Resources, Conservation & Recycling xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Towards an inclusive circular economy: Quantifying the spatial flows of e-waste through the informal sector in China

Xin Tong[a,*], Tao Wang[a], Yanguang Chen[a], Yutao Wang[b,c]

[a] College of Urban and Environmental Sciences, Peking University, Beijing 100871, China
[b] Department of Environmental Science & Engineering, Fudan University, 220 Handan Road, Shanghai 200433, China
[c] Fudan Tyndall Centre, Fudan University, 220 Handan Road, Shanghai 200433, China

ARTICLE INFO

Keywords:
E-waste
Informal sector
Spatial interaction model
Reverse logistics

ABSTRACT

China has built a territory-based formal e-waste recycling system as a response to the global e-waste challenge. This system created a division of labor between the informal sector and formal recycling plants by providing a subsidy to the latter to buy waste products collected by the former. Using provincial data of formal e-waste recycling plants in China in 2014, this paper quantifies the contribution of the informal sector to e-waste transportation at the national level. Despite the intention to plan a regional self-sufficient system for e-waste recycling at the provincial level, we find that significant interprovincial flows exist due to the complex market transactions within the informal collection network, which reveals the deep conflicts between market mechanism and public intervention in the evolvement of e-waste governance structure. We built a spatial interaction model to depict the interregional flows of e-waste that can quantitatively illustrate the change of spatial pattern of this network due to the introduction of the formal WEEE regulation in China. In conclusion, we discuss the policy implications for optimizing regional allocation of the e-waste recycling capacity as well as for improving the transparency of the reverse logistic system to include the informal sector in the future.

"Laissez-faire was planned; planning was not."

Karl Polanyi (1944)

1. Introduction

The existence of an extensive informal sector has been identified as one of the key challenges to develop a financially and environmentally sound recycling and disposal system for e-waste management in developing countries (Hicks et al., 2005; Nnorom and Osibanjo, 2008; Chi et al., 2011; Gu et al., 2016). Given the toxicity of certain pollutants, especially when being processed without proper pollution control, the Basel Convention identified e-waste as hazardous and developed a framework to control the transboundary movement of such waste from developed to developing countries and to formalize the local recycling sectors in the developing regions (Widmer et al., 2005).

Existing research has long come to a consensus that formal e-waste recycling systems should take informal sectors into account, especially in developing countries where bottom-up and market-driven recycling activities are pervasive (Widmer et al., 2005; Davis and Garb, 2015). The policies should target not only increases in the overall accountable recycling rates by reducing improper recycling activities and diverting more e-waste flows into the formal recycling sector, but also the inclusion of informal sectors to improve their working conditions and efficiency in a gradual way (Akenji et al., 2011; Chi et al., 2011). The key challenge is to achieve high environmental protection standards, especially control of the most dangerous practices used by some informal recyclers, while retaining the economic efficiency of reuse and recycling in the efforts to formalize these informal sectors. The market mechanism for efficient recycling and the public intervention for environmental protection jointly shaped the complex dynamics of global recycling networks (Lepawsky and Mather, 2011; Crang et al., 2013; Lepawsky, 2015; Li et al., 2015). However, deep conflicts exit between the territory-based environmental regulations and the transboundary network of market expansion, which leads to the question whether e-waste recycling should be confined to a regional sphere or integrated into a global solution (Li et al., 2013).

As a large country with vast regional disparities, China's experience in e-waste management provides an instructive case on establishing domestic e-waste recycling capacity in developing countries under the background of globalization.

On the one hand, the development of formal e-waste management system in China has followed the territory-based strategy of the Basel

* Corresponding author.
E-mail address: tongxin@urban.pku.edu.cn (X. Tong).

https://doi.org/10.1016/j.resconrec.2017.10.039
Received 9 January 2017; Received in revised form 30 October 2017; Accepted 30 October 2017

Convention and banned the import of several categories of e-waste products after the publication of BAN's influential report on imported e-waste processing in Guiyu in 2002 (Puckett et al., 2002). Thereafter, the planning of the formal recycling capacity for domestic generated e-waste was also territory-based, that is, the capacity of certified e-waste recycling plants that can enjoy government subsidies was planned at the provincial level to achieve a self-sufficient dismantling capacity for local generation. With China's WEEE regulation and government funds to subsidize formal recycling plants, China has built a nationwide formal e-waste recycling system with 109 certified recycling plants that are armed with the best available recycling technology and controlled by very strict environmental protection standards in recent years (Tong et al., 2015; Zeng et al., 2016).

On the other hand, up to now, this system largely relies on the informal sector for collection. More than 90% of the WEEE that were dismantled in certified recycling plants were fed by the informal sector through a hierarchical network ranging from street peddlers to middlemen and major dealers. Through a series of price competitions along the recycling chain, a significant portion of waste products have been successfully diverted into formal recycling plants as a result of the subsidy from the government (MEPC, 2016; Zeng et al., 2016). This collection system is generally market-based. Contrary to the expectation of regional self-sufficiency in planning, a significant portion of the flows cross the boundaries of provinces. Without considering this network effect, the planning and policy focusing on certified recycling plants could severely distort the recycling market.

The aim of this paper is to quantify the spatial flows of e-waste that are being diverted into the formal recycling system in China through the informal collection networks under the government intervention with WEEE subsidy. The next section provides an overview of the spatial dynamics of e-waste recycling activities in China in last decades, highlighting the market forces that strengthen local agglomeration under globalization. With this background, we reviewed the interactions between formal and informal sectors in the current e-waste management system in China to reveal the "flattening" effects of the planned recycling capacity on the recycling market. In Section 3, we introduce the entropy maximization model of spatial interaction to estimate the interregional flows of e-waste. Based on the provincial data on e-waste dismantled by certified recyclers in 2014, we depict the network of interprovincial flows and calculate the overall transportation cost under this circumstance. The results are presented and discussed in Section 4 regarding the optimization of the spatial distribution of the recycling capacity and the reverse logistic system. In conclusion, we generalize the experience in China to attempt to develop an inclusive circular economy at the global scale.

2. The spatial dynamics of e-waste recycling in China: a review

2.1. Local agglomeration under international flows of e-waste

The development of e-waste recycling system in China was rooted in the transnational flows of e-waste from developed countries to developing countries back to early 1990s (Tong and Wang, 2004), which has received considerable attention due to the exposure to serious pollution associated with these recycling activities in some areas in early 2000s (Puckett et al., 2002; Iles, 2004). Due to the lack of systematic formal trade data and prevalence of illicit traffic in transboundary e-waste flows, the quantitative understanding of transboundary movements of e-waste is limited (Lepawsky and McNabb, 2010; Breivik et al., 2014). Based on a global mass balance model, Breivik et al. (2014) estimated approximately 5000 kt (3600 kt–7300 kt) of e-waste may have been exported from the OECD countries to non-OECD countries, which represents ~23% (17%–34%) of the total amount of e-waste generated within OECD countries in 2005. With a review on the literature published in English, China was identified in this research as the largest importer and recycler of e-waste exported from OECD countries, and the informal recycling of imported e-waste was generally concentrated in several major centers, such as Guiyu, Qingyuan, and Taizhou (Breivik et al., 2014).

The spatial concentration of e-waste recycling not only occurs at the national level but also at the local level. The local agglomeration of e-waste recycling in China can be properly represented by the spatial distribution of licensed importers of recyclable category 7 goods,[1] which are mechanical and electronic scraps containing copper (Tong et al., 2015). Due to the constant efforts to formalize import waste recycling activities in east coastal regions since the late 1990s, a proportion of the former informal recyclers of e-waste in these regions accepted government monitoring, changed their recycling techniques, and received a license to import certain categories of scraps mainly for copper recycling. The number of these recyclers has changed over time, but the spatial distribution pattern is comparatively stable, with several concentrations in coastal regions, reflecting the regional disparity in material demands for industrialization (Tong and Wang, 2004; Tong et al., 2015).

There was a debate within policy makers on whether these certified imported waste processors should be included into the new e-waste recycling system in establishing for domestic e-waste generation. The result was that all the established processing facilities for imported waste were excluded from the new system for local generated e-waste. The recycling systems for imported waste and domestic generation were intentionally separated. The reason was that after the government intervention on imported waste recycling activities, those firms that could stay in business had to specialize into more profitable stages in the global recycling chains so as to achieve the economy of scale for single facility, which was not suitable to deal with the domestic generated e-waste collected from the consumers directly. However, the knowledge within the recycling sector and the business linkages between the recyclers and downstream customers still shaped the initial spatial pattern of domestic e-waste recycling system (Tong et al., 2015). When China promulgated the WEEE regulation in the end of 2011, a large share of the first batch of recyclers applying for certifications came from the coastal areas reflecting the spatial pattern of agglomeration inherited from the international division of labor in e-waste recycling. A considerable share of investment on the domestic recycling facility came from the imported waste recyclers, too. Due to such path-dependency in the international labor division, the whole e-waste recycling system in China has a much better knowledge base for material recovery and recycling in production than for market mechanisms in waste collection and consumers' behaviors.

2.2. "Flattening" of the recycling space: construction of formal recycling capacity in China

China is now the world's largest producer and consumer of electronics products. The e-waste recycling (formal as well as informal) activities in China have continued to grow in tandem with the dramatic increase in the production of electronics since the early 1990s (Tong and Wang, 2004). With increasing attention on the environmental pollution related to e-waste disposal, China started to reform its domestic e-waste management since the early 2000s (Tong et al., 2004; Yu et al., 2010). After more than 10 years of rule-making processes with many demonstration projects, China finally implemented the *Management Regulation on the Recycling of Waste Electrical and Electronic Products* (WEEE regulation) in 2011 (Tong and Yan, 2013). A governmental fund was established to collect a unit-based recycling fee from the producers of five categories of products, including TV sets,

[1] Most of the e-waste products are included in this category of import waste, such as cables, electrical motors, PBX, among others. Waste computers, TV sets, and air conditioners used to be included in this category before 2002. After the reinterpretation of the Basel Conventions, these waste products were excluded from category 7 and banned from import.