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Circular economy and e-waste management in the Americas: Brazilian and Canadian frameworks

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A B S T R A C T

The significant e-waste generation in the Americas represents an important opportunity to implement waste recovery systems under the Circular Economy model. This paper conducts an exploratory analysis about the e-waste management at different scales (economic blocs and country levels) in the American continent, emphasizing generation patterns, e-waste fluxes and the regulation frameworks in Brazil and Canada in order to identify how the e-waste management options are driven by specific legal, economic, and environmental criteria. The methodology includes a review of literature covering information and indicators for both quantitative and qualitative analysis and comparison between selected countries regarding positive and negative aspects of e-waste management systems in each jurisdiction. The finds suggest that although Brazil and Canada have differentiated scope of regulation, both ratified the Basel Convention, have an action agenda that seeks to prioritize the management of hazardous substances, as well as lack of harmonized regulation, low control of the e-waste illegal trade and traceability. The identification of e-waste flows and comparison of economic blocs and countries is a still little explored theme and emphasizes the need for adequate legal measures to implement circular economy strategies to avoid impacts and enhance the value recovery of these materials in the production chain. Doing so could support harmonized regulation, new business models and increase sustainability levels for citizens through solutions that integrate policies and practices between and within economic blocs.

1. Introduction

Waste electrical and electronic equipment (WEEE or e-waste) is the fastest growing waste category (Baldé et al., 2017; Awasthi et al., 2018). It is composed of high added value materials (Ongondo et al., 2011; Namias, 2013), but also contains hazardous components (Kidee et al., 2013; Pascale et al., 2016). Therefore, this dual characteristic demand strategic and differentiated streams for guaranteeing adequate treatment and value recovery.

The strategical planning for returning the e-waste to new productive cycles is derived from the principles encompassed by the Circular Economy (CE). This approach refers to measures for allowing the anthropogenic system to reintroduce waste as nutrients for new natural or technological cycles, in a way for generating environmental, social and economic benefits (McDonough and Braungart, 2002).

Under the CE concept, 'urban mining' is a way for implementing a circular pattern for e-waste streams (Ottoni et al., 2020). The existent material stocks in the urban infrastructure (Daigo et al., 2015; Krook et al., 2011), obsolete products and waste support the possibility for their reuse as resources in the productive chain through urban mining strategies (Cossu and Williams, 2015; Zhang et al., 2019). Regions with a high e-waste generation (or the so-called "urban mines") might not only develop logistical infrastructures for waste recovery but also implement legal frameworks to control and promote safe handling of this category due to its toxic components (Kumar and Singh, 2013; Bakhiyi et al., 2018). The impacts can be mitigated by harmonizing management practices, identifying the economic vocation, and proposing regulatory framework.

The Americas are one of the biggest e-waste generators worldwide, with a total estimated in 2019 at 13.1 million tons (7.7 Mt in

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North America, 1.5 Mt in Central America, and 3.9 Mt in South America) (Forti et al., 2020). This fact emphasizes the role played by the Americas as a potentially significant source for e-waste urban mining. In the same region, the two different development hemispheres, South America and North America, allow a rich comparison regarding e-waste management, mainly on generation, fluxes, and regulation.

Some authors have proposed the approach of economic aspects of e-waste management in different countries emphasizing, for example, economic and environmental aspects (Boubellouta and Kusch-Brandt, 2021), recovery of secondary raw materials (Garg, 2020) and risk assessment (Hameed and Petrillo, 2020). Kumar et al. (2017) and Awasthi et al. (2018) analyzed the correlation of Gross Domestic Product (GDP) and e-waste generation in different countries.

In a nutshell, transboundary e-waste movements occur through mostly intra-regional fluxes and are mainly motivated by economic and legal drivers (Lepawsky and McNabb, 2010; Ilankoon et al., 2018). The need to strengthen e-waste collection and management techniques in developing countries and the integration of socio-economic recycling strategies are supported by Ilankoon et al. (2018), while Petridis et al. (2020) identify distance, contiguity, common currency and language, colonial ties as the main reasons for countries' roles in global e-waste trade networks. Previously, Estrada-Ayub and Kahhat (2014) pointed to geographical location and market requirements as important aspects for designing managing policies.

The points discussed by these authors make it possible to inquire about the importance of establishing common policies between economic blocs for the management of e-waste. The logistics infrastructure to manage e-waste fluxes could be improved by the establishment of e-waste management and commercial routes inside the same economic bloc, under similar regulations and economic targets, but this is not a priority for most countries. To date, studies investigating e-waste management alternatives typically examine policy options at the scale of the nation. Only few such studies consider the potential of economic trade blocs beyond the EU's WEEE policies to influence e-waste management solutions, indicating a gap in the literature.

This paper aims to conduct an exploratory analysis about e-waste management at different scales in the Americas, considering both economic blocs and country levels. Therefore, the focus of this study is on e-waste generation patterns in NAFTA and MERCOSUR countries. Further, it examines e-waste fluxes and the regulation frameworks regarding e-waste in Brazil and Canada, developing and developed countries, respectively, of each American bloc. This parallel between both realities is necessary for supporting a discussion on positive and negative aspects of e-waste management policies as an important contribution for material recovery, under the circular economy concept. Different methods for material recovering can be provided according to circularity and urban mining concepts. Techniques such as pyrolysis, leaching, and bioleaching have sustainable potential (Xavier et al., 2019).

1.1. Circular economy: upstream and downstream solutions

The CE concept is related to the idea of generating systems that can be sustained in the long-term. Therefore, this approach states an interconnected set of regenerative actions to reduce (or even avoid) waste generation and to implement secondary raw material recovery systems (EMF, 2013; Kirchherr et al., 2017; Paulik, 2018). CE proposes a less harmful model for the environment, since it promotes virgin material minimization and espousal of clean technologies (Andersen 1997, 1999; Sariatli, 2017). Although the CE and similar concepts (Kalmykova et al., 2018) have received much attention, it still poses a diverse set of practical challenges for finding solutions that can simultaneously allow waste valorization, risk mitigation of hazardous substances, creation of jobs and quality of life improvements (EMF, 2013).

Some countries such as Japan, China and Germany have regulations on the circular economy, which includes the establishment of materials recovery and recycling rates. With an estimated rate of 30% of illegal export, Japan has 50–60% of e-waste stemming collected and processed in countrie's recycling system (Ignatuschtschenko, 2017). In Germany, CE was started by a legislative act in 2012. The German approach enforces three important principles: Precautionary principle, Polluter-pays principle, and the Principle of cooperation, both under a third principle, that of Extended Producer Responsibility (EPR). Current pieces of similar regulation are under elaboration in countries of South America and Africa.

Some initiatives have recently been consolidated as evidence of international interest in the institutionalization of the circular economy concept. In 2018, the International Standardization Organization (ISO) Technical Committee (TC) 323 for Circular Economy (ISO/TC 323). The current TC is secretariat is housed by the Association Française de Normalization (AFNOR) and has 70 participating countries members and 11 observing countries members. ISO/TC 323's work includes environmental management, sustainable cities and communities, sustainable finance, blockchain and distributed ledger technologies and sharing economy. From the countries that take part in NAFTA, Canada was the only NAFTA country to take part in ISO/TC 323 discussions until 2019, when USA changed its position from observing member to participating member, and Mexico began taking part in 2020. Participants from the MERCOSUR bloc currently include Brazil, Uruguay and Argentina.

Inside this movement, a new ingredient is provided to the circular economy concept: the urban mining, one of the practical solutions that emerged from the closed-loop and circular economy concepts (Cossu and Williams, 2015). Both economic and environmental improvements are desired in order to reach a sustainable system of production, consumption and recovering (reuse, repairing, refurbishing, recycling, etc), rather than final disposal.

The CE framework covers a wide range of activities that can be divided into the stages before (upstream) and after discard (downstream). The upstream phases consider the extraction, transport, storage, sorting, designing and processing new products, and the usage phase (Bakhiyi et al., 2018; Shaikh et al., 2020). Potential upstream solutions should focus on fostering commitments from manufacturers on a design for circularity (durable, modular, recyclable and products as services) and a limited usage of hazardous compounds (Bakhiyi et al., 2018).

The downstream level is related to the operations for returning these materials back to the productive chain through various stages and options for re-valorization such as collection, transport, sorting, treatment, refurbishment, remanufacture, recycling, recovering energy and environmentally sound disposal. These solutions should include reverse logistics (or take-back) systems, cleaner recycling and processing technologies, besides actions to progressively reduce the illegal waste trade and integration of the informal sector into the formal recycling system of developing countries (Bakhiyi et al., 2018). The waste hierarchy, as determined by the European Waste directive 2008/98/EC (EU, 2008), should be prioritized in both upstream and downstream operations, considering, in order of priority: avoidance, reduction, reuse, recycle, recover, and adequate final disposal.

Although CE seems to be more linked to solving downstream impacts (since they are more "visible" to the consumers), there are more significant impacts at the upstream stage. The upstream processes (e.g., raw-material extraction and production) usually require significant energy and material inputs, besides being responsible for pollutants emissions that likewise require follow-up mechanisms (Xavier et al., 2019). In short, circularity needs to account for the very different scales of waste arising between the upstream and downstream phases of commodity lifetimes.

1.2. Problems and strategies for e-waste management

In existing policy discussions, e-waste usually refers to products discarded by individuals or households or 'consumers' (Ottoni et al., 2020). After discard, e-waste can become a potential risk for human health and the environment when directed to informal fluxes (from national to international levels), mainly because of its composition containing hazardous substances (heavy metals, persistent organic pollutants, etc) and inadequate management (Ongondo et al., 2011).

Tidd et al. (2007) suggest several factors giving rise to e-waste: (i) strong relationship between market performance and new products; (ii) new products lead to profitability; (iii) the shortening of products lifecycle by replacing products; and (iv) shortening of products' design and production time. Most of these points are the basis of obsolescence and, consequently, result in consumption and waste generation increasing. Researchers have suggested models that accord with CE principles that could mitigate the negative consequences of extant linear economic systems that typically give rise to e-waste. For example, Ungerman et al. (2018) suggests how digitalization and what some call 'Industry 4.0' could enable "individual needs to be satisfied at the price of large-scale production". The customer needs lead to the new devices design and production, those that will turn into e-waste, contributing to the environmental and health impacts. Nwaiwu (2018) considers that manufactures and services providers decide which digital technologies to produce and market, designing needs and ways of life, and "reinterpreting what it means to be a customer and a citizen".

These authors highlight the impact of innovation and technological improvements as a competitive advantage that is characterized by new and efficient products and services that are, under the concept of linear economy, produced, consumed, and discarded worldwide. Globalization has aligned economic blocs and has also blurred borders. While technological products and services have become a pandemic need, there are no well-defined consumption or e-waste generation frontiers.

The international cooperation and the domestic regulations are important measures fostered by the countries to identify and control such illegal e-waste activities. The Basel Convention came into force in 1992 and represents an international treaty that regulates the export of hazardous waste from industrialized countries to less developed nations, addressing the poverty and vulnerability of developing countries in terms of waste management flows of post-consumer products and materials.

Regarding the regulations adopted in a national, regional, or local level, the main strategies adopted by the countries were to confer certain degrees of responsibility that would allow punishments in case of inadequate management of e-waste. In this context, CCME (2014) highlights some types of waste management responsibilities models fostered worldwide, as follows:

(i) **Extended Producer Responsibility (EPR):** programs in which manufacturers, brand owners and first importers are directly responsible for both the funding and the operation of the programs via legislation or regulations.

(ii) **Product stewardship:** programs in which manufacturers, brand owners and importers are neither directly responsible for program funding, nor for program operations. These are waste diversion initiatives funded by consumers or general taxpayers and are operated by public agencies or delegated administrative organizations, being mandated through legislation and regulations or may be voluntary.

(iii) **Shared responsibility (SR):** programs operated by municipal governments or other public agencies, but with varying degrees of producer responsibility and/or funding. All actors (producer, importer, distributors, traders, government, consumers) participate in the waste management, with their respective responsibilities.

The milestones and restrictions proposed through the European Directives (WEEE, *Waste electrical and electronic equipment*, and RoHS, *Restriction of Certain Hazardous Substances*) provide the main basis for European regulation in each member country. The Article 14 of the WEEE Directive proposed the initial coverage of historical e-waste providing the visible fee, which shows the consumer the related logistics costs (collection, treatment, and disposal) of e-waste. This attitude can impact the purchaser in order to rethink about consumption behavior, but this practice was not adopted by all European countries and is not in force anymore. There is no similar policy in American countries on this concern.

Also, some previous studies discussed e-waste management issues in several American nations separately, as the case of Argentina (Torres et al., 2016); Brazil (Souza et al., 2016; Dias et al., 2018; Ottoni et al., 2020; Souza, 2020), Canada (Lepawsky, 2012; Kumar and Holuszko, 2016), Chile (Silva and Baigorrotegui, 2020); Mexico (Estrada-Ayub and Kahhat, 2014; Saldaña-Durán et al., 2020), United States (Lepawsky, 2012; Seeberger et al., 2016), and other Latin American countries (Torres et al., 2016; Forti et al., 2020). The studies of Kumar et al. (2017), Forti et al. (2020), Ahirwar and Tripathi (2021) and Shittu et al. (2021) analyzed the global e-waste generation, collection, legislation, challenges and trends. However, the literature presents a gap of studies that provide an integrated and comparative approach of e-waste management practices and fluxes particularly with the focus on the American countries, especially when considering an analysis through the economic blocs perspective.

2. Methodology

The methodological procedures adopted in this study were conducted in a two-level analysis focusing the Americas in order to evaluate the influence of legal, economic, and environmental criteria in e-waste management options.

Firstly, the analysis at the economic blocs' level was based on NAFTA and MERCOSUR details, due to representativeness as the main American economic blocs in the northern and southern hemisphere, respectively. The identification of the main indicators for e-waste management in both economic blocs was carried out by literature review.

Recent studies (Kumar et al., 2017; Awasthi et al., 2018) propose the correlation of GDP and e-waste generation and emphasize the impact of valuable metals and also health risks due harmful chemicals in their composition. While some countries are prepared to deal with these impacts, many studies assume that developing countries need to coordinate integrated solutions to mitigate environmental and public impacts. Thus, the correlation between e-waste generation amounts and the GDP, as an economic development indicator, was suggest for the Americas to verify the importance of this indicator directly for e-waste management in the region. The methodology, proposed by Kumar et al. (2017) in a global scale, and adapted by Awasthi et al. (2018) for the European countries, was based on linear regression method. Our study builds on Kumar et al.'s (2017) approach by combining it with a Material

Flow Analysis (MFA) as presented and discussed by Islam and Huda (2019). These authors note that MFA can be an important contributor to e-waste management, enabling the comparison of different flows between different countries.

For the country level analysis, Brazil and Canada were selected not only because they play similar environmental and economic roles within their respective economic blocs (MERCOSUR and NAFTA, respectively) but also for their similar territorial dimensions and because these countries represent, respectively, ‘developing’ and ‘developed’ economies. These factors enable a comparative analysis regarding e-waste management, general fluxes and related regulation, the effects of that regulation—both positive and negative—and an assessment of regulatory similarities and gaps between Brazilian and Canadian e-waste management realities.

3. Results and discussion

3.1. MERCOSUR and NAFTA: E-waste indicators and generation

MERCOSUR was stablished in 1991, and is composed by Argentina, Brazil, Paraguay, Uruguay as full members. The NAFTA agreement between Canada, Mexico and United States came into effect in 1994. Despites the economic agreements, there are remaining institutional gaps in terms of e-waste management in both blocs, as the absence of specific requirements on the transit of e-waste between countries. Table 1 displays select characteristics of MERCOSUR and NAFTA regarding economic, politic and e-waste management aspects. The set of indicators analyzed were focused on political, economic, environmental, and legal factors.

Brazil, Canada and the USA face the greatest challenges for reverse logistics, due to the territorial area, population density and volumes generated per capita. Considering the importance of the population and country area indicators, we consider the importance of both. The area is relevant due to the distances to be covered for the collection and disposal of e-waste, which directly impacts the total logistical cost. In this regard, the energy matrix and fuel can also impact this equation. In this way, Canada and Brazil also show similarity in terms of an energy matrix of primarily hydroelectric origin and investment on renewable fuels.

The imbalance between put on market (PoM) volumes and e-waste generation volumes is more evident in developing countries in MERCOSUR than in the developed ones in NAFTA. The population contingent among the analyzed countries varies significantly. The USA, Brazil and Canada have continental dimensions of more than 8 million square kilometers. However, USA population is ten times bigger and Brazilian population is six times bigger than Canada’s population, respectively.

Brazil and Canada are countries that have equivalent GDPs, as well as economic activities with an emphasis on mining, livestock, and agriculture. Brazil generates more than twice as much e-waste as Canada annually, although Canada’s per capita generation exceeds Brazil’s generation by almost seven times.

Argentina, USA and Canada are the only countries in the Americas that do not have specific regulations for e-waste management at the federal level. Except for Argentina, all other MERCOSUR’ countries have opted for shared responsibility (SR) or co-responsibility as an e-waste management model. In Canada and the USA individual provinces and states respectively adopt the Extended Producer Responsibility (EPR) model while in Mexico the SR model prevails.

While Brazil has the highest e-waste generation rates in South America, the USA is the second largest total volume generated worldwide. Both, USA, Canada and Brazil represent the biggest total GDP values comparing to the other countries in MERCOSUR and

Table 1
MERCOSUR and NAFTA main politic, economic and e-waste management aspects in 2019.

Indicators	MERCOSUR				NAFTA		
	Argentina	Brazil	Paraguay	Uruguay	Canada	Mexico	United States
Population (million)	44.9	210.2	7.2	3.5	37.8	126.6	329.0
GDP (billion US$)	449.66	1839.76	38.15	56.05	1736.43	1258.29	21,374.42
GDP per capita (US$)	10,006.15	8717.19	5414.80	16,190.13	46,194.73	9863.07	65,118.36
Area (million Km^2)	2780	8516	0,406	0176	9985	1973	9834
EEE PoM (kg per capita)	12.7	13.3	10.6	13.7	23.8	13.0	25.3
E-waste generation per capita (kg/ inhabitant)	10.3	10.2	7.1	10.5	20.2	9.7	21.0
Total e-waste generation (kt)	465	2143	51	37	757	1220	6918
E-waste documented to be collected and recycled (kt)[1]	11 (2013)	0.14 (2012)	NA	NA	101 (2016)	36 (2014)	1020 (2017)
E-waste Federal regulation	No	2010 – into force in 2019	2009	2019	No	2003	No
Regulation framework start point	Laws No 23,922/1991 and No 24.051/1992 (Hazardous Waste)	Law No. 12,305/2010 BPSW	Law No. 3956/2009	Law No 19,829/2019	Nova Scotia’s Electronic Products Stewardship Program (N.S.Reg. 25/ 1996)	“Ley general para la prevención y gestión integral de los residues”/ 2003	California: Electronic Waste Recycling Act (EWRA), Senate Bill 20 Enacted/2003
Waste management responsibility model	Extended Producer Responsibility	Shared Responsibility	Co-responsibility	Shared Responsibility	Extended Producer Responsibility	Shared Responsibility	Extended Producer Responsibility
Ratified Basel Convention	Yes (1991)	Yes (1992)	Yes (1995)	Yes (1991)	Yes (1992)	Yes (1991)	No

Sources: Data obtained from Bandini (2009) *apud* Araujo et al. (2012), Forti et al. (2020), STeP Initiative (2019), Trading Economics (2019), World Bank (2019a,b)

NAFTA, which might indicate the influence of this parameter and the population number within the e-waste generation amounts. The serial correlation of e-waste generation and GDP values were analyzed under multiple linear regression considering MERCOSUR and NAFTA countries, as illustrated in Fig. 1. The graphs (a) and (b) represent the linear regression for NAFTA and MERCOSUR regarding total and per capita values, respectively. The graphs (c) and (d) present the linear multicorrelation for NAFTA and Brazil in terms of total and per capita values, respectively. The analysis comparing Brazil's GDP and e-waste generation with the NAFTA's countries shows the similarities of this country with those of NAFTA countries.

MERCOSUR and NAFTA have countries with different political and economic contexts that can influence within e-waste management. As highlighted in graphs (a) and (c) of Fig. 1, the USA values were much higher than the other countries, making the correlation analysis between the other countries unfeasible due to the disproportionate scales. As pointed in graph (b), the analysis of per capita values emphasizes two main groups: the developed ones (USA and Canada), and the developing nations of NAFTA and MERCOSUR (Mexico, Argentina, Brazil, Paraguay and Uruguay). In both cases, the findings in Fig. 1 suggest that GDP is directly correlated (all R^2 close to 1) to the e-waste generation in the Americas, as previously verified by the literature for other regions of the globe (Huisman, 2010; Kumar et al., 2017; Kusch and Hills, 2017; Awasthi et al., 2018; Namlis and Komilis, 2019; Boubellouta and Kusch-Brandt, 2021). In the separated analysis of NAFTA and Brazil, in graph (d), the same two groups were identified, and the clear similarities regarding GDP and e-waste generation of Brazil and Mexico can be seen.

Another important aspect is the coverage of e-waste devices by the specific regulation. According to Lepawsky (2012), from the comparison between USA and Canada e-waste regulations, it was found that while Canadian provinces accomplish the main categories of electronic devices, the 24 USA states with e-waste regulation, only Wisconsin and New York states cover the main electronic devices. One of the possible reasons for a low rate of compliance with e-waste regulation among USA states is the non-ratification of the Basel Convention.

In a scenario that disregards the USA because of its disparate GDP and e-waste generation values, Brazil, Canada and Mexico are highlighted as the next biggest e-waste generators and GDP values in the blocs. However, considering that Brazil and Canada have similar area proportions (important e-waste management parameter regarding logistics costs) and represent different development levels (Brazil as a developing country and Canada, a developed one), Brazil and Canada were selected for further comparison analysis regarding their e-waste management systems. The data of GDP value, the geographic area, the legal scope and the devices covered by regulation are the motivation for selection of Brazil and Canada as representatives of the two economic blocs.

3.2. Brazil and Canada: E-waste fluxes and legal framework

3.2.1. Brazilian context

Brazil and Canada were selected for further comparison analysis regarding their e-waste management systems. The data of GDP value, the geographic area, the legal scope and the devices covered

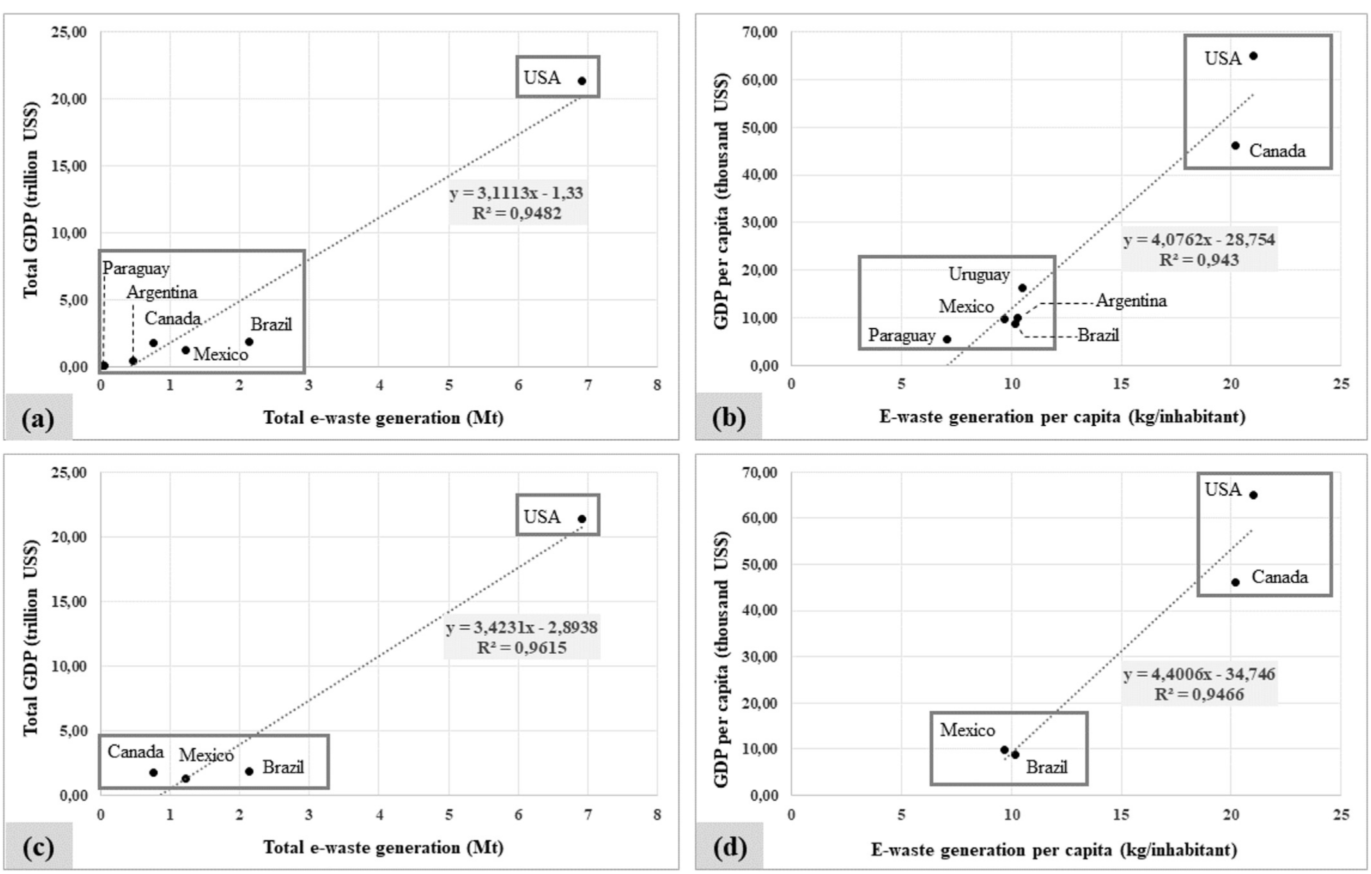

Fig. 1. Linear Regression analysis between GDP and e-waste generation in MERCOSUR and NAFTA countries in 2019: (a) Total GDP and total e-waste generation; (b) GDP per capita and e-waste generation per capita; (c) Total GDP and total e-waste generation in NAFTA and Brazil; (d) GDP per capita and e-waste generation per capita in NAFTA and Brazil.

by regulation are the motivation for selection of Brazil and Canada as representatives of the two economic blocs.

(i) General e-waste fluxes

Brazil stands out in South America as an e-waste generator, consequent diverse fluxes, and to the regulatory mechanisms already implemented by the country to manage those fluxes. Forti et al. (2020) estimated 2143 million ton of e-waste generated in Brazil in 2019, primarily in the Southeast region. Although Brazil announced an e-waste Federal regulation in 2010, Brazil still faces some challenges regarding e-waste management, especially in the metropolitan regions (Ottoni et al., 2020). In most of them, a formal e-waste Reverse Logistics System (RLS) with the structure for collecting and recycling is absent, and, hence, a large share of the e-waste generated is still disposed mixed with household waste in landfills and is destined for informal chains (Souza et al., 2016). This context is possibly a result of the lack of reliable information, the important role of informality in the segment, and the continental proportions of Brazilian territory (Araújo et al., 2012; Souza et al., 2016; Dias et al., 2018; Abbondanza and Souza, 2019; Souza, 2020). The estimated recycling rate for e-waste in Brazil is 2% (Bandini, 2009 *apud* Araujo et al., 2012).

The e-waste fluxes in the country can be divided into formal and informal routes, as illustrated in Fig. 2.

According to Fig. 2, the e-waste generation in Brazil can be originated not only from household, companies, industries, public administration, but also from illegal e-waste imports. Lundgren (2012) indicates illegal e-waste fluxes from the North America countries to Brazil, especially from the USA. However, data from COMTRADE (2019), show that the most usual trade of e-waste (under code 854,810 - Waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators) from Brazil is to European countries such as Belgium, Germany, Spain and Austria.

Furhtermore, Ottoni and Xavier (2019) show that a huge portion of Brazilians (approximately 85%) keep at home their broken or obsolete appliances instead of discarding them in the existing e-waste collection points. The COMTRADE data and Ottoni and Xavier's (2019) study suggest the fluxes of e-waste in Brazil are not a simple story of a 'developing' country importing illegal e-waste from abroad.

Formally, the e-waste generation from a domestic source must be conducted to the RLS through voluntary delivery points (VDP), official collection campaigns, or even directly to the specialized companies for treatment and processing. Ottoni and Xavier (2019) identified 152 organizations acting in the various stages of e-waste reverse logistics segment.

However, in a real context, the domestic e-waste is also directed to Municipal Solid Waste Management (MSWM) companies (mixed with MSW or the special collection for recyclable materials), which are not responsible for the e-waste RLS from domestic sources and can only collect these appliances when properly paid for this service (Brazil, 2010). Also, when discarded in MSWM streams, most e-waste ends up in landfills, wasting their valuable elements and with a huge possibility to generate environmental impacts.

The household e-waste collection and pre-treatment in Brazil can also be performed by the informal sector, such as individual waste pickers or irregular organizations (Souza et al., 2016; Caiado et al., 2017; Dias et al., 2018; Souza, 2020). In a context of social and economic problems in the country (e.g., marginalization, unemployment, poverty), the participation of informal recyclers, sometimes even organized in irregular cooperatives or associations, is an important part of the recycling system. These fluxes handled by the informal sector represent a challenge for e-waste management since most of these informal actors are untraceable. They sell materials to informal markets that may use irregular export channels, or materials may end up in open dumps, which are being managed out of existence since 2010 (Brazil, 2010). The informal sector may also use primary techniques for extracting valuable substances, such as cable burning and acid leaching (Velis and Mavropoulos, 2016; Bakhiyi et al., 2018; Ottoni et al., 2020). Such techniques are dangerous for human health and the environment.

The e-waste generated in the industry sector or public administration usually are included in the formal streams. In this case, since the RLS do not operate for non-domestic e-waste, these materials are collected by outsourced waste companies for adequate treatment and recycling in the country or exported to regular foreign recycling companies. However, in practice, there are cases of irregularity between these institutions and the informal sector in Brazil.

(ii) General e-waste legal framework

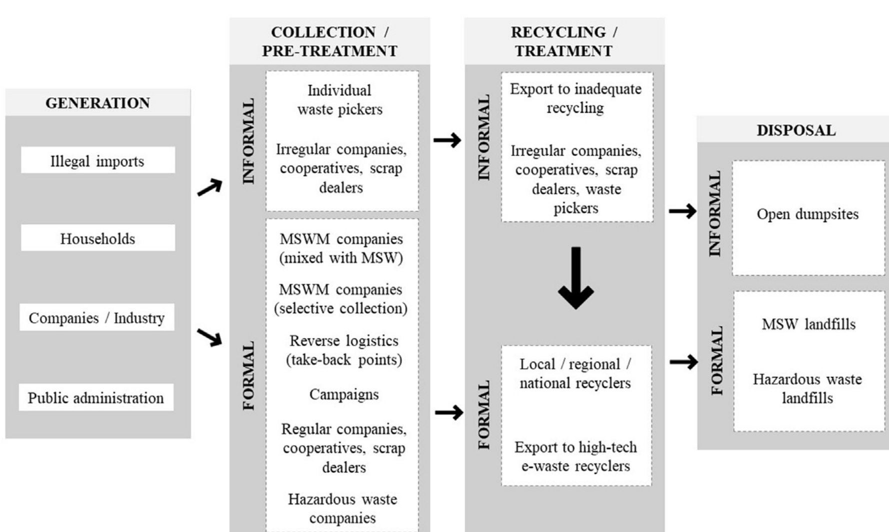

Fig. 2. General formal and informal e-waste fluxes framework in Brazil, based in information from (Caiado et al., 2017; Dias et al., 2018; Souza, 2020).

E-waste management in Brazil is regulated by the Brazilian Policy on Solid Waste (BPSW), under the Law No. 12,305/2010 and the Decree No. 7404/2010. Both documents established the common basis for waste management in public and private levels and secured the inclusion of social agents (waste pickers associations and cooperatives) in the RLS (Dutra et al., 2018).

The BPSW establishes the need for articulation among producers, importers, distributors and traders, which must structure and implement the RLS. Other agents (recyclers, cooperatives, consumers and managing entities) are also responsible for the other stages to support the RLS, configuring the shared responsibility model for waste management. In Brazil, the manager entities, generally non-profit organizations (NGOs), are contracted by producers and sub-contract the operators, that provide complete solutions for all e-waste management stages.

Despites being the main regulation in the federal level, the BPSW does not specify the quantitative goals and deadlines to environmental compliance. Those aspects are included in the Sectoral Agreement for the RLS of electrical and electronic products and their components of domestic use – physical personnel (residential or family) –, in 2019, and later in Federal Decree 10,240/2020, which reinforces the arguments presented in the sectoral agreement and raises its terms at the level of federal law. The decree obliges companies in the segment to implement e-waste collection systems and to correctly dispose of it, not including non-domestic electronic waste – professional use, health services, or large generators – and batteries or lamps, as these already have a reverse logistics agreement (Brazil, 2020).

The collection and destination rate, according to Decree 10,240/2020, varies from 1%, in 2021, of the total electronics products sold on the domestic market for domestic use in the base year of 2018, evolving into 3%, in 2022, 6%, in 2023, 12%, in 2024, and, finally, 17%, in 2025, of the same base year (Brazil, 2020). These goals seem still low for the Brazilian potential to develop structured RLS, especially considering the rates of other countries (Baldé et al., 2017).

3.2.2. Canadian context

(i) General e-waste fluxes

Canada's e-waste generation is one of the highest contributors to e-waste volume in relative quantities in the Americas (Bakhiyi et al., 2018).

The various e-waste discard alternatives in Canada end up at three main destinations: treatment (refurbishment, remanufacturing and recycling), disposal and exportation, as illustrated in Fig. 3.

As shown in Fig. 3, e-waste importation is one of the generation possibilities. Data from COMTRADE (2019) indicate e-waste importation to Canada from Australia, USA, China, Denmark, Japan and Poland, and exportation fluxes from Canada to other countries (Singapore and South Africa).

MSW collection is another alternative for e-waste discard, although this option varies in some provinces. Programs run by retailers (such as Return to Retailer, R2R) also provide an important option, as the case of cell phones (Dewis and Van Wesenbeeck, 2016). Statistics Canada (2011) emphasized that the citizens are more likely to send their general e-waste to a drop-off center or in proper campaigns and donations. Also, over 80% of Canadians have at least one EoL electronics device sitting at home (EPRA, n.d.). The high retention index identified might suggest that the Canadian take-back system faces challenges, such as the lack of awareness regarding disposal methods or unavailability of a drop-off center (Kumar and Holuszko, 2016).

The Canadian e-waste collection and recycling system is operated by national and provincial organizations, that founded programs for each e-waste categories and operate in different provinces (Kumar and Holuszko, 2016). Most collection points in Canada operate as private businesses or at municipal sites, where the materials are generally sorted by typology. If an item can be refurbished and resold or donated to a charitable computers-for-students type of organization, then it is set aside (CM Consulting, 2013). References to informal activities of collection performed by waste pickers in Canada were not found in the literature.

Although many related programs are operating in the country, approximately 20% of the e-waste generated in Canada does not get collected and is either lost as municipal waste or stays in household storage (Kumar and Holuszko, 2016; Baldé et al., 2017). The Canadian e-waste collection rate can be considered low for the its potential, especially when compared to other developed countries, such as Norway (73%), Sweden (69%), Finland (55%), France (44%), Germany (34%), among others (STeP Initiative, 2019). Canada's relatively low collection rate could result from the complicated collection system, divided across geography and by e-waste types. Greater accessibility to drop-off sites for all types of e-waste could enhance the ability of RLS to recover more materials. A single entity for managing those diverse programs would allow them to share drop-off locations and thus increase the overall availability of drop-off locations (Kumar and Holuszko, 2016).

The refurbishment, remanufacturing and recycling companies usually have separated units specialized in dismantling and removal of hazardous substances previously to send to the processing phase in bigger facilities. The pre-treated e-waste is then sent to the proper treatment centers, where this material is shredded and separated into various streams to be directed to the adequate method of value extraction. The long distances to the processing facilities is a barrier to recycling, due to the large volume of material that is required to be transported to other provinces, which is time-consuming and costly (Kumar and Holuszko, 2016). The authors pointed a province-based central recycling facility as a possible solution, considering the local units (for smaller processes) and this bigger center (in each province) for the final stages.

Newfoundland (NL), Nova Scotia (NS) and Prince Edward Island (PE) provinces, the municipality of Vancouver and parts of British Columbia (BC) and Ontario (ON) have banned e-waste disposal in landfills in Canada (CCME, 2014; Kumar and Holuszko, 2016). Dewis and Van Wesenbeeck (2016) pointed to the expressive reduction of residential waste, including here e-waste, to landfilling over the years.

(ii) General e-waste legal framework

The e-waste management in Canada lacks specific federal regulations. Environment and Climate Change Canada (ECCC) (formerly Environment Canada, or the Ministry of Environment) regulates policy regarding the handling, disposal, import and export of hazardous waste, and is also responsible for the development of technical documents about MSWM and waste incineration (Kumar and Holuszko, 2016). The e-waste management is mainly performed by legislated Extended Producer Responsibility (EPR) programs, regulated by the provinces (CCME, 2014; VanderPol, 2014). Finally, the municipal governments are responsible for overseeing local waste management services, providing directions on recycling and disposal, especially regarding landfill bans (VanderPol, 2014).

The emergence of regulations for management of EoL electronics in Canada begins in the early 2000s with two developments in the private and public sectors. In 2003, a consortium of industry actors founded a non-profit organization called Electronic Product Stewardship Canada (EPSC), established to design, promote, and

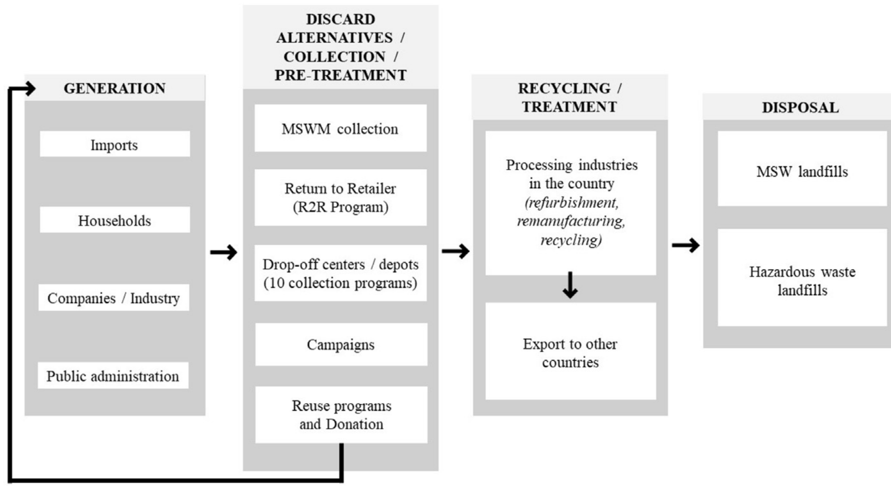

Fig. 3. General e-waste fluxes framework in Canada.

implement sustainable solutions for the recycling of e-waste (EPSC, 2011). In 2004, the Canadian Council of Ministers of the Environment (CCME), an intergovernmental group comprised of ministers from federal, provincial, and territorial governments, released the Canada-Wide Principles for Electronics Product Stewardship, aiming to promote harmonization of approaches to the greatest extent possible, and to prevent market distortions among jurisdictions.

The EPSC, the private sector initiative, and CCME, the public sector initiative, both directed their attention to EoL electronics as a growing problem., but with goals and approaches quite different from one another. EPSC's principles emphasize business efficiencies including explicit advocacy for "industry lead" and "non-prescriptive" regulations. The group makes little reference to the so-called 'waste hierarchy' as part of its guiding principles. Instead, while "reuse" is mentioned, EPSC's guiding principles clearly emphasize a preference for industry controlled and flexible regulation.

In contrast, CCME's public sector approach centred the waste hierarchy, including the important principle to reduce. It also articulated a nascent concept of EPR by noting that manufacturers, brand-owners, and first importers should have the duty to manage e-waste. EPR was understood by CCME to ensure that "costs of program management are not borne by the general taxpayers" (CCME, 2004), which means that producers and importers should bear full financing for such systems, i.e., these costs should not be diluted to the consumer.

Electronic Products Recycling Association (EPRA) is an industry-led, not-for-profit organization that operates regulating recycling programs across Canada, ensuring the safe and environmental sound EoL electronics handling (EPRA, n.d.). The EPRA founding organizations first began collecting and responsibly recycling end-of-life electronics in 2007 (WEEE Forum, n.d.). EPRA, EPSC and Retail Council of Canada promote harmonization of EPR programs (VanderPol, 2014).

Between 2002 and 2019, e-waste legislation was introduced into each Canadian province and today, all provinces and territories, except for Nunavut (NT) (Forti et al., 2020), are covered by such regulations. The licenses for processors and recycling industries are obtained through audit and approval by the EPSC's national Recycler Qualification Program (RQP), that defines the minimum requirements for these organizations to operate safely under a provincial electronics recycling stewardship program (Kumar and Holuszko, 2016).

What has emerged is a system largely designed to suit the needs of the manufacturers, brand-owners, and first importers and that is premised almost completely on recycling (the second-least worst option in the waste hierarchy after reuse and before disposal). Moreover, instead of a genuine EPR system, the financing of the take-back infrastructure in Canada is based on a system of differential fees (sometimes called 'ecofees') charged on electronic items at the point of purchase by consumers, or an extended *consumer* responsibility system (Lepawsky, 2012). The fees charged on new electronics are neither controlled by nor administered by state actors, so they are not technically speaking, a tax. Also, the private sector, represented by EPSC, has managed to have the public sector institute regulations that favour industry by keeping the costs of managing EoL electronics external from business's bottom line and which deflect consumer ire away from businesses and toward government.

3.2.3. Brazil and Canada: comparative analysis

Considering the distinct development realities and contexts faced by Brazil and Canada, a comparison between both represents a challenge. Therefore, the analysis in this section is focused on e-waste management institutional aspects, as presented in Table 2, and comments on positive and negative factors of each country's e-waste management model.

In Table 2 are presented the main regulation drivers for e-waste rules and institutional arrangement in both countries. This framework shows similarities regarding the institutional arrangement, as well as in the proposal for structuring e-waste management channels that are adopted by the different markets that make up the electronic equipment segment. This is a considerable challenge, given the diversity and complexity devices and materials covered by this segment.

From Table 2, the main differences regarding regulations, actors and responsibilities within the e-waste management system in both countries are highlighted, especially in the case of the agents that fund the take-back systems or RLS. Also, the illegal internal e-waste fluxes seem to be more present in Brazilian context (Caiado et al., 2017; Dias et al., 2018; Ottoni et al., 2020; Abbondanza and Souza, 2019; Souza, 2020). The Canadian reality counts with various e-waste take-back programs already working in almost the whole country, while in Brazil, the RLS is still under development in a federal level, although some states already implemented their own systems.

As similarities, both Brazil and Canada have entities representing electronics producers and e-waste recyclers, besides having a considerable advancement in regards to regulations (laws, norms,

Table 2
E-waste management aspects according to the Brazilian and Canadian institutional framework.

Aspect	Brazil	Canada
Responsibility for e-waste collection and treatment	- Producers, importers, distributors and traders (structuring and implementing the e-waste RLS) - Electronic product intended for consumer use only and not specified categories	- Producers (but system is payed by consumers through ecofees) - Electronic product whether intended for consumer, industrial or commercial use, and includes nine categories
Producers	ABINEE and ELETROS	EPSC
Recyclers	Green Eletron and ABREE	Operations certified under EPSC RQP
Federal regulation	Yes. **MMA** - Coordinate the inter-ministry committee - Establishes the laws procedures - Verification of accomplishment	No. **ECCC** - Regulates policy regarding hazardous waste (handling, treatment, disposal, international and national trades) - Transcribes international agreements into national law - Develops technical documents about MSWM and waste incineration
State/Province/territory regulation	- Regulated e-waste before the BPSW and the sectoral agreement - After the agreement, they are responsible for accomplishment verification	- Regulates EPR and intra-provincial movements - Control and license intra-provincial waste generators, carriers and treatment facilities
Municipal regulation	Some regulations were enacted before the BPSW and the sectoral agreement, but are not in force anymore	- Oversees local waste management services (collection, recycling, disposal) - May impose local landfill bans - Provides direction on recycling and disposal to the public
Standards organization	ABNT	EPSC, SCC and SERI
Certification or verification	ABNT NBR 16,156:2013 ABNT NBR 15,833:2018	RQP (audits and approves licenses), R2 Standard, ERRP

standards) for this typology, which represents more mature e-waste management in comparison to other countries in the Americas (e.g., Paraguay, Ecuador, Bolivia, Venezuela, etc).

The identified positive and negative factors of e-waste management in Brazil and Canada are presented in Table 3, divided into the e-waste fluxes and legal framework aspects.

Table 3 highlights the priorities of Brazil and Canada regarding the electronic products lifecycle. In the CE approach, the measures for avoiding waste generation, such as those that extend the product's usage phase (increasing durability, quality, modularity, redesign), must be prioritized. Thus, the upstream strategies should be adopted by the industry, encouraged by government, and demanded by the population. However, this scenario is not a reality in either of the countries analyzed. Although Canada is much more advanced in such measures than Brazil (which is currently in phase of attempting to implement an adequate system for downstream operations), its clear focus relies on treating e-waste after it has already been generated, rather than trying to prevent or minimize its creation in the first place. This fact just emphasizes how far the American countries (represented in this study by Brazil and Canada) can be from implementing real circular solutions for their e-waste streams. Besides, the need of a change of perspective regarding the collected e-waste in both countries as a valuable *product* at its end-of-life, and not a *waste*, is also crucial for avoiding losses and increasing circularity (Parajuly and Wenzel, 2017).

As for the action agenda in terms of circularity for e-waste management, it is worth mentioning that both countries are acting as participating members of ISO/TC 323 and have committed to deadlines for e-waste collection and recovery in their own regulations (federal level, for Brazil, and provincial level, for Canada), and goals for waste, greenhouse gas emissions and hazardousness reduction (CCME, 2014).

Although a draft of a regulation similar to the European Directive RoHS is under consideration by the Brazilian National Environmental Council (CONAMA), significant gaps in the Brazilian waste regulation remain. Such gaps include that recyclers' obligations are not established in federal regulations, and there is not a specific association to represent the recyclers in the country. In the Canadian case, the complex take-back system can be highlighted as one of the main gaps to a more effective e-waste collection rate, and, therefore, e-waste urban mining. According to the study of Kumar and Holuszko (2016), this complexity is a result of the limitations of some recycling programs and drop-off locations on accepting certain types of e-waste. Hence, the public awareness and its willingness to comply with adequate e-waste disposal programs is diminished in Canada (Kumar and Holuszko, 2016).

4. Conclusions

The region of the Americas, due to its dimensions, heterogeneity in socioeconomic terms and potential for e-waste generation, can be considered as an important pole for a global e-waste management analysis. As a main contribution to the literature, this study highlighted important elements of e-waste management in the Americas and brought a comparison and discussion about current e-waste fluxes together with positive and negative aspects of e-waste governance in the selected countries of Brazil and Canada. It also indicated some of the actions adopted toward a more circular pattern of e-waste management in these nations. The relevance of this approach is primarily due to the lack of previous studies correlating the heterogeneous realities of the American economic blocs regarding circular e-waste governance in countries of the region.

Bringing to light solutions that integrate between and within the economic blocs seems a challenge at this moment. Flows of e-waste are highly attractive to large scrap metal refiners many of them located in advanced economies of Europe and Asia. At the same time, low value-added pre-processing techniques remain mostly confined to developing countries which sets up a disproportional distribution of harms and benefits.

The study of indicators that might contribute to many spheres for adequate e-waste management showed the direct correlation between e-waste generation and GDP in the countries of MERCOSUR and NAFTA. The multi-linear correlation presented in the results show how far the USA is from the reality of other American countries. Mexico is quite similar to South American countries, while Canada has a different pattern, and other indicators that evidence the legal and commercial similarities with Brazil. The results reinforce the region's e-waste generation potential and the need for commitment of these countries regarding legal measures

Table 3
Main positive and negative aspects of e-waste management in Brazil and Canada.

Aspect	Country	
	Brazil	Canada
E-waste fluxes	**Positive:** - E-waste federal RLS (for domestic use e-waste) in development phase - E-waste collection points in main cities - More than 150 e-waste organizations across Brazil - Existing e-waste recyclers with standards for e-waste processing	**Positive:** - Varied e-waste collection and recycling programs - Overall collection rate in Canada is on the rise - Lack of academic registers about informal activities performed by waste pickers - More than 150 e-refurbishing and e-recycling facilities exist across Canada (1/3 already meet standards) - Reducing and redirecting residential e-waste from landfill has increased markedly over the years
	Negative: - Continental dimensions - Potential biggest e-waste generator in South America - Lack of an official database for e-waste management - Illegal imports (e-waste and electronic products) - Expressive informality in the segment - High e-waste retention index (85%) - Lack of an integrated e-waste RLS for the whole country (in phase of development) - Very low recycling rate (2%) - Valuable e-waste is exported - E-waste is still sent to landfills and open dumps	**Negative:** - Continental dimensions - One of the biggest e-waste generators in America - Increasing numbers of electronics purchasing/usage - High retention index (80%) - Low e-waste collection rate, 20% (even with many collection programs) - Complex take-back system (different drop-off sites divided by e-waste types) - Lack of central recycling facilities in each province (recycling centers are usually too far from dismantling units) - Evidence of illegal e-waste exportation
Legal framework	**Positive:** - Ratified Basel Convention - Federal and state regulations for e-waste management - Decree 10,240/2020 specifies the producers as payers of RLS - Existing normatives specialized in e-waste management - BPSW points to: - Criteria to the implementation of the RLS - Social inclusion in waste management - Common basis for waste management in public and private levels - Requirements to states and municipalities to provide the Waste Management Plan - E-waste recovery volumes and deadlines come into force from January 2021 to 2025	**Positive:** - Ratified Basel Convention - Most provinces have local regulation - "Canada-Wide Principles for Electronics Product Stewardship" (2004) with guidelines for adequate e-waste management - Good examples of e-waste management provincial programs in BC, MB and ON, that should be also adopted in other provinces - Programs similar to Call2Recycle and Recycle My Cell should be implemented by the ECCC and EPSC - Standards development for adequate e-waste management - Recycling and treatment organizations need a recycling license to operate in the take-back programs - NL, NS and PE provinces (most of BC and ON jurisdiction also) and Vancouver municipality have banned e-waste disposal in landfills
	Negative: - Lack of RLS for non-domestic e-waste - Lack of directed programs to encourage adequate discard by consumers - Goals of the federal RLS in development are still slow and timid - Lack of severe measures for punishing illegal e-waste fluxes - The recyclers obligations are not established on the Brazilian Policy on Solid Waste (BPSW) - There is not a specific association to represent the recyclers in the country - Significant number of informal recyclers in the country	**Negative:** - Lack of a Federal regulation for e-waste management (for guiding provinces) - YT and NT provinces lack e-waste management regulation - System that focus more in recycling than other priorities in the waste management hierarchy (reduce, reuse, redesign) - EPR as "extended consumer responsibility" system (ecofees paid by consumers) - Canada lacks a more strict control of the exporting e-waste - Lack of strict control of e-waste exportation
Action Agenda		- Canada as a participating member of ISO/TC 323

	- Brazil as a participating member of ISO/TC 323 intend to provide discussion basis for harmonize regulation regarding circular economy and waste management - A draft of a Brazilian RoHS regulation was discussed by stakeholders and is to be published under the National Environmental Council (CONAMA)	- Specific regulations on e-waste are being studied and improved in different provinces for achieving goals for waste, greenhouse gas emissions and hazardousness reduction
Main Gaps	- Take-back system still complex for consumers - Some areas are challenging in achievement of collection and processing targets due to distances, low population density rates and low e-waste generation - Centralization of e-waste recyclers distribution in the country, with usually large distance from recycling centers to dismantling units in each province - Unclear rules on taxation system for recyclers (Brazil) - Inexistence of official traceability and monitoring system (and, therefore, data base) for e-waste in the country - Not harmonized regulation between states (Brazil), provinces or territories (Canada) - Both countries have upstream issues to be achieved on e-waste management - There is no specific policy to e-waste trading among these countries - Report of illegal e-waste international trade	

to regulate e-waste management, especially for preventing negative impacts and enhancing waste valorization through urban mining. The harmonization of regulation between the economic blocs of North and South America can result in a symbiotic relationship with significant gains for the countries involved, as well as for the countries peripheral to the blocs.

The comparative analysis of Brazil and Canada, prominent countries of each bloc, pointed to the main e-waste formal and informal flows, advances in legislation, and the strengths and weaknesses of both the legal contexts and trends for e-waste management in the two countries. The identified e-waste flows in these countries and their comparison, a theme that is still little explored in the literature in this region, emphasized the necessary measures in the legislation to avoid contamination and enhance the recovery of valuable materials. These points, represented by Brazilian and Canadian contexts, might be similar to those of the other developing and developed countries, respectively, in the region of the Americas. Thus, the experience of Brazil and Canada may contribute other scenarios and assist in adequate solutions for these e-waste management realities elsewhere in the region.

Thus, collaboration inside the economic blocs is important to reach harmonized e-waste regulation, support circular business models and increase the sustainability and quality of life for citizens. One of the main limitations of the research is the absence of consistent data related to e-waste management for MERCOSUR countries, which could enable a more accurate and shared analysis between the countries in the analyzed blocs.

Finally, as countries with significant operations in mining, the integration of actions for the recovery of secondary and critical raw material and efficient circular economy flows tends to contribute to the reduction of upstream impacts, such as those from the mining industry and even from industry producing electrical and electronic equipment. Aspects related to e-waste prevention also impact the economic and political options for a circular e-waste management and is a thought-provoking approach that can motivate interesting future research.

CRediT authorship contribution statement

Lúcia Helena Xavier: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Marianna Ottoni:** Conceptualization, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Josh Lepawsky:** Data curation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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