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REVIEW

Evaluation of e-waste status, management strategies, and legislations

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Abstract

E-waste is the globally mounting solid waste stream which is increasing due to domestic as well as a result of transboundary exportation. This solid waste stream is considered as an amalgam of valuable and toxic material which is concern of environmental and human health risks. To accomplish successful management of electronic equipment after post-consumer stage, numerous lucid initiatives have been offered globally. The ever-increasing quantum of e-waste has enforced environmental organizations of many developing world such as India and China to invent, and implement environmentally favorable opportunities and strategies for mitigation and control of environmental and human threat. Many developed countries have given topmost priorities for e-waste management, so setup appropriate facilities to treat maximum of the generated e-waste, but in low economic nation like India, economic conditions, infrastructure scarcity, and inappropriate legislations are some of the problematic issues which dodge complete replication of the WEEEs management system. Our study represents an evaluation and valuation, of e-waste generation and cross-border movement to the management strategies followed in highly industrialized as well as developing nations. These findings would expand into regulated and non-regulated countries to put more emphasize on e-waste management.

Keywords WEEEs · E-waste · Transboundary export · Waste management · Strategies · Legislations

Introduction

The market demand of electric and electronic equipment (EEE) is uninterruptedly mounting, which enforces electronic industry to provide updated products with shorter life span. This technological revolution results in obsolescence of electronic products, generally characterized as waste electric and electronic equipment (WEEE) or e-waste (Chauhan et al. 2018; Awasthi et al. 2018). The e-waste or WEEEs includes any type of electronic and electrical equipment such as computers, TVs, laptops, mobiles, refrigerators, etc. which are discarded by the user due to their end-of-life or technological upgradation (Chauhan et al. 2018; Sahni et al. 2016). As every country define e-waste as their own way, but the most satisfactory definition is given by WEEE Directive of European Union EU, 2003a which describe e-waste as all the EEE including the components and sub-assemblies which are of no use are covered under e-waste (Wath et al. 2011). Global E-waste Monitor 2017 revealed that, European Union (EU) account 8% of e-waste solid stream to all of the municipal waste, whereas in developing countries, this waste presents 2% of total municipal waste generation. In the view of global scenario, in 2016 United Nation (UN) reported that 44.7 million ton of e-waste was formed worldwide, which currently reached to 50.2 million ton (Julander et al. 2014; Awasthi et al. 2016; Kumar et al. 2018a). Such projections emphasize on persistent need to address e-waste matter not only in developed countries but in developing world like India and China as well. This new kind of solid waste stream comprises not only loads of valuable material as gold (Au), silver (Ag), but also a heap of toxic constituents such as lead, mercury and brominated flame retardant (Pb, Hg, BRFs, respectively, etc.) which raised up the serious apprehensions about their offensive disposal all over the world (Chatterjee and Abraham 2017; Kumar et al. 2018b). The high value metals from this economical waste are mostly extracted through untrained and unsafe techniques such as burning, acid leaching and roasting, not only in developing but in developed countries as

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well, which is concern of not only environment pollution but for human health as well. In addition, landfilling of residues and informal processing results in carbon emission and cause global warming (Sthiannopkao and Wong 2013). Further, it is estimated that in 2016, the potential raw materials in e-waste were worth approximately 55 billion euro, which means proper processing of this economical waste would not only be an environment and human health protection endeavor but also a possible commercial prospect (Balde et al. 2017; Patil and Ramakrishna 2020).

Developing nations, like India and China, are combating a twofold problem of e-waste due to massive domestic production as well as illegitimate importation from developed countries. The availability of low-priced workers and underprivileged environmental strategies of these countries are the major cause behind the cross-border transportation of e-waste which aim to cheap disposal of e-waste by neglecting their negative effects (Tansel 2017). Therefore, nowadays governments and public facing a significant challenge in regards of the safe e-waste management and processing. However, the peculiar practices utilized for valuable metals extractions are associated with environmental pollution as well as human health threats, which make e-waste management and regulation a point of concern. To tackle the issue of fast growth and to take opportunities from this high value waste, a series of regulations and legislations in regards to transboundary movement, low utilization of hazardous components and formal processing of generated e-waste have been enacted in many countries. According to the Global E-waste Monitor 2017, The United Nation's University (UNU) reported that approximately 66% global community are roofed under e-waste legislation (Patil and Ramakrishna 2020). The Basel Convention is one of the major initiative treaties intended to regulate transboundary movements and disposal of e-waste hazardous constituents among the international borders (Zeng et al. 2017).

Our main objective is to get acquainted with this highly increased solid waste flow, its environmental and human health impact and to conversant with laws and policies which have been initiated and enacted to manage WEEEs. So, in this review article, we are intendingly assess the domestic e-waste generation as well as its cross-border movement, major hazardous constituents of WEEEs and their influence on human health. We intended to evaluated the initiatives and legislative polices enforced for striving e-waste issue. The main motive is to comprehensively prevail initiatives concerned for e-waste management by unfolding the strategies, organizations and legislations followed in highly economic as well as underprivileged countries. However, e-waste legislature is not holistic, as each nation has framed laws in order to address country's own particular problem leading to different management issues. The various strategies and initiative have been listed and enframed to considerate the status quo.

E-waste composition and their impact

WEEEs are an amalgam of organic material, metals and ceramics with more than 1000 substances of "hazardous" and "non- hazardous" material. Majorly, WEEEs comprises ferrous, plastic and non-ferrous metals in the ratio of 50%, 21% and 13%, respectively, along with some amount of glass, wood and ceramic etc. (Vats and Singh 2014; Pant et al. 2012). Base and precious metals like copper, zinc, aluminum and gold, platinum, palladium, respectively, are categorized as non-ferrous metals. However, determination of precise composition is difficult as metallic content of e-waste varies significantly with the type of equipment (Chauhan et al. 2018; Pardhan and Kumar 2014). But typical composition of metallic and non-metallic constituents present in waste printed circuit board is illustrated in Fig. 1. Other than non-hazardous metals, high concentration of polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), brominated flame retardants (BFRs), dioxins and heavy metals like lead, mercury, cadmium, selenium, attribute toxicity and hazardous to environment and human health upon disposal (Uddin 2012; Chauhan et al. 2018; Awasthi and Li 2017). According to Duan et al. (2016), during land filling disposal of e-waste; lead gets reached into ground water then become bioaccumulated and biomagnified in food chain and to pose serious threat to ecosystem. Priya and Hait (2017) also claimed the deposition of these hazardous substances into the soil surrounding the e-waste processing area (Abdelbasir et al. 2018; Priya and Hait 2017). Few hazardous and secondary substances existed in e-waste and their plausible human effects are summarized in Table 1. The enormous generation, complexity, and heterogeneity of e-waste demands its management and disposal in highly organized way in the mean of resources conservation as well as to avert environmental pollution.

E-waste production and transboundary movement

E-waste production is anticipated to excel continuously with an average of 20–50 million tons production every year. Presently, worldwide e-waste production is ascending approximately 53.6 million tons with 4000 tons generation per hour, which was 49.8 million tons in 2017 as shown in

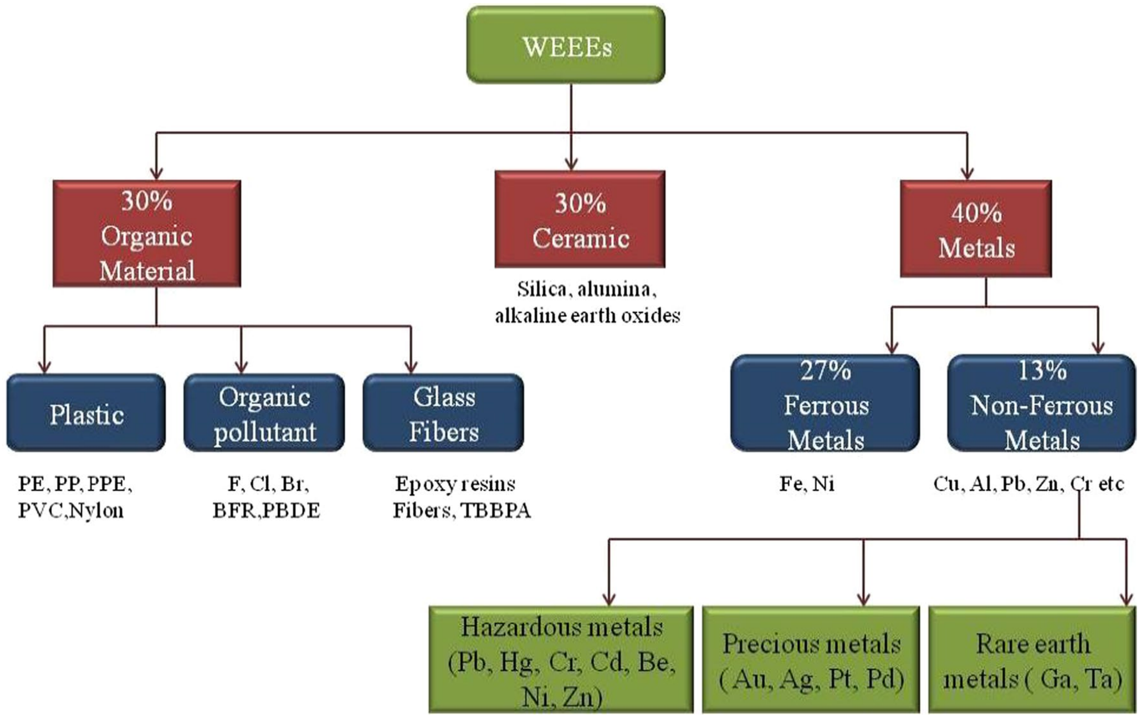

Fig. 1 Constituents of electric and electronic equipment in end- of- life (Chauhan et al. 2018)

Table1 Components consisted in e-waste and their human health influences

Material	E-waste source	Human health impact
Arsenic (As)	Cathode ray tubes screens, diodes and printed circuit boards	Cause various cancers and skin diseases Affects respiratory system, cardiovascular system, and impair reproductive system
Brominated flame retardant (BFR)	Flame retardant for electronic equipment	Causes endocrine and reproductive system, thyroid and liver problem Also include impaired nervous system in children
Copper (Cu)	Printed circuit boards	Causes diarrhea and liver disorders
Chromium (Cr)	Disks, computer housing, cathode ray tubes and batteries	Responsible to cause brain, neurovascular, respiratory and, kidney damage
Lithium (Li)	Batteries	Affect nervous system and intestinal system
Mercury (Hg)	Lamps, batteries and switches	Affect central nervous system and kidney
Nickel (Ni)	Batteries and cathode ray tubes	Responsible for skin and, lungs diseases, Also cause different kind of cancers
Cadmium (Cd)	Printed circuit board, switches, chips in semiconductors	Extremely carcinogenic, Affect bones, kidney and respiratory system
Polychlorinated dibenzodioxins (PCDDs)	Combustion byproducts	Disrupt nervous system, and causes different cancer
Polyaromatic hydrocarbons (PAH)	Released as combustion byproduct	Occupational exposure may lead to cause various types of cancer Responsible for reproductive and developmental health effects

Source: (Perkin et al. 2014)

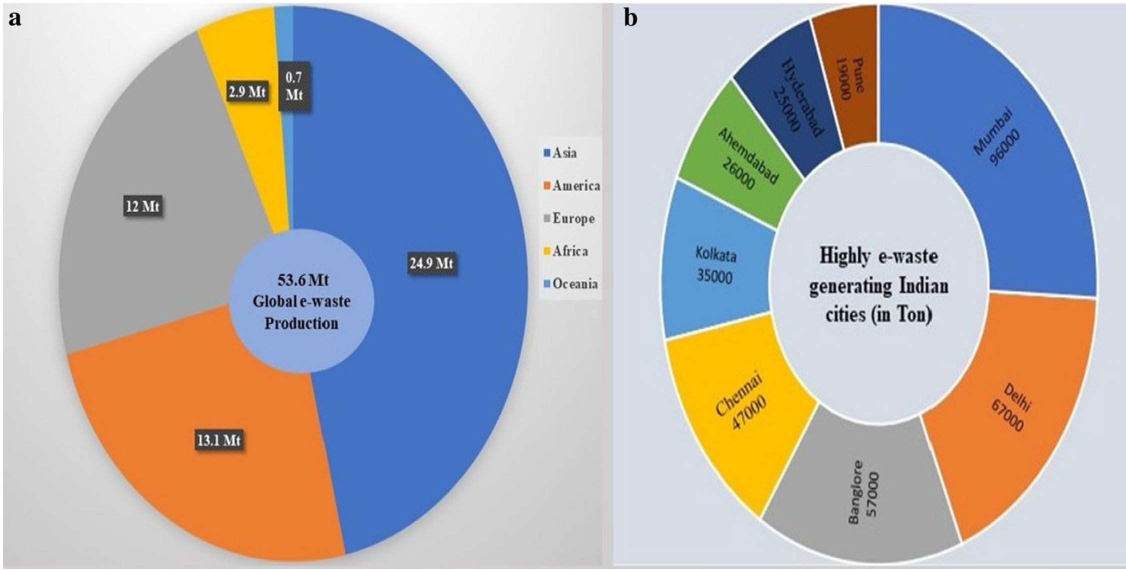

Fig. 2 Statistical contribution of e-waste **a** global e-waste contribution from different continents **b** top Indian cities which contribute majorly in India. (Source: **a** UN's global e-waste monitor 2020. **b** Vats and Singh 2014)

Fig. 2a (Islam et al. 2020; Ari 2016). According to UN's Global e-waste Monitor 2020 Asia is leading internationally with total 24.9-million-ton contribution, whereas America offers 13.1 million ton followed by Europe with 12 million ton, Africa 2.9 million ton and Oceania 0.7 million ton (Chauhan et al. 2018; Thakur and Kumar 2020).

According to the annual estimation of 2016, China positioned at the top with total 7.2 million metric tons contribution. According to EPA statement United State alone contributes 3.19 million tons of e-waste and placed at second rank after China (Julander et al. 2014; Pradhan and Kumar 2014). Besides, the domestic production, illegal exportation from other countries also upsurge the total waste proportion of China (Hopson and Puckett 2016). Ilankoon et al. (2018) stated that 80% exported e-waste from US are received by Asian countries out of which 90% is directed to China only. Above all, Ghana and Nigeria, are considered to be uppermost e-waste center among all the continents. Although low inhabitant of the countries demands less and produce not much of the waste domestically but the massive amount of importation from the developed nations excels their e-waste content (Chatterjee and Abraham 2017; Ilankoon et al. 2018).

In Asian region, India is considered to be second e-waste counting country with 4,00,000 ton annual generation (Kumar et al. 2018a, b). 60% contribution is considered from 65 cities only (Vats and Singh 2014). Maharashtra is the topmost e-waste producing state followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh and West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab for total 70% of e-wastes production (Wath et al. 2011; Ari 2016). In view of top most metropolitan cities Mumbai ranked first with total 96,000-ton e-waste generation as shown in Fig. 2b, followed by Delhi with 67,000 ton, Bangalore (57,000 ton) (Vats and Singh 2014). This contribution is exceeding constantly. According to the United Nation Environment Programme (UNEP) statement India is now generating eighteen times much more discarded mobile phones than 2007 which will increase the rate of total e-waste generation (Vats and Singh 2014).

Developed countries with highly saturated electric and electronic demands are seemed to be major e-waste originating core. In the view of developing and under-developed countries loopholes in regulation permits the cross-border transport as of "hidden flow" which is untraced and undocumented (Hopson and Puckett 2016). Investigation of the cross-border distribution trends indicates that huge amount of e-waste is moved internationally mostly from developed or low populated countries to extremely inhabited countries which are existed with low-priced workforce (Perkin et al. 2014). Priya and Hait (2017) have stated that India and China are imperiled to 50–80% illegal trans-boundary e-waste exportation by few developed countries. The quantification assessment of the exported e-waste amount is a key issue as of illegal transportation. But the Basal Action Network (BAN) is key alternative which works to assess the transboundary flow of e-waste material (Lee et al. 2018). According to Global E-waste Monitor 2017, One of BAN's key verdicts disclosed that there are almost 205 tracker deployments out of which 34% moved through coastline, to developing nations, with 93% exportation of the total 50 million tons to Asia and Africa, where no appropriate recycling facilities are existed, whereas 7% moved to countries such as Mexico and Canada (Duan et al. 2016). The European Environment Agency estimates that EU exports approximately1.3 million ton of e-waste annually to Africa and Asia (Perkins et al. 2014). One of the studies revealed that 80% e-waste of US have been ended up in Asian countries which is tracked by the 200 GPS trackers (Lee et al.2018). In 2007 it was found that India generated 3,82,979 tons e-waste itself whereas an additional 50,000 tons was unscrupulously imported from US and EU countries in the ratio of 80 to 20, respectively, whereas additional 20% is exported in "official" way from US to India and China as of comprehend donation for formal recycling for short term economic benefits (Zeng et al. 2017; Awasthi et al. 2016). Another study by Perkins et al. (2014) claimed that, in 2003, India and Africa were exposed with almost 23,000 metric tons of illegal transportation from the United Kingdom.

Waste management initiatives, strategies and legislations

To concern this ever-growing e-waste and to take advantage of this valuable secondary resource many countries have taken initiatives and levied many legislations. Currently, more than 2000 sections of legislation with over 90 jurisdictions has been in force worldwide to control the detrimental consequences of WEEEs (Ilankoon et al. 2018). Earlier, most of the regulations and strategies have been impelled and aimed to environmental protection, but at present most of management strategies have been implemented with human health concerns (Sthiannopkao and Wong 2013; Hopson and Puckett 2016). There are numerous numbers of international organizations and initiatives shown in Table 2 which have been step forward for suitable monitoring and recycling. These initiatives and organizations are coordinately making efforts to alert consumers and explore key solutions for e-waste management (Perkin et al. 2014; Patil

Table 2 Initiatives and legislation addressing e-waste issues

Initiatives	Key features
Basal convention	Endorsed in 1992 to avoid exportation of hazardous waste from producer countries. 172 nations stand by the agreement but US does not ratify the treaty
Bamako Convention	Aimed to restrain the import of e-waste more stringently than Basel Convention. Applied in African Union nations from 1998
EU WEEE Directive	In 2007 all the EU members adopted the system with initiation of take-back approach for 10 groups of electrical things
Restriction of Hazardous Substances Directive (RoSH)	Enforced along with EU WEEE, particularly aimed to restrain the use of hazardous substances. also validated by various nations, counting China and India as well
Solving the E-waste Problem (StEP)	Initiated in 2007 by UN agencies to promote reusability of the recycled components to limits the waste generation
3Rs (Reduce, Reuse, Recycle)	Initiated by Japan. Work to prevent e-waste generation. Allows exportation to other countries for remanufacture and recycling. Conflicting the goal of Basel Convention treaty
US State laws and the Responsible Electronic Recycling Act (HR2284)	25 states of US, imposed with the law. HR2284 is anticipated to control e-waste exportation. This law enforces assembly and reprocessing of e-waste via stipulating deposits from consumers
US NGOs—Basel Action Network (BAN), Silicon Valley Toxic Coalition (SVTC), Electronics Take-Back Coalition (ETBC)	These three acts work to promote the "Basel Ban" amendment for restrictive transborder exportation. Enhance general e-waste assortment and reusing programs
National Strategy for Electronics Stewardship (NSES), US	Focus to limits the use of harmful substance Improve the handling and management strategies of e-waste in the US or reduce their harmful impact in other nations
International Environmental Technology Centre (IETC) 7– UNEP	Strengthen utilization of environmentally suitable technologies in developing nations on waste management
Global e-Sustainability Initiative (GeSI)	Focus to engage Information and Communication Technology (ICT) companies, industries and organizations to concern e-waste management

Source: (Sthiannopkao and Wong 2013; Ilankoon et al.2018) and Ramakrishna 2020). Some of the initiated strategies opted for e-waste regulation are as following:

Extended producer responsibility (EPR)

EPR was turned up in academic circle as of environmental policy strategy in early 1990s, which sustain producer's responsibility for total life cycle improvements of product system up to its final disposal. EPR is mainly aimed to prevent and reduce e-waste production with maximum reusability and reduction of consuming natural resources. Currently maximum legislation and strategies refer under the concept of "Extend Producer Responsibility," which are widely executed internationally. This EPR program was originally mandated by Germany's directive on the avoiding of packing waste (as 'Green Dot' Programme), and laid a financial influence of producers for assembling, disposing and recycling (Chaterjee and Abraham 2017; Wath et al. 2011). The Organization for Economic Co-operation and Development (OECD) has defined four broad categories of EPR implementation:

1) Take- Back protocol.

This claims the responsibility of producers or manufacturer to control the waste generation and environmental influences of the products. Producers need to mandate "take- back" or "buy back" approach by providing incentives to customers for product return to authorized retailers (Lu et al. 2015).

2) Economic and market-based tool appears in four forms to provide a financial motivation for EPR implementation.

i) Deposit – refund: Consumers need to take responsibility to restore the consumable product to retailer at the end of their shelf life. To abide by this, consumers need to make initial payment which can be reimbursed after overturn of the product.

ii) Advance disposal fee (ADF): Public and private units can charge estimated cost of collection and treatment of certain product from the consumers, which can be utilized for management of end-of-life product system.

iii) Material tax: To use new, non-recyclable and some toxic material, producer is levied by some fee which can be contributed for collection and handling of products to generate incentives for utilization of recycled and less toxic material. This is aimed to enhance recycling and reusability of material for less waste production (Kiddee et al. 2013).

iv) Upstream Combination Tax/ Subsidy (UCS): Tax is levied on producers or a manufacturer to promote waste treatment whereas subsidy is provided to modify product design and material to support recycling and treatment processes.

3) Regulation and performance standard.

Enforced on producers to encourage take back approach and recycling of post-consumer products. This regulation can be obligatory adapted by industries to reinforce incentive for products redesigning.

4) Instruments based on information create public awareness to promote EPR programs. Measures include customer's awareness about producer responsibilities regarding environmental impact of product system, post- consumer product recycling and management (Patil and Ramakrishna 2020).

The basal convention

In 1989 UN assembled 186 nations to initiate the Basel Convention system with an aim to address the transboundary exportation issue. In 1992 this convention system entered into force as treaty entitled "Transboundary Movement of Hazardous Wastes and Their Disposal" (Wath et al. 2010; Patil and Ramakrishna 2020). Latterly this treaty has been endorsed by 181 countries to prevent cross-boundary transportation of hazardous e-waste. In principle this system is intended to charge nation of hazardous waste generation and its exportation to other countries. This induces the responsibility for the safe destruction of waste within the country and avoids transmission to developing countries except prior notifying agreement from the receiving nation (Uddin 2012). The EU was initiator to enforce legislation within the states which was imposed in most of the countries (Sthiannopkao and Wong 2013). The initiative had not been able to eradicate e-waste exportation totally as in 2012 there had been illicit transportation of 50,000-ton e-waste to India from different developing nations (Wang et al. 2016).

EU's WEEE directive and RoHS

After the existence of Basel treaty, the EU commission introduced the WEEE directive but was printed into law in 2003. Further, in 2012, WEEE directive (2012/19/EU) was passed by commission for uniform regulation of e-waste management in its nation (Ilankoonet al. 2018). This directive sets up 10 categories to direct comprehensive strategies for recovery and reprocessing of all WEEEs to obtain higher turnover of recyclable e-waste fractions. The WEEE Directive counsels the state members to focus on environmentally friendly and recyclable EEE products. The directive has implemented with the EPR system in which the manufacturers are enabled to take the responsibility of product recycling after the consumer usage (Patil and Ramakrishna 2020).

Later on, they added "Restriction of Hazardous Substances" (RoHS) directive 2012/ 95/EC intended to modify product designing and packing to limits the consumption of lead, cadmium, hexavalent chromium, mercury and many other hazardous substances (Nnorom and Osibanjo 2008). This directive aims to increase the recycling rate of equipment over excessive production of the waste. Other countries such as Korea, Australia, Japan, Canada and the US have also been also found to be influenced to determine the legislations by these two stated directives, to increase the recycling rate of domestically produced WEEEs.

The 3Rs and StEP

Japan introduced 3Rs (reduce, recycle and reuse) initiatives domestically and globally at a 2004 G8 summit (Zeng et al. 2017). This initiative was prioritized the prohibition of e-waste generation by promoting reusability of technology, this was furthering goal to remove obstacles to the intercontinental transportation for reprocessing and recovery purpose, which is considered to be contradictory to the aim of the Basel Convention treaty (Ilankoon et al.2018).

On the other hand, Solving the e-waste Problem (StEP) is a United Nation initiative, which emphasize on recovery and reusability of materials all over the world. It consists five concentration groups including strategies, reformation, recovery, reuse and capacity building (Sthiannopkao and Wong 2013). Specified characteristic of the initiatives is to formulate an ease and safely disassemble and recyclable products along with negligible usage of toxic substances.

These strategies have not been followed only in developed nation but also being adopted in developing nations. But apart from these strategies each country has enforced its own rules and legislations to manage this ever-growing solid waste stream. India and China are two main Asian developing countries which are not only ahead in terms of population but in aspect of total e-waste production as well. These two countries incessantly facing the illegal exportation and accelerated production of e-waste. China itself produce approximately 11.7 million ton of e-waste. India is following China in total contribution of e-waste. India's own annual domestic production is 400,000 tons but maximum involvement is through importation from highly developed countries (Vats and Singh 2014; Awasthi et al. 2018). Lu et al. (2015) stated that approximately 57,700 ton of e-waste is illegally exported to China alone from other countries. This continuous donation of e-waste from urban nation has led an important issue related to environmental and health concerns in these Asian countries. (Sthiannopkao and Wong 2013). This increased threat of solid waste stream led to develop management and handling rule in the Indian and China as well (Uddin 2012; Abdelbasir et al. 2018). In India, Ministry of Environment, Forest and Climate Change (MOEFs) took initiative and codified its first specific e-waste Management and Handling Rule in May 2011, and become influential in 2012. The rule is conceptualized on the basis of EPR system to introduce the responsibility of equipment manufacturers for handling e-waste after post-consumer stage (Garlapati 2016). After this, most recent e-waste Management Rule has been imposed since October 2016. The rule has been intended to channelize the e-waste among producer, consumer sales purchase, collection centers, dismantlers and recyclers (Nnorom and Osibanjo 2008; Awasthi and Li 2017).

Prior the e-waste (Management and Handling Rule) 2011, India only focused to maintain hazardous waste and enforced many rules and guidelines to resolve the environmental concern of hazardous waste materials. Garlapati (2016) has introduced the rules which have been implemented in India in concern of hazardous waste management. These rules intended to impose some guidelines for complete management of hazardous waste including e-waste and can be used as a model for initiation of awareness programs, implementation of appropriate waste treatment technologies and confining land-filled disposal. Some of the environmental rules which have been followed in India are as following: (i) The Hazardous Waste Management and Handling Rules, 2003, imposed to categorize e-waste and their components under "hazardous" and "non-hazardous" waste (Chauhan et al. 2018). (ii) The Hazardous waste Management, Handling and Transboundary Movement Rules, 2008. This rule was set up for e-waste recyclers (Kumar et al. 2017). According to rule, e-waste handler, desiring to recover or reprocess hazardous wastes of WEEEs are obligatory to enlisted with the central pollution control board (CPCB) (Wath et al. 2011). (iii) Environmentally sound e-waste management guidelines, 2008. Indian government provided the guidelines for classification of various e-waste resources and their components and was permitted by MoEFs and CPCB (Priya and Hait 2017). These guidelines majorly cover the particulars related to e-waste composition, documentation of possible hazardous contents and ecofriendly recycling, re-use and recovery of economically valuable materials. These guidelines also follow the notion of EPR system (Uddin 2012; Hsu et al. 2019). In spite of all these rules and regulation e-waste management in India is still its infant stage and need more stringent and powerful implementations.

Above all, China government also stands up and steps forward to manage this solid waste stream. In 2002, China ratified the Basel Convention to prohibit importation of hazardous e-waste components but low law enforcement could not stop completely and illegal exportation still persists to China (Duan et al. 2016). Hence China drafted certain laws in regards to manage the domestic e-waste production and environment protection, which are more or less on the same line of thoughts of India (Wei and Liu 2012). In 2005, first management measure had taken to specify the limitations on material similar to EU directive to prevent environment pollution caused by e-waste, which has been named as China's RoSH (Kiddee et al. 2013; Lu et al. 2015). Another Environmental Protection Law of China is drafted very similar to India's Environment Protection Act. The only difference existed is that India seems to have a specific law in that sense which is inclusive of "extended producer's responsibility." Now Amendment has been proposed by China government to entail "EPR" as well as Product and Packaging Recycling" programs for appropriate management of electronic products (Cao et al. 2016). In 2009, new waste disposal law has enforced to regulated safe disposal of e-waste by supporting many recycling facilities. Under this law, producers, venders, and reutilizing corporations are to be responsible for safe handling and management of e-waste (Sthiannopkao and Wong 2013).

Conclusion

The continuous domestic production and cross-border transportation of e-waste among the nation has deleterious effect on the ecosystem. The above comprehended literature and discussion reveals that there is dearth of stringent legislations for WEEEs management not only in developing but in developed countries as well, as each country's has different scenario. But to control this ever- growing solid waste it is necessary to implement a systematic e-waste law and make regular amendments to overcome the drawbacks learned from systematic regular evaluation. The prime rule in any e-waste policy must have been a stringent restriction on global transboundary movement of WEEEs with massive penalization on illegal shipment to allow them to focus on effectual e-waste management.

The "repair and reuse" principle should be applied for effective management of e-waste arising to encourage both reduction and recycling of e-waste. To implement this principal, government should also encourage refurbishment model where consumers can be engrossed with enticements such as lesser tax rates to purchase refurbished articles. In addition to encourage the resources reusability and recycling, producer should be bound to legislations to follow the EPR principle and guidelines must include for minimum use of hazardous substances and virgin raw constituent. There is also a need to reinforce the existing laws and policies through consistent assessments and amendments. As e-waste law is not holistic so implementation of country's own legislation would not be adequate to resolve the e-waste concern at the universal level. There should be an international assembly to oversee and synchronize with e-waste management all around the world. An international council should inclusively frame uniform guidelines of global standards for EEE manufactures as well as e-waste recyclers. In addition, e-waste recycling legislation would be proving to be a driving factor that stimuli the e-waste management by recycling of WEEEs actively in many countries through recovery of certain valuable metals. Pyrometallurgy and hydrometallurgy are two conventional methods which have been regularly indulged in metals recovery form WEEEs. But these methods are again concern of environment pollution as these are associated with harmful fumes and strong chemical lixiviants. Furthermore, accomplished recycling of e-waste depends on its cost and these longstanding methods are labor demanding, energy conserved and infrastructure inclusive therefore opted for recovery of only expensive and barely accessible raw materials. But nowadays biohydrometallurgy, an economical and ecofriendly method has been keenly used to overcome the limitations of these usual methods and attracting the attention of research to uplift this technology for industrial scale application. But prior to the recovery of metals, it is necessary to address recycling challenges such as the assortment of e-waste, storage, disposal, disassembly, and material segregation. Now, a private sectors and various research organizations have been grabbing the opportunities from this economical waste and been looking forward for the environmentally sound recycling purposes. So, to achieve sustainable e-waste recycling, the governments and regulatory authorities should provide facilities and also uplift such originations through funding and inducements. Henceforth future efforts to reduce illegitimate abandonment must include a combination of hostile legislation, new technological solutions and communal accountability through greater education on e-waste. In future, biohydrometallurgy (i.e., bioleaching) approaches can be a significant tool for recovery of metals in eco-friendly and economical way. Thus, tools, including legislative policies tied to recommendations for e-waste management and recycling possibilities such as the EPR approach, can ultimately alleviate most e-waste problems.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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