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From Numerical Model to Computational Intelligence: The Digital Transition of Urban Energy System

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Abstract

With the development of digital technologies, especially big data analytics, digital innovations are taking root in various industries, including energy sector. Particularly, urban energy system is also experiencing digital transition; such digital transition not only offers new business models commercially, but also brings new research problems scientifically. The new capabilities enabled by these digital technologies are reshaping the generation, transmission, consumption and storage sections in the urban energy system, sequentially the traditional way of how urban energy system is designed and operated should be reexamined. Starting from here, there have been many studies regarding how various digital technologies can be applied all along the urban energy system value chain; these studies range from individuals' energy consumption pattern characterization by using customer behavior data in smart home, to complex data-driven planning of regional scale energy system. More specifically, numerous computational models have been proposed by the scientific community to mimic the dynamics of various components at various levels in the urban energy system. However, the potential benefits of applying these numerical models are somehow underestimated; we believe there are still several gaps from numerical modeling to computational intelligence which need to be bridged. In such a context, in this paper we strive to present a systematic review on the status of urban energy system related digital innovations as well as prospective outlook on the future application of such digital technologies. Through the study of this paper, we hope to identify several key points where digitalization should be prioritized in urban energy system, picture a roadmap towards future digital technology enabled intelligent urban energy system, and finally points out the research gaps that need to be fulfilled over there.

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Keywords: urban energy system; big data; digitalization; ontology; blockchain

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1. Introduction

We live in an era of data, data is everywhere around us. Particularly in the cities we live, data prevails almost every conceivable object in the city, ranging from GPS data in our mobile phones to our utility bills every month, from our expense records in supermarkets to our daily commutes through the city public transport network, from widespread weather data to professionally designed power grid Phasor Measure Unit (PMU) data [1]. Although such data are usually featured by high velocity, large volume, highly heterogeneity and sparsity [2], yet thanks to the recent advances in data science, most data can be handled by state-of-the-art big data analytics techniques [3]. Based on such wealth of data in urban environments, a new discipline, namely urban informatics, is thriving in recent years [4]. The perspective of urban informatics is trying to use such data to better understand how our cities work, that is knowledge discovery through data mining. Furthermore, the insights discovered through urban data analytics can be implemented to develop various services or applications in the cities. In terms of urban energy system, which is a fundamental cornerstone of city, such applications exist at various spatial scales; for instance, at building level individuals' energy consumption pattern characterization by using customer behavior data in smart home [5], at district level complex data-driven planning of regional scale distributed energy system [6]. Some researchers call such transition of urban energy system enabled by digital technologies as digital transition [7]. Indeed, digital transition is not a novel conception, it has been an active topic in many other fields for several years; some have even been proved as great success, such as the digital transition of banking sector. Inspired by such successes, digital transition of urban energy system is also attracting attention from lot researchers. Smart grid is perhaps the best-known practice under the umbrella of digital transition of urban energy system. However, the components of urban energy system are much more than power grid, so digitalization of urban energy system should not be equalized as smart grid either. In a well-established literature review, James et al. [8] points out that there are six aspects regarding urban energy system modelling, namely technology, building, urban climate, system design, policy assessment, transportation and land use. Their study also leads to the conclusion that urban energy system is indeed a super complex system consisting of tens of thousands of subsystems which interact with each other. Furthermore, most of current researches about urban energy system are still about modelling, which are essentially mimicking the dynamics of various components in the urban energy system, these models cover almost all the components of urban energy system from equipment level to entire building level and finally to the city level [9]. Most of these models are elaborately developed and calibrated, which means they can serve as reliable "avatar" of the corresponding physical entities in overall urban energy system model. However, the potential benefits of applying these numerical models in the digital transition of urban energy system are somehow underestimated; we believe there is still a huge gap from numerical model to computational intelligence in the future digitalized city. Therefore, several key questions need to be answered before further development in urban energy system digitalization could happen.

In this paper, we strive to answer the following questions regarding urban energy system digital transition from numerical models to computational intelligence: What kinds of data exist in urban energy system? How the data can be collected and processed efficiently given the current and potential Information and Communication Technologies (ICT) infrastructure? What kind of services and/or applications can be developed using the data? Who should be responsible for the service and application development? What benefits can be harvested by applying such services and who are the relevant stakeholders? What are the current readiness level of such digital transition technologies? What should be the focus of next-step of digital transition of urban energy system? With these questions in mind, we hope to present a concise summary of the status and recent advances regarding digital transition of urban energy system, meanwhile provide several prospects about such digital transition in this short paper. Nevertheless, it has to be highlighted at the beginning of the paper that since urban energy system is such a broad conception, thus it is neither possible nor desirable to give an encyclopedic review regarding all aspects of urban energy system digital transition in this paper; we only aim to summarize the current active areas regrading digital transition of urban energy system as well as point out the up-to-date research progress, several potential focus as well as prospects are also given in the paper. That is how the paper is structured.