supply and wastewater treatment systems.[1,45]

Water utilities have the least influence on the implementation of water end use opportunities, compared to thermal energy opportunities and life cycle opportunities. Not surprisingly, *Waternet* only included two water end use opportunities in their inventory. One of them is the use of shower heat exchangers in households (i.e., also a thermal energy opportunity, based on a pilot study[38]). While water utilities can advise the use of shower heat exchangers, they may not be the competent authority for the installation and monitoring of these devices.

In Australia, the Water Efficiency Labeling and Standards scheme was commenced in 2006 to mandate water efficiency labeling for indoor water-using fixtures and appliances. It was estimated that the scheme has significant long-term economic benefits and GHG emissions abatement (53.5 MtCO_2-eq over 30 years) from the energy savings from reduced water heating.[46] In the US, a study used average national data to assess energy efficient opportunities for the average household.[26] The results show that many water-related opportunities (e.g., water-efficient showerhead, water-efficient faucet, heat pump water heater) are economically attractive and offer a substantial energy savings potential. A national-scale analysis in the US has shown that shifts in residential hot water systems from electric to natural gas or solar water heating can lead to GHG emissions abatement in most regions.[11] In a study on energy efficiency retrofitting to existing houses in Australia, upgrading hot water systems (i.e., electric heating to gas heating, existing gas heating to higher efficiency gas heating or gas-boosted solar heating) is also found to be a significant economically attractive measure for household GHG emissions abatement.[47]

Life Cycle Opportunities. Taking a life cycle perspective implies that water utilities account for their upstream and downstream impacts. In the case of GHG emissions accounting, these life cycle impacts are the scope 3 emissions. This type of indirect emissions is a consequence of water utilities' activities, but the emissions are not from sources owned or controlled by the water utilities. The question is who should get the credits for reducing these emissions. For instance, the use of recovered materials such as struvite and polyhydroxyalkanoate from wastewater can potentially reduce GHG emissions by avoiding the production of conventional materials that are more carbon-intensive.[48] Should this emissions abatement be credited to the water utilities who invest in recovering these materials, or should this be credited to the users who choose these recovered materials over conventional materials?

While there is the question on allocating emissions abatement credits among stakeholders (i.e., who should get the credits for reducing these life-cycle emissions?), in the end it is a societal challenge to reduce GHG emissions. GHG emissions accounting and allocation should not be an obstacle to realize abatement opportunities, especially when they are economically attractive. A consistent accounting framework is needed for all stakeholders to clearly account for both their upstream and downstream scope 3 emissions impacts (e.g., water utilities account for the impacts of resource recovery as downstream emissions abatement, while users of recovered resources count the impacts as upstream emissions abatement).

Waternet partially accounts for their scope 3 emissions. In addition, they consider that they get the GHG emissions abatement credits for opportunities initiated by them. For instance, reuse of calcite in drinking water softening and struvite recovery from wastewater have resulted in both cost savings and GHG emissions abatement.[14] The GHG emissions abatement of both initiatives are credited to *Waternet.*

While many life cycle assessment studies credited scope 3 emissions abatement to wastewater treatment systems through the approach of "system expansion" with substitution (e.g., fertilizer offset for nutrient recycling through sludge reuse and struvite use for agriculture,[16] energy export from biogas generation[49]) and some studies paid special attention to scope 3 emissions accounting,[50,51] in practice, many water utilities only include scope 1 and scope 2 emissions in their GHG emissions accounting.[52]

Enabling Factors. This case study of *Waternet* in The Netherlands and some worldwide examples suggest that there are enabling factors that can potentially catalyze water utilities to support wider water-related opportunities for GHG emissions abatement in cities.

Crediting Wider Opportunities. Developing mechanisms to credit water utilities for their initiatives to reduce GHG emissions at water end use (and wider systems) is an enabling factor. These mechanisms could enable wider opportunities to generate tradeable carbon credits that water utilities can purchase to offset their emissions. In Australia, Sydney Water received tradeable carbon offset credits through the New South Wales Greenhouse Gas Abatement Scheme (discontinued) for their WaterFix Program that helped reduce residential customers' electricity use by installing water-efficient fixtures.[53,54] In Japan, the domestic carbon credit trading scheme includes GHG emissions abatement from using water-saving fixtures.[55,56]

Building Partnerships. The building of partnerships with other water utilities and other sectors (e.g., end users of recovered resource, energy suppliers) is an enabling factor. It helps water utilities to better manage the risk of implementing opportunities that are outside their core businesses. *Waternet* partnered with other water utilities, business sectors, and research institutes to, for example, recover thermal energy from drinking water for industrial cooling[13] and to sell recovered raw materials (from drinking water and wastewater) and their derived products.[57,58] In Australia, Yarra Valley Water (YVW) built an anaerobic digestion facility for biogas generation from food waste, oil and grease, and animal processing waste.[59] The facility supplies energy to the nearby wastewater treatment and recycled water plants and exports excess energy to the electricity grid. The partnership with East Bay Municipal Utility District (EBMUD) in California provided insights for YVW to pursue this waste-to-energy initiative that is not typical for water utilities.[60] EBMUD implemented codigestion of food waste and sludge in its main wastewater treatment plant, which became the first net-positive and energy-generating wastewater treatment plant in the US.[61] Carbon credit is also generated from exporting the surplus energy.

Accounting for Scope 3 Emissions. If water utilities (voluntarily or are regulated to) account for scope 3 emissions, they would have a stronger incentive to investigate measures to reduce their indirect upstream emissions (e.g., outsourced services, chemicals production)[62] and downstream emissions (e.g., sludge disposal, water end use).[62] Scope 3 emissions do not have to cover a full life cycle scope but need to practically assess the major indirect emissions attributable to the water utilities' activities.[63] Since *Waternet* includes scope 3 emissions (e.g., sludge transport, residual materials transport and processing, chemicals production and transport, building materials and piping materials, business transport) in its total GHG emissions, *Waternet* counted emissions abated from their initiatives on life cycle GHG emissions.[23]

Extending the Roles of Water Utilities. Another enabling factor is that water utilities are open to extend their role beyond providing water supply and wastewater treatment services to explore economically viable opportunities outside their core businesses. In the case of energy recovery from food waste, both YVW in Australia and EBMUD in the US recognized that they have the relevant skills and technology in their wastewater treatment facilities to handle food waste.[60,61] Revenue for treating food waste, reducing energy cost, and selling the surplus energy provide significant economic incentives. In Denmark, under the national energy saving scheme, water utilities can sell the energy savings from implementing opportunities such as supplying district heating from drinking water and wastewater heat recovery.[64] *Waternet* has a thermal energy program to investigate what role it can play as an operator of heat networks and/or a supplier of heating, when Amsterdam is transiting into a natural gas-free city.[57]

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.0c05385.

Additional information on GHG emissions abatement opportunities, economic assessment of GHG emissions abatement opportunities, abatement potential and marginal abatement costs of GHG emissions abatement opportunities, and sensitivity analysis (PDF)

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Notes

The authors declare no competing financial interest.

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