Urban Water Utility Sustainability: A Framework for Assessment and the Role of Energy-Related Measures

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ABSTRACT

This paper presents a framework to determine which key indicators provide a "snapshot" assessment of U.S. urban water utility sustainability. Specifically, this paper focuses on energy-related measures and practices, which can have both direct and indirect impacts on sustainability measurements.

External drivers and market shifts require urban water utilities to operate differently and consider whether their operations are sustainable. These utilities play an important role in the country's energy-water nexus, a relationship directly relevant to the economic, environmental, and social health of our urban areas.

The framework brings together information from literature and from two qualitative methods to assess the sector's inclination towards energy-related practices as a component of sustainable urban water utilities. Preliminary results from the interviews and freelisting indicate that direct and indirect energy practices are a prevalent theme among responses from water utility leaders and water quality professionals.

Introduction

Urban water utilities are crucial to the economic, environmental, and social health of urban areas. Water infrastructure provides an essential service to residences, businesses, and industry. Potable water supply depends on the management of water sources, sometimes far from urban centers. Potable water is typically sourced from groundwater or surface water from lakes or streams, treated, and distributed to end users. Used water, or wastewater, is collected via systems of pipes and typically conveyed to a centralized treatment plant, or water resource recovery facility (WRRF). This treated water is generally discharged to another waterbody – a stream, lake, or ocean. All of this water treatment and conveyance requires sophisticated management and significant infrastructure, much of which is near the end of its useful life in the U.S. The investment needed for the next 20 years is $384 billion for drinking water (EPA Office of Water 2013) and $298 for wastewater and related stormwater infrastructure (EPA 2009).

While our current urban water infrastructure generally functions as designed, cracks are literally and figuratively showing in the systems. Aging infrastructure and increasing regulatory requirements contributed to both water and wastewater receiving a "D" grade in the 2013 American Society of Civil Engineers' Report Card for America's Infrastructure (ASCE 2013). A number of external pressures, including urbanization and population growth, climate change, fiscal constraints, and the previously mentioned aging infrastructure and increasing regulations, all adversely affect the infrastructure. This raises the question of how sustainable the U.S. urban water infrastructure is over the long term.

There is a shift in the thinking of some leading urban water utility leaders due to the external pressures listed above and the new reality of severely decreased or eliminated federal grants for water infrastructure. What has emerged is the concept of the "Utility of the Future," presented in a 2013 report by three organizations serving the wastewater sector, *The Water Resources Utility of the Future: A Blueprint for Action* (NACWA, WERF, WEF 2013). The report describes the transformation of utilities from simply collecting and treating wastewater to being a "manager of valuable resources, a partner in local economic development, and a member of the watershed community seeking to deliver maximum environmental benefits at the least cost to society." The "Utility of the Future" accomplishes this by reusing water, recovering and utilizing nutrients and other constituents, capturing energy from biosolids and liquid streams, generating renewable energy, and implementing green infrastructure for stormwater management and other quality of life benefits. The current resource recovery paradigm in the water sector primarily addresses "N-E-W," or nutrients, energy, and water. This paper focuses on the energy component of resource recovery, but energy indirectly impacts the other two resources, as well as other facets of utility operations.

A *sustainable* urban water utility takes a long-term, inter-generational approach to its operations and resource consumption. A triple bottom line (TBL) framework (economic, environmental, and social components) is frequently-used for sustainability assessment and all three components are needed to ensure sustainability for U.S. urban water utilities and their services. As noted, water utilities are often part of a larger municipal government. Relative to other uses, the energy requirements for a water utility are often the largest of the municipality's energy needs (PAGI 2008) (WEF 2009). Within the water utility itself, energy costs are typically the second largest expense after personnel expenses (Copeland 2014). Therefore, the energy consumed by water utilities has a significant impact on the economic sustainability of a water utility and beyond to the municipal government level where applicable.

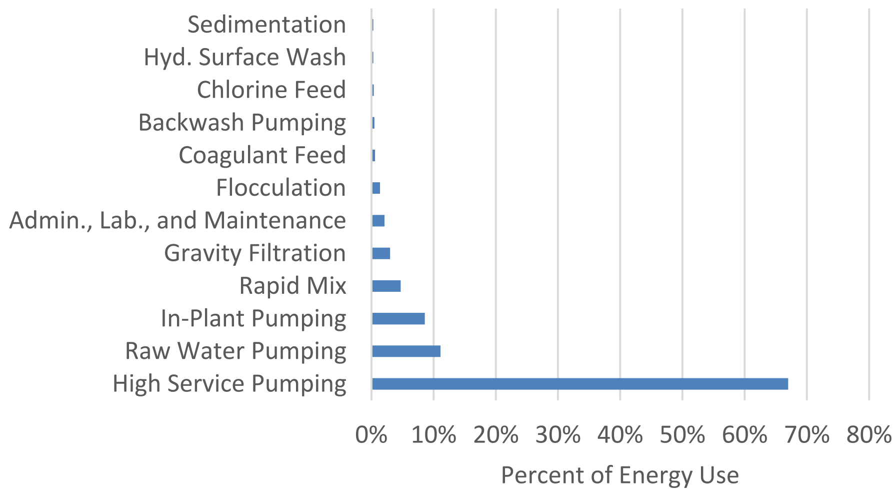
Despite the importance of energy needs and costs to urban water utilities, direct energy usage, conservation, sourcing, and indirect energy indicators are rarely measured, tracked, or compared as part of a larger assessment of a utility's sustainability. This paper presents a framework for a larger research project to develop a "snapshot" sustainability assessment for U.S. urban water utilities. It also focuses on the energy components of urban water utility sustainability, based on preliminary input from literature reviews, interviews of 10 U.S. urban water utility leaders, and surveys of 19 water utility management professionals.

Energy-Water Nexus In The Municipal Water Sector

The energy-water nexus refers to the interrelationship between energy and water, where "water is an integral element of energy resource development and utilization… [and] an integral part of electric-power generation." Additionally, "satisfying the Nation's water needs requires energy for supply, purification, distribution, and treatment of water and wastewater." (DOE 2006). This paper focuses on the latter part of the energy-water nexus: energy usage by the water sector.

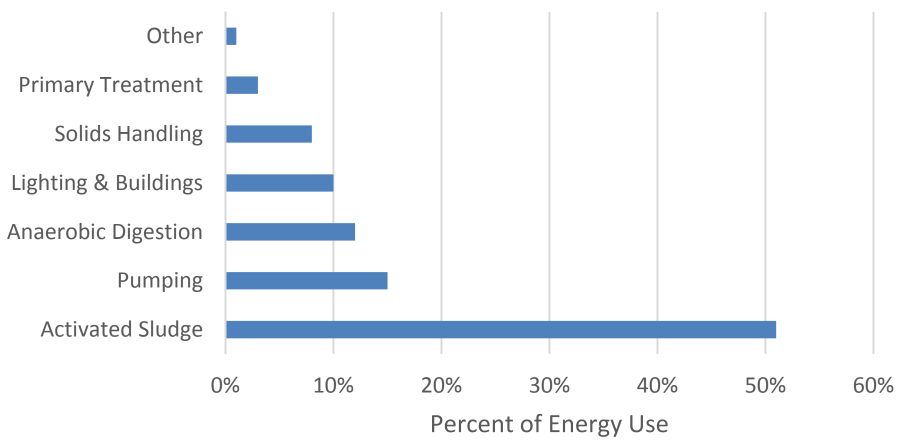
Estimates for national energy consumption for water and wastewater vary. A value of approximately 4% of the nation's power is frequently cited for water supply and wastewater treatment (EPRI 2002). A 2014 Water Environment Research Foundation (WERF) report cites 0.6% for municipal wastewater (Tarallo 2014). Figure 1 shows the majority of energy consumption is related to pumping at a typical surface water treatment plant. Figure 2 shows about half of the energy consumption is for the activated sludge process, or the aerated biological reactors that serve as "secondary treatment" at a typical WRRF.

Figure 1. Energy consumption in a surface water treatment plant



(adapted from WEF 2009)

Figure 2. Energy consumption in a typical WRRF



(adapted from WEF, 2013)

The energy intensities for water and wastewater utilities are highly variable and will depend on water source, water quality, topography, treatment requirements, and distribution/collection pipe length, age, condition, and material (DeMonsabert et al. 2009; WEF 2009; Santana, Zhang, and Mihelcic 2014).

Utilities can reduce net energy consumption by either reducing energy consumed or recovering the water's embedded energy. Energy *cost* reduction can result from peak load shaving or shifting demands to lower-rate periods. Energy *recovery* can come from the water's thermal, chemical, or kinetic energy. Electricity or fuel can also be generated by wastewater byproducts (Liner et al. 2014) or via onsite renewable sources, such as wind or solar.

Importance Of Energy-Water Nexus To Urban Water Utility Sustainability

For the purpose of this research, a *sustainable* utility will provide its services for current and future generations, protect public and environmental health, and enable economic growth, all while minimizing resource consumption. This builds on a commonly-used definition of sustainability from the World Commission for Environmental and Development's publication, *Our Common Future*, known as the Brundtland Report (WCED 1987). This report describes sustainable development as "…development that fulfils the needs of the present generation without compromising the abilities of future generations to meet their own needs." A frequently-used framework for sustainability measurement is the triple bottom line (TBL), which categorizes actions, measurements, or metrics into economic, social, and financial components.

Water utilities' future energy use will likely increase for two reasons. First, new regulations requiring more stringent water quality are linked to increasing energy needs (Kiparsky et al. 2013). Second, the population will grow, increasing demand and the energy needed for more supply and treatment (Sanders and Webber 2012) (Stillwell, Hoppock, and Webber 2010). This population growth will likely occur in urban rather than rural areas (UN 2012), straining urban water utilities in particular.

Energy usage is directly linked to a utility's sustainability. As noted above, the energy required to pump, treat, distribute, and clean potable and used water is significant. Because energy demands for urban water utilities will grow, a utility's financial sustainability is therefore directly linked to energy costs and its ability to manage those costs.

The "Utility of the Future" concept introduced above addressed this issue by encouraging energy efficiency and resource recovery, including energy resources. This transition is now occurring in a select number of utilities (Liner and Stacklin 2013) and is reflected in the 2011 position statement from the Water Environment Federation (WEF) on Renewable Energy Generation from Wastewater:

> *WEF believes that wastewater treatment plants are not waste disposal facilities, but rather water resource recovery facilities that…have the potential to reduce the nation's dependence upon fossil fuel through the production and use of renewable energy.* (WEF 2011)

Potable water utilities have the potential to recover energy in the form of kinetic energy using micro-hydropower but recovery is dependent on system topography and pressures (McNabola et al. 2014). Recent research showed that significant energy generation from WRRFs is possible, with the total available energy embedded in domestic wastewater to be five times the energy currently used to treat that wastewater (Tarallo 2014). But there are limited examples of this in the U.S. Currently, the East Bay Municipal District in Oakland, CA is energy net positive with other utilities such as Gloversville-Johnstown, NY and Sheboygan, WI generating up to 90% of their own energy (Liner and Stacklin 2013). Most of the energy produced at these plants comes from biogas generation and subsequent conversion to energy. However, there is great potential for more energy recovery. Of the more than 5,000 WRRFs in the U.S. with flows greater than one million gallons per day, just over 1,000 beneficially use the biogas for purposes such as heating or power generation. Only 270 are generating electricity from the biogas. (WEF and NBP 2013)

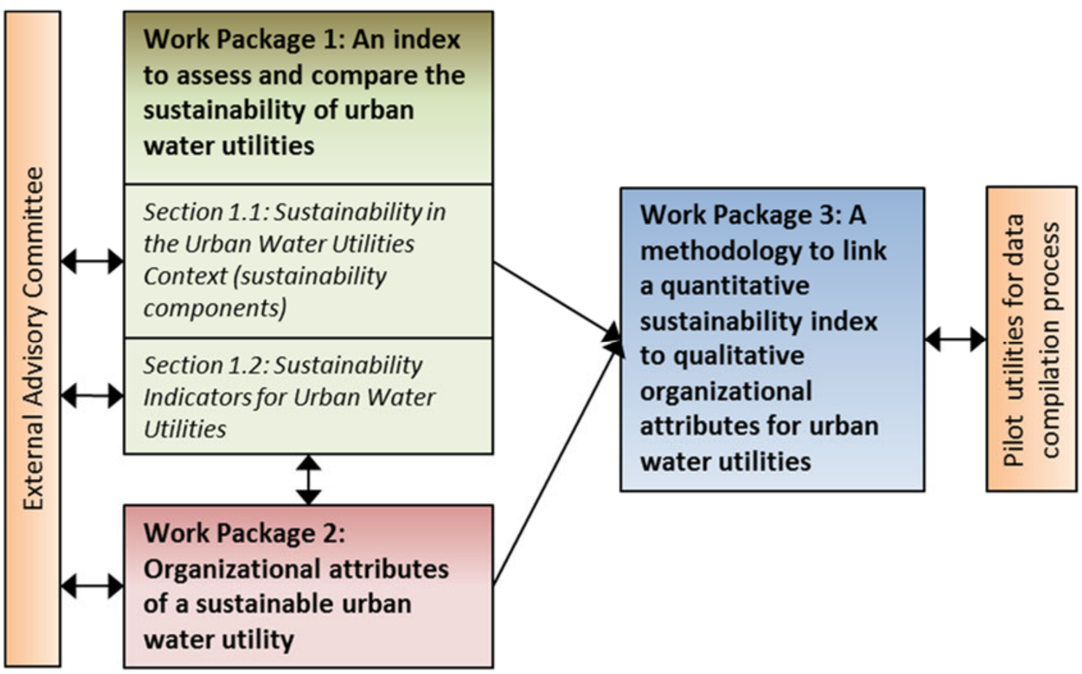
Although biogas has been the primary focus for energy recovery, recent research showed the national energy recovery potential, mainly in the form of heat (81%), with far less chemical energy potential (19%) and a very small amount of kinetic energy recovery (<1%) (Tarallo 2014).

Therefore, urban water utilities have the potential to offset their energy needs with energy generation from the water conveyance and treatment, significantly contributing to a utility's sustainability. Yet, examples of this are rare. Various barriers exist, including the regulatory reality that the mission of most urban water utilities is to meet their water quality permit, not to generate energy. The next section will describe a method to reveal what leading urban water utility leaders think about utility sustainability and the role of energy-related practices in sustainability measurement.

Methods

The framework presented in this paper is part of a larger research program to assess and prioritize key organizational attributes that drive sustainability for U.S. urban water utilities. It is building on previous research to develop an indicator-based system to quickly assess sustainability and define a set of key organizational attributes for those utilities. Ultimately, the research will propose a method to link the sustainability assessment to organizational attributes, helping prioritize actions in the transition to a more sustainable urban water utility. The overall research program is shown in the three work packages in Figure 3. This paper's focus on the prevalence of energy and its direct and indirect connection to potential indicators for sustainability assessment is generated from Work Package 1.

Figure 3. Research structure



There is a gap in current literature regarding U.S. urban water sustainability assessment. Furthermore, there has been very limited research on linking a sustainability assessment to a utility's internal attributes. Part of this gap relates to scale. Only about 11% of the papers on integrated water resource management in the last decade focused on cities or municipalities, much less the water utility itself. Most were focused on river basin or country-wide scales (Gallego-Ayala 2013). For those focused on cites, they tended to be European-centric (Van Leeuwen and Sjerps 2014) or studies on Australian cities (Brown and Farrelly 2009) (Brown, Keath, and Wong 2009), two regions that operate in a different regulatory and reporting scheme than the U.S.

Three primary sources are generating data to develop sustainability indicators for this research program. First, a literature review of sustainability indicators from water sector and non-water sector frameworks was conducted. Second, an external advisory committee (EAC) was formed and is being interviewed about sustainable practices using a semi-structured interview process. Third, the author is surveying water sector professionals using a process called freelisting to establish a domain of sustainable practices.

The EAC is comprised of 12 U.S. water utility leaders from across the country. Participants were selected using the technique of "convenience sampling," representatives to whom the researcher has access and who are familiar with sustainability concepts. Convenience sampling "often grants the researcher a level of access to and familiarity with the sample that guarantees a richness of data that could not be attained if the sample were less familiar, and therefore less convenient, to the researcher" (Koerber and McMichael 2008). Utilities were selected to achieve a balance of utility geography, service (water, wastewater, or both), and governance structure.

For the semi-structured interviews, a set of predetermined questions is used, but unlike structured interviews, which cannot stray from the predetermined questions, semi-structured interviews allow the researcher to ask additional questions that emerge from the interview responses. Key sustainability questions asked of each EAC member are listed in Table 1. Whenever possible, these individual interviews are occurring face-to-face and all interviews are recorded and will be transcribed. Transcriptions will be analyzed using discourse analysis, an approach that can identify frequently-used terms and phrases among all participants. Computer Assisted/Aided Qualitative Data Analysis Software such as HyperRESEARCH may be used to identify general patterns and themes regarding sustainable practices.

Table 1. Key sustainability interview questions

Sustainability question number	Question
1	What do you believe are the most important *economically*-sustainable practices for U.S. urban water utilities?
2	What do you believe are the most important *environmentally* sustainable practices for U.S. urban water utilities?
3	What do you believe are the most important *socially* sustainable practices for U.S. urban water utilities?
4	What do you believe are the most important *infrastructure-related* sustainability practices for U.S. urban water utilities?

Freelisting is a standard anthropological method used to establish a domain, or items included in a particular category by surveying not more than a few dozen people who are familiar with that category (Schrauf and Sanchez, 2008). Depending on the coherence of the domain, about 20 to 30 participants are usually adequate (Weller and Romney 1988). For this research program, freelisting input is being collected via online surveys and participants remain anonymous. Eligible participants in the freelisting exercise include water professionals familiar with urban utility management. They were solicited from existing networks of water professionals (via the American Water Works Association's (AWWA's) Management and Leadership Division, Strategic Management Practices Committee, and Finance, Accounting and Management Controls Committee, and WEF's Utility Management Committee) and from the researcher's sector contacts using referral and convenience sampling. Freelisting as a method has the benefit of measuring convergence around a domain which can be determined by analyzing responses as they are completed. Survey participants are asked to first indicate which type of water utility they primarily work with (water, wastewater, or both) and to provide no more than 20 examples of sustainable practices for U.S. urban water utilities, a "free list" of ideas that fit in that domain.

Results from the freelisting survey will be evaluated to identify and define the domain of sustainable practices for U.S. urban water utilities. Software such as Anthropac and SPSS will be used to analyze the results, including which concepts are most frequently cited and the degree of agreement on those concepts. To date, 19 participants have completed the freelisting survey.

Preliminary Results

Literature Review

Current literature on water utility sustainability indicates energy plays an important role in sustainability assessment, whether it is a *direct* or *indirect* link to energy. Direct links include practices that specifically target *energy*, such as energy conservation and energy generation related to the water conveyance, collection, or treatment systems. For example, this would include pumping or treatment energy efficiencies or digestion processes for the purpose of generating energy. Indirect links include other practices that happen to impact energy usage or generation either inside or outside of the water utility. For example, water reuse is a practice that can reduce overall energy consumption compared to extraction of other water sources. Biosolids land application indirectly impacts energy consumption by offsetting the energy otherwise needed to generate nutrients for fertilizer.

The City Blueprint is a comprehensive set of indicators to assess the sustainability of water management in an urban area or region (Van Leeuwen et al. 2012). While it does not specifically assess a water *utility*, this system, developed in the Netherlands and primarily applied to European cities to date, provides an example of an attempt to measure urban water sustainability.

When the 24 City Blueprint indicators were assessed for a link to energy, half have either a direct or indirect link, as shown in Table 2. While some connections are subject to interpretation, it generally shows that energy pays a significant role in the sustainability assessment of a region's or city's water management. Analysis of earlier papers on water utility sustainability indicators resulted in a somewhat smaller percentage of energy-related indicators. Hellström et al. (2000) developed a list of 32 sustainability indicators for Swedish water and wastewater utilities, with two directly-related to energy and eight indirectly related. Similarly, Balkema et al. (2002) reviewed 15 papers, compiling sustainability indicators for wastewater treatment systems. Of the 37 indicators, one was directly related to energy and eight were indirectly related.

Table 2. Mapping of direct or indirect relation of City Blueprint indicators to energy

		Indicator link to energy*	
Category	Indicator	Direct	Indirect
Water Security	1. Total water footprint		1
	2. Water scarcity		
	3. Water self-sufficiency		
Water Quality	4. Surface water quality		1
	5. Groundwater quality		1
Drinking Water	6. Sufficient to drink		
	7. Water system leakages		1
	8. Water efficiency		1
	9. Consumption		1
	10. Quality		
Sanitation	11. Safe sanitation		
	12. Sewage sludge quality		1
	13. Energy efficiency	1	
	14. Energy recovery	1	
	15. Nutrient recovery		1
Infrastructure	16. Maintenance		
	17. Separation of WW and SW		
Climate Robustness	18. Local authority commitments		1
	19. Safety		
	20. Climate-robust buildings	1	
Biodiversity and Attractiveness	21. Biodiversity		
	22. Attractiveness		
Governance	23. Management & action plans		
	24. Public participation		
	totals	3	9

* further information on the indicator descriptions can be found at van Leeuwen et al. 2013

Semi-Structured Interviews

To date, 10 of the 12 interviews with urban water utility leaders comprising the EAC are completed. One is from a drinking water-only utility, three are from wastewater-only utilities, and five are from combined water/wastewater utilities. The recordings have not been transcribed and discourse analysis has not been performed yet. However, notes taken during the interviews provide preliminary insights from frequency of the responses on the role of energy indicators in measuring sustainability from the perspective of urban utility leaders. In the open-ended questions about the most important economically, environmentally, socially, and infrastructure-related sustainable practices, 3 of the 10 responded that energy generation and energy conservation were both important practices, each having a *direct* link to the utility's energy. Four of the 10 revealed that measuring their carbon footprint was a current practice, with two stating a future goal of energy neutrality and one stating a future goal of carbon neutrality. As a comparison, the theme of community engagement/outreach emerged in 8 of the 10 interviews from the same open-ended questions. However, all of the water leaders responded that energy indicators were important when asked about them specifically in the interviews.

Freelisting Survey

To date 19 participants have completed the freelisting survey. A full statistical analysis of the results will not be completed until at least 25 responses are collected per the freelisting literature, but preliminary results from responses to date suggest emerging trends.

Sustainability practices with a *direct* link to energy (conservation or generation) ranked fairly high compared to other practices. Energy conservation measures were cited by 10 of the 19 respondents. Energy generation was cited by 7 of the 19 respondents. However, only 1 of the 6 drinking-water-only participants listed energy generation, reflecting increased opportunities for energy recovery in WRRFs.

Sustainability measures with an *indirect* link to energy varied, with both water reuse and water conservation, for example, cited by 9 and 8 out of 19 participants, respectively. After that, use of renewables, land application of Biosolids, and asset management systems each were cited by 5 participants and recycling (not including nutrients, energy, or water from the plant) was cited by 4 respondents. Carbon footprinting was not cited by any of the 19 freelisting participants.

The only other practices *not* related to energy that received more than one mention so far were the two practices in the social component of the TBL-plus framework: professional development for staff (5 responses) and stakeholder outreach (2 responses). The practice of financial planning in the economic component of the TBL-plus framework received 3 responses. Unlike the urban water utility leaders, community engagement/outreach is not emerging as a dominant theme with this group of water professionals.

Discussion And Next Steps

A final set of indicators for the "snapshot" urban water sustainability index is not yet complete. However, roughly half of the emerging priority sustainability practices have either a direct or indirect link to energy. The prevalence varies depending on the respondent population, with some EAC members noting energy-related practices, but with a stronger inclination towards community-based indicators during open-ended questions about sustainable practices. But all EAC members indicated energy-related measures are important when asked about them specifically. The population of water professionals responding to the online survey had a strong inclination towards energy-related practices in their open-ended responses.

When the semi-structured interviews and freelisting surveys are completed, statistical analysis will reveal where energy-related indicators will rank compared to other topics in the recommended set of indicators for the "snapshot" sustainability assessment. When evaluating practices that are directly and indirectly-related to energy, it appears that related indicators will emerge in all four components of the TBL-plus framework.

Conclusions

The U.S. urban water utility sector is undergoing a transformation. The transition to the "Utility of the Future" is raising awareness of the importance of resource recovery, including energy, and the need to be more efficient with energy use. The energy-water nexus interrelationship is extremely important for water and wastewater utilities as energy is often one of the highest costs for a municipality.

Water utilities have the opportunity to recover energy from their wastewater and water infrastructure. They are also exploring more efficient ways to operate their systems. These concepts of energy generation and conservation can be measured and are important in the overall assessment of a water utility's sustainability. In addition to these directly-related measures of conservation and generation, there are many practices with indirect relevance to energy because they may conserve or save energy in other parts of a utility's operations or beyond the utility's footprint.

Initial results from research to establish a "snapshot" of U.S. urban water utility sustainability indicates that many of the preliminary indicators are closely connected to energy. Further study will finalize the set of recommended indicators, but it is clear that energy will play a key role in the "snapshot" assessment of urban water utility sustainability.

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