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Internet of things and Big Data as potential solutions to the problems in waste electrical and electronic equipment management: An exploratory study

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ABSTRACT

Management of Waste Electrical and Electronic Equipment (WEEE) is a vital part in solid waste management, there are still some difficult issues require attentionss. This paper investigates the potential of applying Internet of Things (IoT) and Big Data as the solutions to the WEEE management problems. The massive data generated during the production, consumption and disposal of Electrical and Electronic Equipment (EEE) fits the characteristics of Big Data. Through using the state-of-the-art communication technologies, the IoT derives the WEEE "Big Data" from the life cycle of EEE, and the Big Data technologies process the WEEE "Big Data" for supporting decision making in WEEE management. The framework of implementing the IoT and the Big Data technologies is proposed, with its multiple layers are illustrated. Case studies with the potential application scenarios of the framework are presented and discussed. As an unprecedented exploration, the combined application of the IoT and the Big Data technologies in WEEE management brings a series of opportunities as well as new challenges. This study provides insights and visions for stakeholders in solving the WEEE management problems under the context of IoT and Big Data.

1. Introduction

Waste Electrical and Electronic Equipment (WEEE), or known as e-waste, has become one of the largest and fastest growing waste stream in the world (Rahimifard et al., 2009). At global level, WEEE has an average annual growth rate of 3–5% which corresponds almost three times the growth of municipal solid waste in general (Rahimifard et al., 2009; Duygan and Meylan, 2015). The global quantity of WEEE is estimated to be 41.8 Mt in 2014, 43.8 Mt in 2015, and it is expected to grow to 49.8 Mt in 2018 (Baldé et al., 2015). With a rapid annual growth rate around 13–15% (Gu et al., 2016a), China generated approximately 8.53 Mt WEEE in 2014 and has already become the largest WEEE generator worldwide (Zeng et al., 2016a).

WEEE contains various valuable resources as well as a wide range of pollutants (Dewulf et al., 2010; Zeng et al., 2017b). Owing to limited reserves (Du and Graedel, 2011), recovering materials from WEEE is a promising practice for sustainable development of the related industry. For examples, the rapid development of electric vehicles demands a higher recycling rate (over 90%) for lithium (Zeng and Li, 2013) and cobalt (Zeng and Li, 2015), and recycling indium from spent liquid crystal displays (LCDs) is of critical importance to support continuous production of new LCDs (Zhang et al., 2015a). WEEE recycling is regarded as a profitable business (Cucchiella et al., 2015; Zeng et al., 2016a). Recovering precious metals such as gold, can sustain the profitability of a WEEE recycling plant (Cucchiella et al., 2016). Asides from resource sustainability and economical gains, environmental impacts of WEEE can be significantly reduced through recycling those metal contents (Wäger et al., 2011). Moreover, recycling is proved to be the best option of disposing polymeric fractions in WEEE from an life cycle environmental perspective (Wäger and Hischier, 2015), and the end markets of these recycled plastics are expanding (Gu et al., 2017a). However, improper treatments of WEEE lead to catastrophic results, as environmental pollutions caused by WEEE recycling are frequently reported (Tao et al., 2015; Awasthi et al., 2016; Wu et al., 2016). Consequently, physical health of the nearby

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Nomenclature

Abbreviations

BAN	Basel Action Network
BDBA	Big Data Business Analytics
CE	consumer electronic
CGA	Customs General Administration of the People's Republic of China
CPS	cyber-physical system
CRT	Cathode Ray Tube
DfE	Design for Environment
EC	European Commission
EEE	Electrical and Electronic Equipment
EOL	End-Of-Life
EPA	United States Environmental Protection Agency
EPR	Extended Producer Responsibility
ERP	enterprise resource planning
EU	European Union
GFO	Green Fence Operation
GIS	Geographic Information System
GOSC	General Office of the State Council of the People's Republic of China
ICT	information and communications technology
IOT	Internet of Things
ITU	International Telecommunication Union
kt	kilo tonnes
L	litre
LCD	liquid crystal display
LTE	Long Term Evolution
MIS	Management Information System
MPA	Ministry of Environmental Protection of the People's Republic of China
MSW	municipal solid waste
Mt	million tonnes
NDRC	National Development and Reform Commission of the People's Republic of China
NGO	non-governmental organisation
NBS	National Bureau of Statistics of the People's Republic of China
OECD	Organisation for Economic Co-operation and Development
PBB	polybrominated biphenyl
PBDE	polybrominated diphenyl ether
POM	placed on the market
POP	persistent organic pollutant
RFID	Radio Frequency IDentification
RoHS	Restriction of Hazardous Substances
SC-SCM	Service and Manufacturing Supply Chain Management
SEPA	State Environmental Protection Administration the People's Republic of China
SVTC	Silicon Valley Toxics Coalition
WEEE	Waste Electrical and Electronic Equipment
WR2	WEEE recovery/recycling
WSN	Wireless sensor network
WTP	Willingness To Pay

residents and the workers is in great peril due to exposure to heavy metals and persistent organic pollutants (POPs) released from WEEE recycling sites (Huang et al., 2016; Lu et al., 2016a; Wang et al., 2016a), especially that of children (Tang et al., 2015; Zeng et al., 2016b).

Recognising the delicate nature and the importance of recycling, the management of WEEE has become a topical issue in solid waste management. In this study, we discuss the potential of using big data technologies in solving existing problems in WEEE management. This paper is organised as follows: the current problems are depicted and analysed in Section 2, the characteristics of the WEEE "Big Data" are examined in Section 3, the state-of-the-art communication technologies for acquiring the WEEE "Big Data" are illustrated in Section 4, the framework of implementing the IoT and the Big Data technologies in WEEE management is proposed in Section 5, two application scenarios based on real-world cases are delivered in Section 6, both the opportunities and challenges discussed according to different perspectives in Section 7, the conclusions are given in Section 8 while the shortcoming of this study is also identified.

2. Existing problems

2.1. Ineffective legislation

Across the globe, governments have proposed laws, regulations and policies to facilitate WEEE management. Yet, according to the extent literature, the effectiveness of these legislations remains questionable.

2.1.1. Low collection rates

WEEE Directive 2002/96/EC (European Union, 2003a) required all member states from 13th August 2005 to collect at least 4 kg per capita of WEEE from households annually and to ensure that 'producers provide at least for the financing of the collection, treatment, recovery and environmentally sound disposal of WEEE from private households deposited at collection facilities'. But the collection requirement does not reflect the actual situation of member states of European Union (EU) (Huisman et al., 2007). The upgraded version - Directive 2012/19/EU (European Union, 2012) applied a WEEE collection target which is based on volumes placed on the market (POM): 45 wt% of the EEE (Electrical and Electronic Equipment) POM in the past three years must be collected by 2016, and 'from 2019, the minimum collection rate to be achieved annually shall be 65% of the average weight of EEE placed on the market in the three preceding years in the Member State concerned, or alternatively 85% of WEEE generated on the territory of that Member State'. However, it was estimated that the collection rate was below 50 wt% and average for the entire EU was 38 wt% (Król et al., 2015). For consumer electronics such as laptops and mobile phones, their collection rate was even lower, as material flow analysis revealed collection rate for laptops and mobile phones were 35 wt% and 37 wt% in Switzerland, the state which has a well-established recycling system operating since 1992 (Duygan and Meylan, 2015). An exceptional example in EU is Finland, which has an average WEEE recycling rate of 92% (Ylä-Mella et al., 2014). Legislations similar to EU have been placed in the United States, such as *Electronic Waste Recycling Act of 2003* (California government, 2003). However, the WEEE collection rate is lower than 30%, and rest of WEEE ended up in landfill or exportation (Kahhat et al., 2008; Namias, 2013).

In China, a "Old-for-New" policy was used for collecting End-Of-Life (EOL) household EEEs including televisions, refrigerators, washing machines, air conditioners and personal computers, and this policy was in place from June 1st, 2009 to December 31st 2011 (Zeng et al., 2013b). This policy had facilitated the recycling of categorised WEEE, even after it expired (Cao et al., 2016a,b).