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Modelling the correlations of e-waste quantity with economic increase

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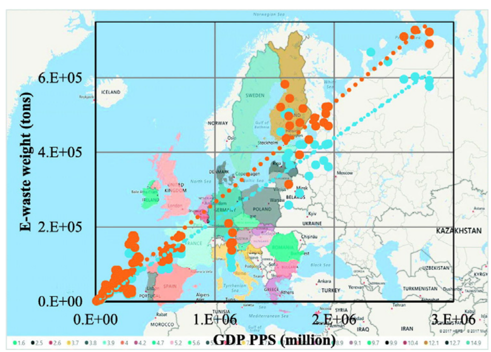
HIGHLIGHTS

- An increase of 1000 GDP PPS means an additional 0.27 kg of e-waste collected.
- An increase of 1000 GDP PPS means an additional 0.22 kg of e-waste reused/recycled.
- An increase of 7.7 kg of e-waste collected for each additional citizen.
- An increase of 6.2 kg of e-waste reused/recycled for each additional citizen.
- Eleven countries have higher values than EU 28 ones in all the three indicators examined.

GRAPHICAL ABSTRACT



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ABSTRACT

Waste from Electrical and Electronic Equipment (WEEE or e-waste) is regarded as one of the fastest growing waste streams in the world and is becoming an emerging issue owing to adverse consequences on the natural environment and the human health. This research article reveals the presence of a strong linear correlation among global e-waste generation and Gross Domestic Product. The obtained results indicate that the best fit for data can be reached by comparing e-waste collected volumes and GDP PPS. More in detail, an increase of 1000 GDP PPS means an additional 0.27 kg of e-waste collected and 0.22 kg of e-waste reused/recycled. Furthermore, for each additional citizen, there will be an increase of 7.7 kg of e-waste collected and 6.2 kg of e-waste reused/recycled. The better collection of e-waste acts an important role concerning the circular economy, and it can be an advantageous approach. Therefore, e-waste could be considered as an opportunity for recycling or recovery of valuable metals (e.g., copper, gold, silver, and palladium), given their significant content in precious metals than in mineral ores.

1. Introduction

Waste from Electrical and Electronic Equipment (WEEE or e-waste) is considered as the fastest increasing stream of waste in the world (Guo and Yan, 2017; Zeng et al., 2017b). The increasing publications in the recent two decades (Fig. S1 in Supplementary content (SC)) indicate that

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e-waste management has become a global and emerging issue, from developing countries to industrial nations (Awasthi and Li, 2017; Li et al., 2015; Sthiannopkao and Wong, 2013). The generated quantities of e-waste are highlighted owing to its fundamental significance in both new policies definition and process development. In principle, the experts described e-waste generated amounts like a logical effect of the technological progress, especially in developed countries (Song et al., 2016). The main idea was that it is useless trying to estimate future e-waste generation because there are so many factors influencing these amounts that there are very few chances to give a real value (Cucchiella et al., 2016b; Zeng et al., 2016). The same issue can be described for yearly growth rates. The list of obsolete products considered as e-waste is so variegated and numerous that there are too many different customer behaviours to consider for doing a real estimation of trends (Guo and Yan, 2017; Tran et al., 2016). As evidenced in some work (Cucchiella et al., 2015), the disruptive innovation characterizing some technological product, together with new environmental measures and critical materials restrictions, modified the natural obsolescence of some electrical and electronic equipment (EEE), by actively increasing their substitution rate. A typical example reported in the literature is about the technological shift between cathode-ray tube and liquid-crystal display screens (Sun et al., 2016).

Recently, some authors started in studying the possible presence of any mathematical relation among e-waste generated volumes and the anthropogenic behaviour in developed (and developing) countries (Duan et al., 2016; Song et al., 2017). For example, Kumar et al. (2017) evaluated the relationship among e-waste generated volumes, national Gross Domestic Product (GDP) and population. Kusch and Hills (2017) refined the previous results by considering GDP at Purchasing Power Standards (PPS) – instead of usual GDP – for limiting/standardizing the effect of different purchasing powers in different nations taken into account during their work.

GDP-PPS is an artificial currency unit, that analyses factors of each country to define a number on a person's standard of living within that country. For this reason, GDP PPS is better than usual GDP (Coccia, 2010; Dennett, 2014). However, the analysis of data characterizing e-waste volumes, including—collection, reuse and recycling with macro-variables are not well analysed in literature. Given a vast difference between generated and collected volumes subject to both illegal flows of WEEE (Li et al., 2013), absence of standardized measuring systems (Ongondo and Williams, 2011), and population habits (Wang et al., 2011), it is of utmost importance to have two distinct views of the context. In general terms, generated volumes are those amounts that, usually, are estimated through statistical data by experts (Garlapati, 2016; Ongondo et al., 2015). Given the previous issues, real data on these amounts are very challenging to gather. As opposite, collected volumes are those numbers that are measured by national governments and that give a correct idea of the real recycling performance of nations (Nelen et al., 2014; Salhofer et al., 2016). However, both generated and collected volumes refer to waste amounts prior to their treatment. Instead of reuse, recycling and recovery are resorted to waste amounts after their treatment (Robinson, 2009). Reused/recycled numbers refer to wastes that, after treatment, can directly re-enter within the traditional value chain (e.g., plastics, wood, glass, metals). Recovered amounts, instead refer to wastes that – given their physical features – cannot re-enter in the value chain and must be incinerated for the production of green energy (Bovea et al., 2016; Golsteijn and Valencia Martinez, 2017). This way, it is important to distinguish the two measures also when there is a need to define a new performance parameter.

Considering the global challenges subject to e-waste, this paper aims to reach two objectives: (1) the mathematical relationship among economic growth, population, and e-waste amount, concerning the 28 European countries during the year of 2009–2014, will be examined in six case-studies such as GDP PPS and collected amount, GDP PPS and reuse & recycling amount, population and collected amount, population and reuse & recycling amount, GDP PPS per capita and collected amount per capita, GDP PPS per capita and reuse & recycling amount per capita. And (2) the future projection of e-waste amount will be uncovered with a comparison among 28 European countries.

2. Materials and methods

This section is structured as follows. Section 2.1 will present a general discussion about circular economy principles. Section 2.2 will link these principles with European governmental actions, evidencing current and future strategies regulated by the EU Commission towards the sound management of e-waste. Section 2.3 will demonstrate a state-of-the-art analysis on e-waste management, uncovering the existing literature gaps. Finally, Sections 2.4 and 2.5 will describe the model used within this work, proposing assumptions and input data at the base of its functioning.

2.1. Circular economy

The CE system originates from eco-industrial development theory and thought (Geng et al., 2012). It is based on the 'win-win' philosophy in which economic opportunities and environmental protection can co-exist (Park et al., 2010). The great challenge of CE is to overcome the linear 'take, make and dispose' economic model (McDowall et al., 2017).

CE aims to reduce both virgin materials input and wastes output through closing resource flow loops in a sustainable way (Islam, 2017). This topic is multidisciplinary, and it is a solution to series of challenges such as resource scarcity, waste generation, environmental pollution and economic opportunities providing by waste (Lieder and Rashid, 2016; Winans et al., 2017). This system is analysed by industrial actors and researchers in several contexts, as (i) eco-industrial park, (ii) waste-to-energy supply chain, and (iii) waste-to-resource supply chain (Chiang and Pan, 2017).

The first is a critical research issue in the field of recycling economy (Zhao et al., 2017) and the eco-industrial park is an effective way to promote the sustainable development and CE (Zeng et al., 2017a). The second field of research aims to create synergies with energy and climate policy without compromising the achievement of higher reuse and recycling rates (Cucchiella et al., 2017). The waste-to-energy supply chain has the potential to conjugate energy demand, waste management, and greenhouse gas emission (Pan et al., 2015). Also, waste-to-resource supply chain has the goal to resolve the issues of waste management and CO_2 emissions and in addition to recovering critical and valuable materials (Pan et al., 2017). A social analysis defines that some values such as trust behaviour, waste cognitive domain, and environment engagement, are necessary to develop these systems (Ceglia et al., 2017).

Industrial waste reuse contributes to both economic growth and carbon emission reduction, even if the environmental benefits are mitigated when the economy is less developed (Zhang et al., 2016a). CE is considered an alternative to today's linear business model. However, the definition of the benefits of CE in many business sectors is not yet entirely defined. Two critical pathways promoted by CE are reuse and recycling and consequently, e-waste management represents a segment of potential interest (Parajuly and Wenzel, 2017) and e-waste is defined as an important resource of the circular economy agenda (Golsteijn and Valencia Martinez, 2017).

2.2. EU policy measures supporting circular economy and e-waste management

The European Union re-knowns the importance of a correct recovery of e-waste for many years. A new version of the WEEE Directive entered into force on 13 August 2012, obliging the Commission to adopt a common methodology for the calculation of EEE placed on the national market in each Member State and of e-waste generated. The collection