The IEEE Smart Cities Initiative brings together 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 set the global standard in this regard by serving as a neutral broker of information among industry, academic, and government stakeholders. These smart city technologies draw upon expertise in several functional domains, including

- sensors and intelligent electronic devices
- communication networks and cybersecurity
- systems integration
- intelligence and data analytics
- management and 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 later in this article.
To that end, the IEEE Smart Cities Initiative has identified several application domains in which to apply its expertise. These are systems for

- smart energy
- smart water
- smart mobility
- smart health care.

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 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 second article in this issue, smart mobility and health-care systems are discussed.

**Smart city energy systems**

**Drivers**

In 2018, 55% of the world’s population resided in urban areas, a proportion that is expected to increase to 68% by 2050. As populations grow, so do cities’ energy consumption (Fig. 1). 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 (RE). Furthermore, other disruptive technologies and services in energy, communications, and transportation will accelerate this trend toward 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.

In recent years, efforts to better manage energy consumption have led to greater deployment of 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 continues to accelerate competition. According to the IEA “Key World Energy Statistics 2019,” the RE share of world total primary energy supply 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 a rapid response to unexpected changes in net load.

As cities and countries pledge to meet the Paris Agreement target emission reductions, a report from IRENA highlights that the combined strategy of RE and energy efficiency offers the most timely and feasible route to decarbonizing the global energy system. In that regard, RE 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.

**Challenges**

The rapid growth of cities’ populations 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. To tackle the sustainable energy transition of the electric power system, locally
available energy sources [e.g., rooftop solar photovoltaics (PV)] must be fully exploited, and generation surpluses from surrounding rural areas need to be transmitted to urban and industrial centers. A bidirectional 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 RE sources, their 100% integration remains seemingly distant. The cost of RE sources is 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 life span than other energy sources, and we will soon require innovative waste management solutions.

Despite being much more environmentally friendly than traditional energy sources, RE still has an impact on 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 the adoption of new technologies is often slowed 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 cybersecurity of the increasingly digitized “smart grid” also presents a tremendous challenge. As more assets are connected to a multiplicity of sensors and information systems, they create a large-scale “attack surface” for adversaries to exploit security vulnerabilities and potentially shut down critical infrastructure. New cybersecurity measures in the face of the increasing attack surface must be adopted with the aim to 1) guard against threats, 2) detect cyber/physical attacks immediately, 3) limit the impact of such attacks, and 4) 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, whether 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 kilowatthour sale of energy and require utilities to offer new products and services to their customer base.

Smart city water systems
The concept of smart city water systems is more commonly referred to as intelligent water systems (IWSs) within the water sector: “IWSs emphasize the opportunity the water sector has to take advantage of advanced technologies and dramatically shift management decision making” (Water Environment Federation, 2017). 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—has helped shepherd new opportunities for water sector utilities to adopt novel 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, IWSs allow 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**: IWSs allow predictive and preventative maintenance as well as provide insight to improve capital planning.

The impact of IWSs can be seen in all aspects of utility management, from customer service and back-office functions such as finance, to control systems for pipe networks and treatment facilities, to capital planning. Opportunities exist across utility operations to pilot new aspects of IWSs, 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.

**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 are required. IWS tools, such as augmented reality, provide water and wastewater utilities the ability to retain and transfer institutional knowledge in the face of a rapidly retiring cohort. On the flip side, the need to attract technology-savvy millennials as these baby boomers retire is critical. By introducing IWSs into water utilities, younger employees seeking to use these tools can learn and build on 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.

Compliance with increasingly stringent regulations and reporting requirements is necessary.

As the IoT implementation grows, water agencies are seeing an increase in both the 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 effort are necessary. IWSs 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.

**Challenges**

The implementation challenges for smart city water systems will vary among utilities, as size, culture, and resources 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 in 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 to interoperability, and the number of proprietary systems used within the utility industry makes developing a common standard difficult. Ultimately, advances in data governance and standards as well as security are 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 caused by external pressures, such as political requirements to limit water rate increases, despite increasing demands for performance and compliance. An 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 the IWS is recognized.

The benefits of an IWS 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 IWSs.

**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 IoT 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 who 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, which focuses on smart mobility and smart healthcare systems.

**Read more about it**

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