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The future of waste management in smart and sustainable cities: A review and concept paper

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ABSTRACT

The potential of smart cities in remediating environmental problems in general and waste management, in particular, is an important question that needs to be investigated in academic research. Built on an integrative review of the literature, this study offers insights into the potential of smart cities and connected communities in facilitating waste management efforts. Shortcomings of existing waste management practices are highlighted and a conceptual framework for a centralized waste management system is proposed, where three interconnected elements are discussed: (1) an infrastructure for proper collection of product lifecycle data to facilitate full visibility throughout the entire lifespan of a product, (2) a set of new business models relied on product lifecycle data to prevent waste generation, and (3) an intelligent sensor-based infrastructure for proper upstream waste separation and on-time collection. The proposed framework highlights the value of product lifecycle data in reducing waste and enhancing waste recovery and the need for connecting waste management practices to the whole product lifecycle. An example of the use of tracking and data sharing technologies for investigating the waste management issues has been discussed. Finally, the success factors for implementing the proposed framework and some thoughts on future research directions have been discussed.

Contents

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1. Introduction

In recent years, there has been some controversy over the role of technology in meeting sustainable development goals. While traditionally, based on IPAT formula ($I = PAT$), technology (T) along with Population (P) and the level of Affluence (A) are viewed as the main contributors to environmental Impacts (I) (Ehrlich and Ehrlich, 1997)., later on, the IPAT equation has been reshaped to emphasize that technology can influence environmental impacts in a positive way, $I = (PA)/T$ (York et al., 2003; Anderson, 1998).

The role of technology becomes ever more important, as we experience the fourth industrial revolution and new emerging infrastructure and capabilities offered by Cyber-Physical Systems (CPS), Blockchain technology, and the Internet of Things (IoT). CPS is a new class of engineered systems that offer coordination among physical and computational infrastructures and are the foundation of Industry 4.0, smart factories, and other smart systems such as smart buildings, security systems, data centers and medical systems (Khaitan and McCalley, 2015). If the networking functionalities offered by the internet are added to CPS, a new networking paradigm known as IoT is emerging where communications among all types of physical entities would be possible over the internet (Han et al., 2013). In addition, the capabilities offered by Blockchain technology for creating a decentralized public ledger facilitates information sharing among various users involved in a system and opens the door for new transparent business models.

IoT is expected to change the urban development and future cities, similar to other engineered systems. The impact of technology and innovation on urban development was highlighted under the term "smart city" (SC) coined in early 1990 (Gibson et al., 1992) and most recently under the term "City 2.0". Various definitions and dimensions have been provided for a smart city (Albino et al., 2015), among these definitions, the one offered in (Caragliu et al., 2011) is close to sustainable development, where it suggests that a city is smart when the aim of investing in cyber-infrastructure is to foster sustainable economic growth, better quality of life, and efficient management of natural resources.

There is a shared definition of what makes a smart city and what constitutes a sustainable one, where a smart city is not just about smart infrastructure but the extent at which such infrastructure assists in achieving sustainable development objectives. For instance, waste generation is a fast-growing problem of modern societies, particularly in growing urban regions. Around 1.7–1.9 billion metric tons of municipal solid waste is generated every year worldwide (Environment and Programme, 2010). If the city's population as a result of rural-urban migration is growing at the existing rate of 3–5 percent a year, then the waste generation will double every 10 years (UN-HABITAT, 2009). Although according to the environmental Kuznets curve (EKC) by increasing income per capita, the environmental degradation, and pollution decreases, the economy of scale and the population growth may offset the benefits of economic development. Further, there are controversial discussions on the accuracy of EKC. According to Stern (Stern, 2004), the statistical evidence behind EKC are not robust and the relation between environmental impacts and per capita income is not predictable. Waste generation is a concern for modern societies due to both the service cost of waste collection, and the environmental issues of landfills. The IoT seems a promising solution for handling waste collection and recovery operations in SCs (Zanella et al., 2014).

The number of studies that have discussed waste management practices in SCs is limited. The objective of this paper is to first review the existing studies on the topic and then introduce a data-driven model for waste management practices in SCs considering the circular economy concept.

Table 1 provides a list of previous review papers. As shown, the previous reviews were primarily focused on either smart and sustainable cities or waste management. The scope of every previous review provided is limited to the concept of SCs with one recent paper on ICT-enabled models for waste collection (Anagnostopoulos et al., 2017).

The current paper proposes a conceptual framework for waste management in SCs. The proposed framework consists of three main elements: (1) a Product Lifecycle Management (PLM) framework for collecting product lifecycle data and monitoring a product over its entire lifespan, (2) new business models compatible with circular economy and sharing economy concepts, and (3) intelligent infrastructure for proper separation, on-time collection, and

Table 1
Previous review papers and their scope.

Previous review papers	Scope
Cocchia (2014), Meijer and Bolívar (2016), Anthopoulos (2015), Arroub et al. (2016)	Smart and digital cities concepts
Kyriazopoulou (2015)	Technologies and architectures in SCs
Bibri and Krogstie (2017)	Smart sustainable cities
Talari et al. (2017)	SC and the concept of Internet of Things
Chauhan et al. (2016)	SC and big data challenges
Khajenasiri et al. (2017)	Energy control in buildings of SCs
Alibasic et al. (2016)	Cybersecurity for SCs
Shuai, Maillé, Pelov (2016)	Electric vehicles in SCs
Giusti (2009)	Waste management and human health
Zacho and Mosgaard (2016)	Waste prevention in waste management
Goulart Coelho et al. (2017)	Decision-making methods to support waste management
Beliën et al. (2012)	Solid waste collection
Sharholy et al. (2008)	Waste management in Indian cities
Anagnostopoulos et al. (2017)	ICT-enabled waste collection models