URBAN MINING AND E-WASTE MANAGEMENT IN SOUTH AMERICA

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ABSTRACT: waste management is one of the greatest challenges of this century. Important solutions are emerging from the convergence of different areas of acknowledgment. The Waste Electrical Electronic Equipment (WEEE) or e-waste has been specially regarded in scientific literature and business strategy. The collaboration between environmental and economic issues is the focus of circular economy; a proposal that brings together concepts related to sustainability in the supply chain and postulates the closed-loop business model. In developed countries, it is clear the correlation between e-waste generation and GDP related variables, but this aspect has not been sufficiently studied in developing countries. This ongoing research reached preliminary findings that suggest a strong correlation between those variables in South America countries. As results, it was possible to verify the correlation between e-waste generation and GDP related values for the 12 South American countries. The findings suggest that e-waste urban mining in the developing countries analyzed have similar behavior regarding correlations. However, Brazil has some particular characteristics due to its dimension and the quantity of e-waste annually generated. Thus, according to results, we propose specific management procedures regarding Brazilian case.

Keywords: urban mining, WEEE, e-waste, reverse logistics, circular economy, developing countries.

1. INTRODUCTION

Waste management initiatives need multidisciplinary experts to contribute in solving challenges of different natures and acknowledgment areas, to meet environmental, social and economic requirements in a sustainable way (Zheng et al., 2016; Malinauskaite et al., 2017). While most of the European and North American countries have consolidated regulations and infrastructure support, developing countries require broad regulation, technical and economic support and guarantees for society, with the purpose of better addressing the basis of the waste management: collection and disposal of post-consume material (Awasthi et al., 2015).

The circular economy concept breaks with the traditional economy linear model and suggests the circularity in economic approaches aiming the sustainability, proposing closed-loop business models (Urbinati et al., 2017; Jabbour et al., 2017). Although it seems to be an innovative proposal, the concept of the circular economy (CE) brings together several previous concepts and, for this reason, its innovative character has been questioned (Reike et al., 2018). Despite the criticism, we focus on the analysis of one of the tools inserted within the scope of the CE, that is urban mining applied in the management of e-waste, the fastest growing waste stream in the world (Debnath et al., 2016).

Planned obsolescence is another aspect that contribute to e-waste generation increasing and is also close related to the consumer’s purchasing power. On the other hand, according to a market analysis developed between 2013 and 2015, smartphone replacing times are getting subtly longer each year.
(Kantar, 2016) (Table 1). The exception of this trend is verified for China, Germany and Italy. The same research points out as the reason for this pattern in China the low equipment lifespans as a characteristic of the main brands preferred by Chinese consumers. In Italy, the reason would be based on purchasing power and the desire to acquire a new device by Italian consumers.

Table 1. Smartphone life cycles in countries (months).

<table>
<thead>
<tr>
<th>Year</th>
<th>USA</th>
<th>China</th>
<th>EU5</th>
<th>France</th>
<th>Germany</th>
<th>Great Britain</th>
<th>Italy</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>20.5</td>
<td>18.6</td>
<td>18.3</td>
<td>18.0</td>
<td>17.1</td>
<td>20.0</td>
<td>18.6</td>
<td>16.6</td>
</tr>
<tr>
<td>2014</td>
<td>20.9</td>
<td>21.8</td>
<td>19.5</td>
<td>18.2</td>
<td>22.0</td>
<td>22.0</td>
<td>18.7</td>
<td>18.2</td>
</tr>
<tr>
<td>2015</td>
<td>21.6</td>
<td>19.5</td>
<td>20.4</td>
<td>21.6</td>
<td>18.8</td>
<td>23.5</td>
<td>17.7</td>
<td>20.0</td>
</tr>
</tbody>
</table>

These values are result of an exploratory research with market purposes, but can demonstrate the weak relation of a pattern of products’ life time among the countries analysed. In this case, observation for a longer period could lead to more consistent results.

As expected, the generation of e-waste derives directly from the amount of EEE placed on the market. World e-waste generation amount is about 41.8 million of metric tons in 2014 (StEP, 2014), of which 17% is generated in the USA, 17% in China and 4% in India (Table 2). According to Baldé et al. (2016), in 2016 were produced 44.7 million of metric tons, an increasing of almost 7% since 2014.

Table 2. Average quantity of EEE put in market and E-waste generated (StEP, 2015).

<table>
<thead>
<tr>
<th>Country</th>
<th>EEE put in the market in 2012</th>
<th>E-waste generated in 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total produced (million metric tons)</td>
<td>Per capita (kg)</td>
</tr>
<tr>
<td>World</td>
<td>56.5 (100%)</td>
<td>8.2</td>
</tr>
<tr>
<td>USA</td>
<td>7.4 (13%)</td>
<td>23.5</td>
</tr>
<tr>
<td>China</td>
<td>12.4 (22%)</td>
<td>9.2</td>
</tr>
<tr>
<td>India</td>
<td>3.0 (5%)</td>
<td>2.5</td>
</tr>
<tr>
<td>South America</td>
<td>3.7 (7%)</td>
<td>9.8</td>
</tr>
</tbody>
</table>

In South America countries the e-waste generation in 2014 exceeded the ammount put in the market in 2012. Considering an average lifespan of 24 months, as proposed by

In Latin American countries some citizens obtain post-consume material resources from the individual collection and recycling of materials by waste pickers and, for the most part, are still unaware they are contributing to the circular economy in their countries.

Pascale et al. (2016) emphasize an important aspect, the exposure to hazardous substances through the improper e-waste handling. Among the 11 South American countries considered in this study, only six have regulations in force on the subject. Another critical matter is the market value of e-waste (Kidee et al., 2013), that leads a significant number of people in precarious economic conditions to act as waste-pickers, under questionable health conditions. Guiyu city in China is known for its primitive e-waste processing and recycling activity, they receive about 4,000 tons of post-consume electronic equipment per hour and have critical levels of contamination (Wong et al., 2007; Xing et al., 2009).

Despite the effort to restrict the handling of hazardous waste through the Basel Convention, many countries still receive e-waste from various parts of the world (Andrade-Lima et al., 2014).
America, Paraguay and Venezuela are countries that still receive e-waste illegally (Baldé et al., 2017).

Another relevant question is pointed out by Awasthi et al. (2018). They state that “e-waste management has become a global and emerging issue, from developing countries to industrial nations” and describe the importance of e-waste urban mining in the recovering of critical and strategic materials. It is estimated that up to 60 elements from the periodic table can be found in e-waste (Baldé et al., 2017). Among these elements, base metals (e.g. Cu), precious metals (e.g. Au, Ag, Pd) and critical elements (e.g. lanthanides, Li) are highlighted as raw materials, making e-waste an attractive secondary resource of valuable elements (Zhuang et al., 2015).

In previous studies about urban mining some authors concluded that urban and landfill mining was considered as primarily theoretical and emphasized the need for applied approaches (Krook, 2010; Krook and Baas, 2013). Since then, researchers have engaged and released promising results in e-waste management procedures (Awual and Ismail, 2014; Wagner and Raymond, 2015; Tesfaye et al., 2017). Additionally, significant efforts have been made in developing techniques for the recovery of valuable elements from e-waste, especially by pyro- and hydro-metallurgical approaches. Innovative bio-hydro-metallurgical strategies also are gaining increasing prominence as an environmentally sustainable e-waste recycling process (Cui and Zhang, 2008; Priya and Hait, 2017).

Krook (2010) pointed out that in Sweden urban mines there were obsolete power cables that contained four times more copper than that which is annually consumed in this country. This example reinforces the importance of urban mining. Hereinafter we will propose the term urban mine as the definition of urban areas where urban mining can take place.

2. METHODOLOGY

From a review of the scientific literature on e-waste management, circular economy and urban mining, the methodology approach that seemed to provide an interesting contribution to the analysis of e-waste management behavior are those that consider the correlation of annual generation of e-waste and the GDP of each country in billion dollars. In this sense, it was chosen to use the method proposed by Awasthi et al. (2018) as the methodological basis for this article. The authors proposed the correlations modelling of e-waste quantity and economic increase applied to a set of European countries data. It is important to highlight the scarcity of e-waste management work that relates the economic aspects.

From the evaluation of the politics and main initiatives on e-waste management in South America, we proposed the simple linear regression analysis between e-waste generation and Gross Domestic Product (GDP) and GDP Purchasing Power Parity (PPP) for each South American country, besides respective per capita data. According to Awasthi et al. (2018), this is the most basic type of regression and strongly used for predictive analysis and supporting decision making.

The comparative analysis of e-waste amount generation and GDP PPP indicators were chosen in order to consider the income inequality in the developing countries studied. On one hand, this inequality harms economic growth and poverty reduction, but on the other hand it is responsible for increasing consumption observed from the higher incomes strata from the population. The 12 South American independent countries were considered in the research, including Guyana and Suriname whose e-waste generation and population were not expressive for the final results of this research.

3. E-WASTE URBAN MINING IN SOUTH AMERICA

Developing countries are historically known as raw material providers. However, in the last two decades, other scenarios are emerging: (i) developing countries importing e-waste and exporting
secondary resources or (ii) developed countries trading secondary resources and developing industrial processes for valuable materials and elements recovering (Lepawsky, 2015).

Nevertheless, there is a remarkable characteristic, European developed countries have the highest per capita e-waste generation, in average 24 kg per person per year (Baldé et al., 2017). The opposite is observed for African countries, where are the lowest e-waste generation values, less than 1 kg per capita in average.

Through urban mining concept, waste can be turned into a resource and contribute to sustainability objectives (Cossu and Williams, 2015; Arora et al., 2017). Urban mining applied to e-waste recovering and recycling is recognized as an important source of critical and strategic materials of the circular economy agenda in Europe. This pattern leads to an intuitive comprehension about the relations between economic status and e-waste generation. However, other issues can be analyzed to highlight the aspects involved in e-waste management. For example, the purchasing power, public policies in force and social engagement in e-waste initiatives.

3.1 Environmental and economic aspects

From electrical and electronic equipment can be recovered valuable and critical elements that can be reinserted in several supply chains and combine the desired environmental effect of negative impact mitigation or elimination. In this context, urban mining is an important tool for circular economy effectiveness. Some examples of critical materials are rare earth elements (REE), niobium, beryllium, platinum, cobalt, titanium and others. Some of them can be used in clean energy technology such as wind turbines, photovoltaic cells and hybrid vehicles.

E-waste generation have different sources. In the previous studies proposing urban mining concept, Bergbäck et al. (2001) and Brunner and Rechberger (2004), presented the concept of “cold spots”, which mean in few words the urban sites where are obsolete industrial infrastructure, such as subterranean pipes, cables and tubes, for example. Nowadays, these are valuable materials under urban mining concept. Bakhiyi et al. (2018) emphasize that in the 1970’s and 1980’s e-waste and other hazardous waste were usually shipped to less developed nations from developed ones.

The rate of growth of e-waste generation in Latin America countries is estimated at 5 to 7% annually (GSMA, 2015). Brazil (1,534 kt) and Mexico (998 kt) lead e-waste generation in this geographical area, respectively (Baldé et al., 2017). The same authors show that, among the American countries, the United States has the highest rate of e-waste generation, totaling 1,632 kt in 2016.

The social and economic inequalities in those countries lead some people to depend of waste picking to guarantee incomes since e-waste is a valuable category of waste. Chile (9.9 kg per person) and Uruguay (9.5 kg per person) presented the highest per capita e-waste generation along 2016.

The origin of the problems resulting from inadequate e-waste management all over the world seems to be the continuously rising of electrical and electronic equipment producing, consumption and discharge. Many aspects are responsible for the e-waste impacts, and according to the literature, most of them are related to economic indicators (Di Maio et al., 2017; Golsteijn and Martinez, 2017; Awasthi et al., 2018).

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In Table 3, as follows, are presented the database for the correlation analysis developed in this study. All GDP indicators were obtained from the same source, the IMF WEO (http://www.imf.org), whereas the values related to e-waste generation were collected and verified from different sources.
Table 3. Data of key-variables in South America in the years 2014 and 2016.

<table>
<thead>
<tr>
<th></th>
<th>GDP (^2) US Billion dollars</th>
<th>GDP per capita (^2) US Billion dollars</th>
<th>GDP PPP (^2) US Billion dollars</th>
<th>GDP PPP per capita (^2) US Billion dollars</th>
<th>E-waste generation (^1) kton/year</th>
<th>E-waste per capita (^1) kg/inhab.year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>33.616</td>
<td>40.467</td>
<td>2.989.072</td>
<td>3.465.298</td>
<td>63.165</td>
<td>5.616.468</td>
</tr>
<tr>
<td>Chile</td>
<td>263.115</td>
<td>300.455</td>
<td>14.856.024</td>
<td>16.690.122</td>
<td>352.224</td>
<td>19.887.291</td>
</tr>
<tr>
<td>Colombia</td>
<td>387.692</td>
<td>434.726</td>
<td>8.125.893</td>
<td>8.899.243</td>
<td>559.659</td>
<td>10.694.698</td>
</tr>
<tr>
<td>Paraguay</td>
<td>29.550</td>
<td>34.496</td>
<td>6.895.068</td>
<td>7.843.912</td>
<td>49.330</td>
<td>8.735.121</td>
</tr>
<tr>
<td>Peru</td>
<td>216.674</td>
<td>254.182</td>
<td>9.628.459</td>
<td>11.084.184</td>
<td>368.777</td>
<td>7.134.443</td>
</tr>
<tr>
<td>Suriname</td>
<td>5.322</td>
<td>6.241</td>
<td>17.121.063</td>
<td>18.640.034</td>
<td>7.578</td>
<td>11.735.344</td>
</tr>
<tr>
<td>Uruguay</td>
<td>58.283</td>
<td>63.887</td>
<td>11.231.148</td>
<td>11.051.348</td>
<td>59.201</td>
<td>17.390.654</td>
</tr>
<tr>
<td>Venezuela</td>
<td>342.067</td>
<td>347.186</td>
<td>3.945.328</td>
<td>4.455.682</td>
<td>412.099</td>
<td>13.530.524</td>
</tr>
</tbody>
</table>

\(^1\) Source: StEP (2014), GSMA (2015) and Baldé et al. (2017)

\(^2\) GDP, GDP per capita, GDP PPP and GDP PPP per capita from IMF WEO.
Compared to other South America countries, Brazil presents huge values both for population, e-waste generation and products placed on market, but the Brazilian per capita e-waste generation amount is outweighed more than 9.5% by Argentina, Chile, Suriname and Uruguay (Table 3). Regarding this observation, the values verified for the per capita generation of e-waste seem to be more related to the values for PPP GDP per capita than to GDP per capita values.

In Figure 1 is presented the annual per capita e-waste generation in South America, according to StEP (2015) and Baldé et al. (2017). In this chart, the 2015 values were estimated from the arithmetic mean between 2014 and 2016 values.

3.2 E-waste regulations

Brazil occupies about 50% of total area and its population represents more than 52% of the total South America inhabitants. Its continental proportion is an aspect to be considered in environmental management public policy, especially in waste transboundary movements (Andrade-Lima et al., 2014).

The Brazilian Policy on Solid Waste (BPSW) was enacted in 2010 (Law no 12,305/2010) as the first regulation instrument for e-waste management in national level among South America countries. The stakeholders recognized that it would be a misconception if the Extended Producer Responsibility (EPR) concept were added as a requirement in this law (Li and Tee, 2012).

In this way, the BPSW adopted the shared responsibility concept (Souza et al., 2016), from which the agents involved in reverse logistics have complementary responsibilities. From this understanding, it was proposed an interesting initiative to encourage the first step of reverse logistics, the reverse logistics credit model in recovering of post-consume products and materials (Caiado et al., 2017).

Despite the Brazilian pioneering in regulating the management of e-waste through the BPSW, there has still been no finalization by means of the signing of the specific document called Sector Agreement. For this reason, the Global E-waste Monitor (Baldé et al., 2017) does not consider the regulation as
effective in Brazil. On the other hand. Argentina, Chile and Uruguay, which have higher rates of e-waste generation per capita, have specific regulations in force.

4. RESULTS AND DISCUSSION

4.1 Model definition

According to literature, there are some intrinsic characteristics of the countries that seems not to change along the time concerning economic and environmental issues. We present two aspects that must be considered in the correlation analysis of e-waste generation and GDP.

The first one, emphasizes the linkage between GDP and e-waste generation, even while population doesn’t have a significative correlation with GDP (Kumar et al., 2017 and Awasthi et al., 2018); the second states that the presence of developing countries in this type of analysis could negatively influence with non-linear effects (Awasthi et al., 2018). These last authors propose as solution the use of GDP PPS (Power Purchasing Standards) per capita to limit the effect of total population. Thus, our model followed this method considering specifically GDP PPP (Purchasing Power Parity).

4.2 Input data

In Latin America or Mercosul, there is not a single databank as Eurostat in European Union and others. Thus, to obtain the basic data of GDP for each country and the different presentations (GDP per capita and GDP PPP), were analysed different data sources, such as World Bank, StEP Initiative, Global E-waste Monitor report (Baldé et al., 2017) and IMF WEO (http://www.imf.org). This last one showed more complete data set for economic indicators, while StEP and the Global E-waste Monitor presented a set of reliable and relevant data.

As the data for e-waste generation and e-waste per capita generation were not available for 2015 in South America countries, for this reason these data were not considered in this research.

4.3 Correlation model results

The methodological approach allowed the analysis of the occurrence of correlation between the data available for the e-waste generations and the economic indicators for the 12 countries analyzed. Despite the lack of consolidate indicators about e-waste generation in the countries studied, there were no missing data. A total of 15 correlation charts were performed considering the five variables (population, GDP, GDP per capita, GDP PPP and GDP PPP per capita). There were no available values for 2015 e-waste generation in South America. Thus, in the analysis were considered values only to 2014 and 2016.

The results are presented below. In Figure 3 are presented the charts with the results for correlation between e-waste generation and GDP or GDP PPP, both reveals strong correlation with $R^2$ values up to 0.93. In these figures it is possible to observe the difference for Brazil’s value (the most distant dot in all the charts). This pattern may be result of the magnitude of e-waste and GDP values for Brazil, and probably, the need of specific requirements in e-waste logistics management among the South American countries.
Figure 2. The correlation between e-waste generation and GDP or GDP PPP.

Figure 3. The per capita correlation between e-waste generation vs GDP or GDP PPP.
This second set of charts presented in Figure 3 series evidences the correlation between GDP per capita and GDP PPP per capita versus the e-waste generation.

Awasthi et al. (2018) stated that “the presence of developing countries within the set of nations considered by other works could have negatively influenced the calculation with nonlinear effects”. By this reason, they have opted to remove some countries to minimize the impact in the correlation.

Thus, this same analysis was carried on for South American countries in the present article, except for the exclusion of some countries. Despite lower $R^2$ values, it is possible to identify the linear effects of correlation, mainly for GDP PPP per capita values, contrarily to what suggested Awasthi et al. (2018).

The results for the correlation between population and e-waste volumes from 2014 to 2016 reveals strong correlation ($R^2 = 0.99$ for each result) and very similar graphical representations as presented in Figure 4. This same pattern was observed for developed countries (Awasthi et al, 2018).

The behaviour of Brazilian data was similar to the pattern observed for other South American countries in the economical analysis. However, due to the magnitude of the absolute values, the Brazilian pattern seems to distance itself from the values of other countries (see Figure 2 and 4).

This observation allows inferring that it must be taken into account in e-waste management actions proposed for the block of South American countries may not meet the requirements of Brazil, probably due to its size and quantity of waste generated. Thus, specificities regarding transport, packaging and processing logistics should be particularized in Brazil.

5. CONCLUSIONS

The findings suggest strong linear correlation among per capita e-waste generation and GDP for South American countries. However, when the same methodology uses GDP instead of GDP per capita, the correlation is extremely weak. This observation may have some possible origins, such as: (i) the income concentration observed in developing countries, which tends to reduce homogeneity of results or (ii) a
significant part of the population outside the defined limit for the purchasing power.

In comparison to traditional mining, e-waste or urban mining can be considered as a sustainable poly-metallic secondary resource. They are generally composed of base metals and rare/noble metals with great economic value in up to 50 times higher concentrations than natural ore mines (Tay et al., 2013; Kaya, 2016). In this perspective, countries that have both the consumption and the production of EEE have secondary sources of valuable elements in sufficient quantities to be considered as urban mine. It is important to highlight that both EEE producing or importation provides greater availability of materials and elements, besides it also increases e-waste stock as they reach their end of life and compound the urban mines.

Brazil, Chile and Uruguay are among the world's most important mining nations and presents a high correlation of generation of e-waste and the GDP and GDP PPP, which would make them very competitive in the global market for base and precious metals through implementation and consolidation of e-waste regulations and circular economy practices.

However, urban mining as an opportunity to compete with traditional mining since mining costs increase because ‘easy’ mineral mines are becoming scarcer, and many developed countries do not have mineral reserves (Tilton, 1999). An impending example is the dependence on rare-earth imports into Europe which resulted in a strategy for a sustainable rare-earth European economy based on implementation of an e-waste recycling for rare-earth recovery (European Commission, 2010).

The recycling of e-waste to obtain valuable elements is competitive once it is carried out through the same processes used in traditional mining. The mainly advantages in building-up an e-waste recycling comprises the lower dependency on foreign material supply and, in the case of rare-earth, that no radioactive wastes arising in secondary processing (Binnemans et al., 2013).

An important limitation of the work was the availability of reliable of data that could allow a broad analysis with the inclusion of other indicators with economic and environmental impact in the management of e-waste. From to the strong correlations verified for population and e-waste volumes, it would be interesting to evaluate if this behavior repeats in Latin American countries.

From the results, further studies can be conducted to analyze other variables related to the generation and collection of e-waste in the South American countries. Thus, identify potential geographical areas and economic aspects of urban mines can be regarded as the next frontier of e-waste management.

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