Smart City Drivers & Challenges in Energy and Water Systems

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1. Introduction

The IEEE Smart Cities Initiative brings together the IEEE's broad array of technical societies and organizations to advance the state of the art for smart city technologies for the benefit of society and to set the global standard in this regard by serving as a neutral broker of information amongst industry, academic, and government stakeholders. These smart city technologies draw upon expertise in several functional domains including:

- Sensors and Intelligent Electronic Devices
- Communication Networks & Cyber Security
- Systems Integration
- Intelligence & Data Analytics
- Management & Control Platforms

Together, this functional expertise serves to achieve the mission of the IEEE Smart Cities initiative:

1. To be recognized as the authoritative voice and leading source of credible technical information and educational content within the scope of smart cities identified below.
2. To facilitate and promote both the collaborative and individual work of its Member societies regarding smart city technology.

To that end, the IEEE Smart Cities initiative has identified several application domains in which to apply its expertise. These are:

- Smart energy systems
- Smart water systems
- Smart mobility systems
- Smart healthcare systems

Each of these systems has generally developed in its own right in response to the needs and context of the domain. Each faces its own set of drivers and challenges. And yet, as each of these systems gains greater "digital intelligence", recurring themes of technology integration do emerge. This sequence of two articles serves to highlight these domain-specific drivers and challenges within the broader smart city landscape. This first article focuses on smart energy and smart water systems. In the sequel article, smart mobility and healthcare systems are discussed.

2. Smart City Energy Systems

2.1. Drivers

In 2018, 55 percent of the world's population resides in urban areas; a proportion that is expected to increase to 68 percent by 2050. As populations grow, so do cities' energy consumption. Electric vehicles, and electrified transportation more generally, are disrupting the supply and demand dynamics of electricity. Similarly, advanced urban farming allows food to be grown all year long; albeit at a high electrical intensity. These two emerging drivers erode the proverbial "duck curve" of electricity net load caused by the integration of large quantities of renewable energy. Furthermore, other disruptive technologies and services in energy, communications, and transportation, will accelerate this trend towards digitization and 24/7 accessible service. Finally, autonomous vehicles and drone deliveries represent a new and potentially intensive form of energy consumption.

In the meantime, there is an increasing number of active consumers or prosumers with energy management requirements beyond simply high reliability at a low cost. Such prosumers are often selecting clean and local sources of energy, and wish to actively participate in the management and control of their energy consumption.

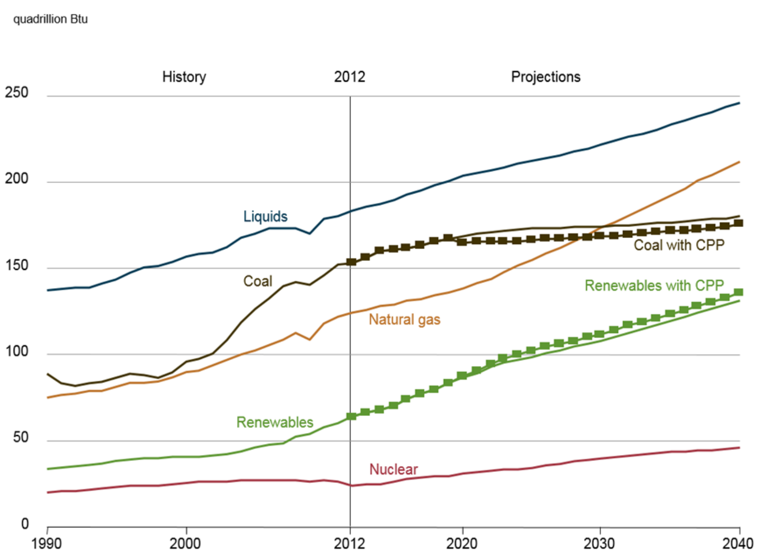

Figure 1. World energy consumption by energy source, 1990-2040 ***(International Energy Outlook U.S. Energy Information Administration)***

In recent years, efforts to better manage energy consumption has led to greater deployment of renewable energy (RE) sources. As their cost continues to drop through technological development to grid-parity levels, the appetite for greener sources of energy has grown and further continues to accelerate the competitive position. According to the IEA "Key World Energy Statistics 2019", the RE share of World Total Primary Energy Supply (TPES) was around 14% in 2015 and is expected to increase in all scenarios through to 2040. Similarly, storage technologies present a great opportunity for smoothing out the electricity supply from renewable technologies with variable output such as wind and solar, and will also ensure rapid response to unexpected changes in net load.

As cities and countries pledge to meet the Paris Agreement target emissions reductions, a report from IRENA highlights that the combined strategy of renewable energy and energy efficiency offers the most timely and feasible route to decarbonizing the global energy system. In that regard, renewable energy resources often take a distributed form. Small hydro, biomass, biogas, solar power, wind power, and geothermal power are all typically found on the grid periphery. Combined heat and power plants are also often implemented in a distributed fashion to achieve efficient energy management outcomes. Finally, such distributed energy resources may be integrated into microgrids to limit the impact of harsh natural disasters and offer greater energy resilience.

2.2. Challenges

The rapid growth of cities' population implies the need for a reliable and efficient electric distribution system that serves billions of devices in a wide range of applications including buildings, offices, medical facilities, shopping centers, transportation systems, factories, public institutions, and water utilities. Moreover, every city requires its own energy mix solution. In order to tackle the sustainable energy transition of the electric power system, locally available energy sources (e.g. rooftop solar PV) must be fully exploited and generation surpluses from surrounding rural areas need to be transmitted to urban and industrial centers. A bi-directional energy flow occurs as a result. One particular challenge is the control of the large number of distributed generation plants, which often exhibit low generation capacities and a variable behavior of supply (e.g. wind speed and solar irradiance). Consequently, it is necessary to introduce information and communication technologies that efficiently and reliably monitor, control, analyze and optimize electric power. Such a "smart grid" concept has the potential to make the entire power system more reliable and resilient.

Despite the growing interest in renewable energy sources, their 100% integration remains seemingly distant. The cost of RE sources are challenged by the dropping prices in natural gas. Batteries and other energy storage technologies still need to improve their cost performance before they can effectively fill "duck-curve" troughs in net load. Solar and wind technologies have a much shorter operational lifespan than other energy sources and we will soon require innovative waste management solutions. Despite being much more environmentally friendly than traditional energy sources, renewable energy still has an impact on the natural and human environments. Hydropower must guarantee water flow for aquatic wildlife. Meanwhile, new wind farms and the transmissions lines that are required to bring energy to load centers are often blocked by local communities as a nuisance or a disruption to the natural landscape.
The trajectory of adoption also differs from region to region. In developed countries, the pace of adoption of new technologies is often slowed down by aging existing infrastructure that was not designed to accommodate them. Meanwhile, in developing countries, large-scale capital investments may not always be readily available despite the opportunity for "leap-frogging" with new technologies. In both cases, it is necessary to break the barriers between existing functional, information, and data silos within conventional utility systems.

The cyber-security of the increasingly digitized "smart grid" also presents a tremendous challenge. As more and more assets are connected to a multiplicity of sensors and information systems, they create a large scale "attack-surface" for attackers to exploit security vulnerabilities and potentially shut down critical infrastructure. New cybersecurity measures in the face of increasing attack surface must be adopted, with the aim to (a) guard against threats; (b) detect cyber/physical attacks immediately; (c) limit the impact of such attacks; (d) provide a fast recovery. This challenge, combined with high capital costs, makes investors wary despite the rapid return on investment of these assets.

Finally, these new supply-demand dynamics, coupled with new city and state regulations leave many utilities struggling to adapt their established business models. Behind-the-meter distributed energy resources; be they in the form of solar PV or active grid edge assets, are marginally visible to utilities and present a clear operational challenge. Furthermore, they erode the kWh sale of energy and require utilities to offer new products and services to their customer base.

3. Smart City Water Systems

The concept of Smart City Water Systems is more commonly referred to as "Intelligent Water Systems" within the water sector: *"Intelligent Water Systems (IWS) emphasize the opportunity the water sector has to take advantage of advanced technologies and dramatically shift management decision making." [6]*

Although still in the early stages, water and wastewater utilities have embarked on Smart City Water System implementation efforts. The Internet of Things (IoT), notably sensors, real-time operational data, the cloud, dashboards, and data modeling and analysis software, have helped shepherd new opportunities for water sector utilities to adopt new technologies and processes to better manage and administer their infrastructure. Some of the early use cases of Smart City Water Systems include the following:

- *Information Integration for Improved Performance.* Predictive analytics provide real-time asset systems-modeling, increasing efficiency.
- *Data Driven Process Optimization.* Through data analysis and mining, IWS allows disparate systems to communicate with other systems in real time across water, wastewater and stormwater treatment, collection, and distribution, enhancing operational decisions.
- *Capital Planning and Elevated Service Levels.* IWS allow predictive and preventative maintenance, and provide insight to improve capital planning.

The impact of intelligent water systems can be seen in all aspects of utility management, from customer service and back-office functions like finance to control systems for pipe networks and treatment facilities to capital planning. Opportunities exist across utility operations to pilot new aspects of IWS, as shown by the participation of dozens of utilities in the LIFT Intelligent Water Challenge, sponsored by the Water Environment Federation and Water Research Foundation.

3.1. Drivers

Although Smart City Water Systems are predominantly a technology initiative, water utilities are a business, and thus many of their drivers are financial and institutional.

- Knowledge capture and new resources. IWS tools such as augmented reality provide water and wastewater utilities the ability to retain and transfer institutional knowledge a rapidly retiring cohort. On the flip-side, the need to attract technology-savvy millennials as these baby boomers retire is critical. By introducing IWS into water utilities, younger employees seeking to use these tools can learn and build off both existing and new technologies and practices.
- Customers, the community, and other stakeholders are demanding more information. They want to know where and how their money is being spent. In the age of smartphones, social media and online payment, customers expect "real-time" and transparent information regarding costs as well as water quality and uses.
- Utilities are being asked to do more with fewer resources. Incorporating optimization software into a water/wastewater utility's existing system, an IWS can also allow for the optimization of energy, operations, and capital improvement plans (CIP).
- Compliance with increasingly stringent regulations and reporting requirements.
- Velocity and Volume of Data. As the IoT implementation grows, water agencies are seeing an increase in both volume and velocity of information. IWS tools are needed to effectively analyze the large amounts of data..
- Proper quality assurance and quality control of operations and maintenance efforts. IWS aid water/wastewater utilities in determining the efficiency of their operations. Optimization and modeling tools provide a clearer picture of how water treatment and conveyance facilities are operating and recommend adjustments in real-time operations, as well as with long term maintenance.

3.2. Challenges

Smart City Water Systems implementation challenges will vary between utilities, as size, culture, and resources will define the constraints. In general, the challenges can be grouped into three categories: people, data, and funding.

- People - Many utility staff are concerned that automation will cost them their jobs. While the day-to-day operations may change, institutional knowledge of existing staff is still a critical asset. Having said that, new skill sets are required and training is needed to minimize the learning curve to implement an IWS to its fullest effect. As the water sector integrates these new technologies, academia needs to evaluate the effectiveness of education for preparing future data scientists, engineers, operators, environmental scientists, and managers.
- Data - Historically, water/wastewater utilities have operated in a siloed data environment and there is no universal or uniform data management platform or standard. The range of databases and legacy systems in operation pose significant challenges with interoperability and the number of proprietary systems used within the Utility industry make developing a common standard difficult. Ultimately, advances in data governance and standards, as well as security will be needed to ensure the accuracy, effectiveness, and reliability of a successful IWS.

- Funding - Many organizations seek to implement an IWS based on recommendations from technology and operations staff, only to be limited by a lack of funding. This can be due to the conflict between capital and operational funds. It can also be due to external pressures, such as political requirements to limit water rate increases, despite increasing demands for performance and compliance. IWS is a digital transformational effort and thus requires engagement with stakeholders of all levels, beginning with the initial planning stages, to ensure that the value of the investment in IWS is recognized.

The benefits of an intelligent water system are substantial and the water industry is in the early stages of embarking on this implementation and adoption curve. As the industry advances along its digital transformation journey it will identify additional benefits and drivers, as well as refine its response to the technical and larger organizational challenges that threaten the broader success of IWS.

4. Conclusion

This article has served to highlight several domain-specific drivers and challenges within the context of smart energy and smart water systems. While each of these sectors has its own specificities, it is clear that from a smart city perspective there are at least two common themes. First, the "***Internet of Things***" applies equally to both infrastructures. Each infrastructure system is at varying levels of development and deployment but ultimately each infrastructure is robustly adopting the IoT paradigm. Second, this increased adoption of IoT technology is leading to ever-greater ***distributed intelligence***. At its heart, cities are encouraging empowered and engaged inhabitants that increasingly wish to play active roles in their quality of life and ultimately the infrastructure services that they receive and utilize in the city. This discussion around common themes in smart city drivers and challenges is investigated in the sequel to this article that focuses on smart mobility and smart healthcare systems.

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