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3R Technologies for WEEE

(Background Paper for Plenary Session 7 of the Programme)

Final Draft

This background paper has been prepared Dr. Sunil Herat, for the Eighth Regional 3R Forum in Asia and the Pacific. The views expressed herein are those of the author only and do not necessarily reflect the views of the United Nations.

3R Technologies for WEEE

Final Draft of Background Paper

8th Regional 3R Forum in Asia and the Pacific

9-12 April 2018, Indore, Madhya Pradesh, India.

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Foreword

The demand for consumer electrical and electronic equipment (EEE) has been on the increase since the 1980s and a countless number of EEEs, especially computers, televisions and mobile phones, has been sold to consumers around the world. Rapid advances in technology and ready availability of newer designs at cheap prices have motivated customers to discard old EEEs even before their useful life is over. This has resulted in mountains of used EEEs, referred to as electronic waste or e-waste, to be managed by the relevant authorities. Finding a sustainable, economically viable, technically feasible and socially acceptable strategy to deal with end-of-life (EOL) management of EEEs has been not easy due to their large quantities and toxic nature.

India generates about 1.85 million tonnes of e-waste annually and is ranked 5th in the world among top e-waste producing countries. India is likely to generate 5.2 million metric tonnes of e-waste per annum by 2020, growing at a compound annual growth rate of 30%. Only 1.5% of India's total e-waste ends up in recycling due to poor infrastructure, legislation and framework with over 95% of e-waste generated is managed by the unorganised sector and scrap dealers in the market using poor recycling practices. Growing human health concerns and environmental hazards caused by poor e-waste management have led to the development E-waste (Management) Rules, 2016 in India. Proper scientific processing/disposal reuse/recycle of e-waste will be contributing factor towards the success of the campaign of Swachh Bharat launched by the government of India aimed to accomplish various goals and fulfil the vision and mission of "Clean India" by 2nd of October 2019 which is 150th birth anniversary of the great Mahatma Gandhi.

Against this background, a Position Paper has been prepared (a) to investigate the economic and business opportunities for resource recovery and recycling of e-waste in India and (b) to promote 3R as an economic opportunity towards effective management of electronic waste.

The paper covers five broad areas:

- Major challenges in e-waste management in India
- Potential business and economic opportunities of e-waste
- Role of e-waste inventory, Extended Producer Responsibility (EPR), private sector and manufacturers and Public Private Partnerships (PPPs) in transforming e-waste sector into an economic industry in India
- Role of Research & Development (R&D) and technology transfer as key driver for harnessing economic potential for e-waste sector
- The way forward

The Paper identifies and discusses a number of issues in relation to each of these areas and presents valuable input to the policy makers in India as well as the Asia-Pacific region. This review is central in ensuring high levels of commitment from the Governments in Asia-Pacific region towards harnessing the business and economic potential of resource recovery and recycling of e-waste.

All Government representatives attending the 8th Regional Forum for Asia and Pacific are urged to contribute to their sustainable e-waste policies by reading and responding to this Position Paper.

Abbreviations and Acronyms

ADF	Advanced Disposal Fees
BFR	Brominated flame retardant
Bo2W	Best-of-2-Worlds
CPU	Central Processing Unit
CRT	Cathode ray tube
DfE	Design for environment
EEE	Electrical and electronic equipment
EOL	End-of-life
EPR	Extended producer responsibility
ESM	Environmentally sound management
Mt	Million tonnes
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturers
PBB	Polybrominated biphenyl
PBDE	Polybrominated diphenylether
PCB	Printed circuit board
PGM	Platinum group of metals
PPP	Public private partnership
PRO	Producer responsibility organisation
R&D	Research and development
RoHS	Restriction of Hazardous Substances
StEP	Solving the E-waste Problem
WEEE	Waste electrical and electronic equipment

Table of Contents

Executive Summary

E-waste covers all items of electrical and electronic equipment (EEE) and its parts that have been discarded by the consumers. It includes almost any household or business item with circuits or electrical components using power or battery supply. E-waste is one of the fastest growing waste streams in the world today. The toxicity and resource potential of e-waste varies significantly by product, thus, making it very difficult to manage. Rapid innovation and uptake of information technology around the world coupled with the advent of new design and technology at regular intervals in the electronic sector is causing the early obsolescence of many EEE used around the world today.

The total amount of EEE put on market has increased from 51.33 million tonnes in 2007 to 56.56 million tonnes in 2012 with Asia emerging as the largest consumer of EEE accounting for nearly 50% of the total EEE put on market with 20.62 million tonnes in 2007 and increasing to 26.69 million tonnes in 2012. The global quantity of e-waste generation in 2014 was around 41.8 million tonnes (Mt). This amount is estimated to reach 50 Mt by 2018, with an annual growth rate of 4 to 5 per cent. The e-waste generation in East and Southeast Asia increased by 63% between 2010 and 2015.

India generates about 1.85 million tonnes of e-waste annually and is ranked 5th in the world among top e-waste producing countries. Only the United States (11.7 million tonnes), P.R.China (6.1 million tonnes), Japan (2.2 million tonnes) and Germany (2 million tonnes) are ahead of India. India is likely to generate 5.2 million metric tonnes of e-waste per annum by 2020, growing at a compound annual growth rate of 30%. Only 1.5% of India's total e-waste ends up in recycling due to poor infrastructure, legislation and framework with over 95% of e-waste generated is managed by the unorganised sector and scrap dealers in the market.

In 2016, the Central Government of India notified the E-waste (Management) Rules, 2016 (the EWM Rules, 2016) which now supersedes the E-waste (Management and Handling) Rules, 2011 and came into force from 1st October 2016. One of the highlights of the EWM Rules, 2016 is the concept of Extended Producer Responsibility (EPR).

The campaign of Swachh Bharat launched by the government of India is aimed to accomplish various goals and fulfil the vision and mission of "Clean India" by 2nd of October 2019 which is 150th birth anniversary of the great Mahatma Gandhi. The Swachh Bharat Abhiyan puts focus on awareness and aims to ensure 100% collection and scientific processing/disposal reuse/recycle of municipal solid waste. Since over 95% of the e-waste is handled by the unorganised informal sector using non-scientific processing techniques, e-waste is one of the waste streams that need lot of consideration to achieve these goals.

Improper handling of e-waste can cause harm to the environment and human health due to its toxic components. Several countries around the world are now developing policies and regulations to deal with this emerging threat. Although the current emphasise is on end-of-life management of e-waste activities such as reuse, servicing, remanufacturing, recycling and disposal, upstream reduction of e-waste generation through green design and cleaner production is gaining much attention. Recently, a perception has grown that e-waste is not only a problem but also an opportunity. E-waste can provide an alternative source of raw materials for the manufacturing industry, thus, reducing the need for extraction of natural resources and at the same time reducing the associated environmental impacts.

The aim of this position paper is to investigate the business and economic potential of resource recovery and recycling from e-waste in India. The first section of the paper will describe the major barriers/challenges (policy, institution, technology) of resource recovery and recycling from e-waste in India. This section will cover e-waste generation, problems associated with e-waste, scientific studies on environmental and health impacts of e-waste, e-waste regulations, and the issues and challenges of environmental sound management of e-waste.

The second section of the paper will address the potential business and economic opportunities, including market potential of resource recovery and recycling in e-waste by describing the significance of resource recovery and recycling of e-waste followed by the successful cases/business examples from various parts of India. The third section of the paper will investigate the role of e-waste inventories, public-private sector cooperation, EPR in transforming the e-waste sector into an economic industry followed by examples from India. The fourth section of the paper will investigate the role of research and development and technology transfer towards harnessing the economic potential of e-waste sector. The final section of the paper will recommend how India can create enabling conditions to enhance the business and economic potential of resource recovery and recycling of e-waste.

Environmentally sound management (ESM) of e-waste in India is a complex task. Transboundary movement of e-waste is a major issue in the region. Dealing with the informal recycling sector is a complex social and environmental issue. Significant amounts of e-waste containing toxic materials can be seen dumped in open spaces and waterways. The open burning of e-waste to recover precious metals causing severe environmental and health impacts is very common. Lack of funds and investment to finance formal environmentally sound recycling infrastructures, absence of appropriate legislation to deal with the issue, tackling the informal e-waste recycling sector and achieving appropriate technology transfer are only few challenges faced by India.

While we are concentrating on solving the health and environmental impacts of poor e-waste management, it is easy to overlook the opportunities associated with it. E-waste contains many valuable materials such as iron, copper, aluminium and plastics and also many precious metals such as gold, silver, platinum and palladium. For example, the gold content of e-waste generated in 2014 is around 300 tonnes representing 11% of the gold mined in 2013. Unfortunately these valuable resources are lost during inefficient resource recovery and recycling practices adopted by the unorganised recycling sector in India.

There is an urgent need for India to develop innovative business models to incorporate the widespread informal e-waste recycling sector with the formal e-waste recycling sector to combine each other's strengths to achieve environmentally sound e-waste management. One of the prerequisites for harness the business and economic potential of e-waste is a proper inventory of e-waste. Unfortunately, globally, there is a lack of reliable data on generation, collection, import and export, and management schemes in general. Proper inventory will attract the investors in the e-waste recycling industry as they can clearly evaluate the resource recovery potential of valuable materials contained in e-waste.

Effective collaboration between the private and public sectors India is seen as a key contributor to achieving the overall objectives of e-waste management. The ESM of e-waste cannot be achieved by public sector alone. However, these partnerships will only materialise if the enabling conditions are met for both parties. The development of fair and reasonable environmental regulations, encouragement of industry led voluntary agreements, clear definition of responsibilities of different actors in the recycling chain, OEMs given the option of treating the collected wastes in their overseas contracted treatment facilities, reasonable and fair obligations (financial and physical) for manufacturers and importers where EPR schemes exist, are few of such conditions to be met. The paper cites number of examples where successful partnerships are developed between the public and private sectors to achieve sustainable resource recovery and recycling of e-waste in India.

R&D plays an important role in proper resource recovery and recycling of e-waste. Adopting practices such as Design for Environment (DfE) where toxic materials in EEE are replaced with environmentally friendly raw materials can lead to increased efficiency in the recovery process. R&D can also contribute towards developing state-of-art resource recovery and recycling techniques for environmentally sound management of e-waste. However, a decision on technology transfer cannot be made purely on technology only. For example, advanced high-technology, capital intensive e-waste recycling processes adopted in highly industrialised countries may not be suitable for countries like India. Such technology transfer must take into account the social, institutional, political and legal aspects India to ensure the sustainability of the adopted technology.

The Regional 3R Forum for Asia and Pacific, through Tokyo 3R Statement, Singapore Forum on the 3Rs in Achieving a Resource Efficient Society in Asia, Ha Noi 3R Declaration on Sustainable 3R Goals for Asia and the Pacific for 2013-2023 and Surabaya Declaration on Promotion of Multilayer Partnerships and Collaboration for the Expansion of 3Rs in Asia and the Pacific, has identified and called upon the Asia and Pacific countries to develop action plans for environmentally sound management of e-waste in the region. Such action plans will also contribute towards the goals of post-2015 development agenda where we need to achieve substantial reduction in waste generation through prevention, reduction, recycling and reuse by year 2030. The issues and challenges related to e-waste must be addressed as a matter of high priority given its highest generation rate among all other waste streams.

As a way forward, India must develop well defined national e-waste management strategies based upon 3R concepts. Such strategy should not only address the environmental and health impacts of e-waste (end-of-pipe) but also look at the reduction of e-waste through green design (up-the-pipe). It should also create enabling conditions for relevant stakeholders to develop business and economic opportunities to recover the materials from e-waste. The strategy should also take into account the financial, institutional, political and social aspects of e-waste management, in particular, incorporation of informal e-waste recycling sector activities. Appropriate regulations and standards related to collection, storage, transport, recovery, treatment and disposal of e-waste should be a key component of this strategy. Provision of enabling conditions to develop public partnership partnerships to harness the business and economic potential of resource recovery and recycling of e-waste would ensure the sustainability (financial) of the developed strategy. Identification of organisations or institutions with potential to function as centres for excellence in developing and promoting environmental sound resource recovery and recycling practices would assist the implementation of such strategy.

India has made a significant commitment to safe management of e-waste by formulating new E-waste (Management) Rules, 2016. However, the challenge is to ensure that, say in 5 years time, these Rules have made a significant contribution towards solving the e-waste problem in India. The key to this success will largely depend on the following:

- How the strengths and capabilities of informal and formal e-waste recycling sectors are combined to develop a sustainable e-waste management system in India
- How enabling environment is created for the private sector to harness potential business and economic opportunities in recycling and resource recovery e-waste in India
- How the consumer's e-waste disposal behaviour and awareness are addressed in the context complex socio-cultural and economic conditions in India

1.0 Major Challenges in E-waste Management in India

1.1 E-waste generation around the world

E-waste covers all items of electrical and electronic equipment (EEE) and its parts that have been discarded by the consumers. It is also referred to as WEEE (Waste Electrical and Electronic Equipment) or electronic waste and includes almost any household or business item with circuits or electrical components using power or battery supply. United Nations University's Solving the E-waste Problem Initiative (StEP) classifies e-waste into the following six categories[1]:

- Temperature exchange equipment (commonly referred to as, cooling and freezing equipment and could include refrigerators, freezers, air conditioners, heat pumps).
- Screens, monitors (could include televisions, monitors, laptops, notebooks, and tablets).
- Lamps (could include straight fluorescent lamps, compact fluorescent lamps, high intensity discharge lamps and LED lamps).
- Large equipment (could include washing machines, clothes dryers, dish washing machines, electric stoves, large printing machines, copying equipment and photovoltaic panels).
- Small equipment (could include vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, electrical and electronic toys, small electrical and electronic tools, small medical devices, small monitoring and control instruments).
- Small IT and telecommunication equipment (could include mobile phones, GPS, pocket calculators, routers, personal computers, printers, telephones).

Due to greater access to electrical and electronic equipment (EEE) around the world coupled with economic development and rapid advances in information and computing technologies, the global demand for EEE has boomed during the last decade. The United Nations University has estimated that the total amount of EEE put on market has increased from 51.33 million tonnes in 2007 to 56.56 million tonnes in 2012 with Asia emerging as the largest consumer of EEE accounting for nearly 50% of the total EEE put on market with 20.62 million tonnes in 2007 and increasing to 26.69 million tonnes in 2012 [2].

The generation of reliable data on the exact amount of e-waste generated in different regions of the world is difficult to achieve as the amount of used EEE reaching its end-of-life cannot be measured directly with some reliability. Most of the estimates available are based upon predictions made incorporating production or sales data, and the estimated life span of the EEE. Several countries have conducted e-waste inventories to determine the quantities and composition of e-waste. Unlike other used products, there is a tendency for consumers to store used EEE at home and in offices thus making estimation a challenging task.

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[1] Balde, C.P., Wang, F., Kuehr, R., Huisman, J. (2015), The Global E-waste Monitor – 2014, United Nations University, IAS-SCYCLE, Bonn, Germany http://i.unu.edu/media/unu.edu/news/52624/UNU-1stGlobal-E-Waste-Monitor-2014-small.pdf

[2] Honda, S., Sinha Khetriwal, D and Kuehr, R. (2016), Regional E-waste Monitor: East and Southeast Asia, United Nations University ViE-SCYCLE, Bonn, Germany http://ewastemonitor.info/pdf/Regional-E-Waste-Monitor.pdf

One of the most recent information can be found in the Global E-waste Monitor 2014, published by the United Nations University[1]. According to this report, the global quantity of e-waste generation in 2014 was around 41.8 million tonnes (Mt). This amount is estimated to reach 50 Mt by 2018, with an annual growth rate of 4 to 5 per cent. The study found that the Asian region produced the highest amount of e-waste (16 Mt or 38% of total), followed by Americas (11.7 Mt) and Europe (11.6 Mt). Furthermore, the study found that the top three Asia-Pacific countries with the highest e-waste generation in absolute quantities are P.R.China (6 Mt), Japan (2.2Mt) and India (1.7Mt).

The United Nations University's Regional E-waste Monitor for East and Southeast Asia estimates that in East and Southeast Asia, amount of e-waste generated has increased by 63% between 2010 and 2015 [2]. The study further estimates that P.R.China alone more than doubled its generation of e-waste between 2010 and 2015 to 6.7 million tonnes which is an increase of 107%.

1.2 Why e-waste is a problem?

Problems associated with e-waste are becoming well known in the scientific literature. In general, e-waste is a complicated assembly of a number of different materials, many of which are highly toxic. For example, the production of semiconductors, printed circuit boards, disc drives and monitors used in computer manufacturing utilises many hazardous chemicals. Computer central processing units (CPU) contain heavy metals, such as cadmium, lead and mercury. Printed circuit boards (PCB) contain heavy metals, such as antimony, silver, chromium, zinc, lead, tin and copper. Lead (Pb) is used in cathode ray tubes (CRTs) in monitors, tin–lead solders, cabling, PCBs and fluorescent tubes.

E-waste also contains brominated flame retardants (BFRs), such as polybrominated biphenyls (PBB) and polybrominated diphenylethers (PBDEs), which are used in PCBs, connectors, covers and cables. There is a growing body of literature suggesting that BFRs have negative environmental and health effects, and, hence, should be limited or replaced altogether. Exposure to PBDEs of personnel working in e-waste recycling facilities and of people in surrounding areas has been studied by researchers worldwide.

1.3 Scientific studies on environmental and health impacts of e-waste

The environmental and health impacts of e-waste is thoroughly investigated by the global research community, In particular, there is significant interest related to environmental and health impacts of e-waste recycling by the informal sector. Song and Li (2014a, b)[3] [4] undertook a detailed systematic review of both environmental and human impacts of informal waste recycling in P.R.China. Findings of their studies are summarised below:

Human impacts

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[3] Song, Q. and Li, J. (2014a) A systematic review of the human body burden of e-waste exposure in China, *Environment International*, 68, 82-93

[4] Song, Q. and Li, J. (2014b) Environmental effects of heavy metals derived from e-waste recycling in China: A systematic review, *Waste Management*, 34, 2587-2594

This study investigated the recent studies on human exposure to e-waste in P.R.China, with particular focus on exposure routes (e.g. dietary intake, inhalation, and soil/dust ingestion) and human body burden markers (e.g. placenta, umbilical cord blood, breast milk, blood, hair, and urine) and assesses the evidence for the association between such e-waste exposure and the human body burden in P.R.China. The results suggested that residents in the e-waste exposure areas, located mainly in the three traditional e-waste recycling sites (Taizhou, Guiyu, and Qingyuan), are faced with a potential higher daily intake of these pollutants than residents in the control areas, especially via food ingestion. Moreover, pollutants (PBBs, PBDEs, PCBs, PCDD/Fs, and heavy metals) from the e-waste recycling processes were all detectable in the tissue samples at high levels, showing that they had entered residents' bodies through the environment and dietary exposure[5].

Environmental effects

This study investigated the reviews recent studies on environmental effects of heavy metals from the e-waste recycling sites in P.R.China, especially Taizhou, Guiyu, and Longtang. The intensive uncontrolled processing of e-waste in P.R.China has resulted in the release of large amounts of heavy metals in the local environment, and caused high concentrations of metals to be present in the surrounding air, dust, soils, sediments and plants. Though the pollution of many heavy metals was investigated in the relevant researches, the four kinds of heavy metals (Cu, Pb, Cd and Cr) from e-waste recycling processes attracted more attention. The exceedance of various national and international standards imposed negative effects to the environment, which made the local residents face with the serious heavy metal exposure.[6]

A summary of number of scientist studies undertaken to evaluate the health and environmental impacts of e-waste management in Asia-Pacific region could be found in (Herat and Agamuthu, 2012)[7].

A critical review of environmental pollution of electronic waste recycling in India can be found in (Awasti et al, 2016a)[8] and a critical review of relationship between e-waste reycling and human health risk in India can be found in(Awasti et al., 2016b)[9] . Both these reviews highlight severe environmental and health impacts due to informal e-waste recycling in India and recommended that open dumping of e-waste and informla e-waste recycling systems to be replaed by the best available technologies and environmental practices.

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[5] Song, Q. and Li, J. (2014a) A systematic review of the human body burden of e-waste exposure in China, *Environment International*, 68, 82-93

[6] Song, Q. and Li, J. (2014b) Environmental effects of heavy metals derived from e-waste recycling in China: A systematic review, *Waste Management*, 34, 2587-2594

[7] Herat, S. and Agamuthu, P. (2012) E-waste: a problem or an opportunity? Review of issues, challenges and solutions in Asian countries, *Waste Management & Research*, 30, 11, 1113-1129

[8] Awasti, A.K., Zeng, X., Li, J. (2016a) Environmental pollution of electronic waste recycling in India: A critical review, *Environmental Pollution*, 211, pp 259-270

[9] Awasti, A.K., Zeng, X., Li, J. (2016b) Relationship between e-waste recycling and human health risk in India: A critical review, *Environmental Science and Pollution Research*, 23, pp 11509-11532

2.0 Major Challenges of E-waste management in India
2.1 E-waste generation in India

In India, e-waste is a major issue due to the generation of domestic e-waste as well as imports from developed countries. India's electronic industry is one of the fastest growing industries in the world. The formal e-waste recycling sector in India is currently being developed in major cities. However, informal recycling operations have been in place for a long time in India with over 1 million poor people in India being involved in the manual recycling operations. Most of these people have very low literacy levels with little awareness of dangers of the operations. Severe health impacts and environmental damage are wide spread in India due to e-waste processing by the informal sector.

There is no official e-waste inventory in India. However, there are a number of studies which have estimated the current levels of e-waste generation in India. Below are the findings of two such studies:

1) The Associated Chambers of Commerce and Industry of India (ASSOCHAM) – cKinetics Study 2016 (Business Standard, 2016)[10]

- India is likely to generate 5.2 million metric tonnes of e-waste per annum by 2020 from a current level of 1.8 million tonnes growing at a compound annual growth rate of 30%.
- Computer equipment accounts for almost 70% of e-waste, followed by telecommunication equipment (12%), electrical equipment (8%) and medical equipment (7%) with remaining 4% from household e-waste.
- Only 1.5% of India's total e-waste ends up in recycling due to poor infrastrucute, legislation and framework.
- Over 95% of e-waste generated is managed by the unorganised sector and scrap dealers in the market.
- About 400,000-500,000 child labourers between age group of 10-15 are observed to be engaged in informal e-waste recycling activities without adequate protection and safeguards
- The government, public and private (industrial) sectors account for almost 75% of total e-waste generation in India

2) The Associated Chambers of Commerce and Industry of India (ASSOCHAM) – KPMG Study 2016 (Banega Swachh India NDTV May 30, 2017)[11]

- India generates about 1.85 million tonnes of e-waste annually
- India ranks fifth in the world among top e-waste producing countries. Only the United States (11.7 million tonnes), P.R.China (6.1 million tonnes), Japan (2.2 million tonnes) and Germany (2 million tonnes) are ahead of India

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[10] Business Standard June 3, 2016
http://www.business-standard.com/article/technology/india-s-e-waste-growing-at-30-per-annum-assocham-ckinetics-study-116060300619_1.html

[11] Banega Swachh India NDTV May 30, 2017
http://swachhindia.ndtv.com/e-waste-tackling-indias-next-big-waste-problem-6126/

- From 310 million subscribers in 2001 to 1.1 billion in 2016, the number of mobile phone users in India is nearly 4 times that of United States today and it is second only to P.R.China in the world, which has 1.3 billion subscribers
- Among the cities in India, Mumbai generated the highest amount of e-waste with 1,20,000 tonnes annually followed by Delhi (98,000 tonnes), Bangaluru (92,000 tonnes), Chennai (67,000 tonnes), Kolkata (55,000 tonnes), Ahmedabad (36,000 tonnes), Hyderabad (32,000 tonnes) and Pune (26,000 tonnes).

According to Borthakur and Singh (2012), 65 cities in India generates more than 60% of the total e-waste generated in India and 10 States generate over 70% of the total e-waste generated. Out of all the States, Maharashtra ranks first for e-waste generation in India, followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab [12]

2.2E-waste regulations in India

In 2005, India's Central Pollution Control Board developed guidelines for environmentally sound management of e-waste in India. The guidelines provided assistance for identification of various sources of e-waste and prescribed procedures for handling of e-waste. The Ministry of Environment and Forest as part of the Environmental Protection Act of India enacted the 'E-waste (Management and Handling) Rule of 2011 which took effect from 1st May 2012. The rule mandates producers to be responsible for the collection and financing the systems according to extended producer responsibility concept. The rule clearly defines the responsibilities of the producer, collection centres, consumer or bulk consumers, dismantlers and recyclers.

In 2016, the Central Government of India notified the E-waste (Management) Rules, 2016 (the EWM Rules, 2016) which now supersedes the E-waste (Management and Handling) Rules, 2011 and came into force from 1st October 2016. One of the highlights of the EWM Rules, 2016 is the concept of Extended Producer Responsibility (EPR). According to the new Rules, the producers of electrical and electronic equipment have to implement the EPR to ensure that e-waste is properly channelized to authorised recyclers. Below are the features of new EWM Rules, 2016:

- Manufacturer, dealer, refurbisher and Producer Responsibility Organization (PRO) have been introduced as additional stakeholders in the rules (2011 rules limited the responsibility to the brand owners of the electronic products, consumers, dismantlers and recyclers).
- The applicability of the rules has been extended to components, consumables, spares and parts of EEE in addition to equipment as listed in Schedule I.
- Compact Fluorescent Lamp (CFL) and other mercury containing lamp brought under the purview of rules.
- Collection mechanism based approach has been adopted to include collection centre, collection point, take back system etc for collection of e-waste by Producers under Extended Producer Responsibility (EPR).

[12] Borthakur, A., Singh, P. (2012) Electronic waste in India: Problems and policies, *International Journal of Environmental Sciences*, 3, 1, 353-362

- Option has been given for setting up of PRO, e-waste exchange, e- retailer, Deposit Refund Scheme as additional channel for implementation of EPR by Producers to ensure efficient channelization of e-waste.
- Provision for Pan India EPR Authroization by CPCB has been introduced replacing the state wise EPR authorization.
- Collection and channelisation of e-waste in Extended Producer Responsibility - Authorisation shall be in line with the targets prescribed in Schedule III of the Rules. The phase wise Collection Target for e-waste, which can be either in number or Weight shall be 30% of the quantity of waste generation as indicated in EPR Plan during first two year of implementation of rules followed by 40% during third and fourth years, 50% during fifth and sixth years and 70% during seventh year onwards.
- Deposit Refund Scheme has been introduced as an additional economic instrument wherein the producer charges an additional amount as a deposit at the time of sale of the electrical and electronic equipment and returns it to the consumer along with interest when the end-oflife electrical and electronic equipment is returned.
- The e-waste exchange as an option has been provided in the rules as an independent market instrument offering assistance or independent electronic systems offering services for sale and purchase of e-waste generated from end-of-life electrical and electronic equipment between agencies or organizations authorised under these rules.
- The manufacturer is also now responsible to collect e-waste generated during the manufacture of any electrical and electronic equipment and channelise it for recycling or disposal and seek authorization from SPCB.
- The dealer, if has been given the responsibility of collection on behalf of the producer, need to collect the e-waste by providing the consumer a box and channelize it to Producer.
- Dealer or retailer or e-retailer shall refund the amount as per take back system or Deposit Refund Scheme of the producer to the depositor of e-waste.
- Refurbisher need collect e-waste generated during the process of refurbishing and channelise the waste to authorised dismantler or recycler through its collection centre and seek one time authorization from SPCB.
- The roles of the State Government has been also introduced in the Rules in order to ensure safety, health and skill development of the workers involved in the dismantling and recycling operations.
- Department of Industry in State or any other government agency authorised in this regard by the State Government is to ensure earmarking or allocation of industrial space or shed for e-waste dismantling and recycling in the existing and upcoming industrial park, estate and industrial clusters.
- Department of Labour in the State or any other government agency authorised in this regard by the State Government need to ensure recognition and registration of workers involved in dismantling and recycling; assist formation of groups of such workers to facilitate setting up dismantling facilities; undertake industrial skill development activities for the workers involved in dismantling and recycling; and undertake annual monitoring and to ensure safety & health of workers involved in dismantling and recycling.
- State Government to prepare integrated plan for effective implementation of these provisions, and to submit annual report to Ministry of Environment, Forest and Climate Change.
- The transportation of e-waste shall be carried out as per the manifest system whereby the transporter shall be required to carry a document (three copies) prepared by the sender, giving the details.

- Liability for damages caused to the environment or third party due to improper management of e-waste including provision for levying financial penalty for violation of provisions of the Rules has also been introduced.
- Urban Local Bodies (Municipal Committee/Council/Corporation) has been assign the duty to collect and channelized the orphan products to authorized dismantler or recycler.

The Central Pollution Control Board of India has published the 'Guidelines on Implementation of E-waste (Management) Rules, 2016. These guidelines can be accessed through the link below:
http://cpcb.nic.in/upload/Latest/Latest_135_GUIDELINES-E-WASTE_RULES_2016.pdf

2.3 Issues, challenges and barriers for resource recovery and recycling of e-waste in India

The issue of environmentally sound management of e-waste is a global problem arising from transboundary movement among all countries and regions, and thus requires global solutions. Large amounts of e-waste are currently being exported to developing countries for the purpose of reuse, refurbishment, recycling and recovery of precious materials. India is one of the most favoured nations for receiving e-waste from developed countries. However, many recycling and recovery facilities in India operate in an environmentally unsound manner causing significant environmental and health impacts.

Significant amounts of e-waste containing hazardous materials can be seen dumped in open-land and waterways. The major environmental and health impacts occur during open burning of e-waste to recover precious metals. In spite of these significant environmental and health impacts, recycling and recovery operations have generated a huge informal employment sector in India. In addition to receiving e-waste from developed countries, India is also emerging as significant generators of e-waste themselves.

One of the major issues faced by India in dealing with e-waste is how to tackle the emerging informal e-waste recycling sector. In India formal recycling of e-waste using best practice technologies in modern recycling facilities is rare. As a result, most of the e-waste is managed using various improper methods, such as open dumps, backyard recycling and disposal into surface water bodies. It is common to see open burning of plastics to reduce e-waste volumes, copper wires to salvage valuable metals and acid leaching to recover precious metals from printed circuit boards.

One of the main problems faced by India is the lack of funds and investment to finance formal recycling infrastructures, and the absence of appropriate legislation to deal with the issue. EPR is seen globally as one of the most effective ways of dealing with the e-waste issue. However, unlike in the developed world, implementing EPR in developing countries like India is a major challenge for policy makers. The competition between the formal and informal recycling sectors to gain access to e-waste is also a major problem. The consumers in India expect some form of financial benefits while discarding their e-waste. This creates a challenging situation for EPR.

Following are some of the major issues, challenges and barriers for resource recovery and recycling of e-waste in India:

- Increasing volume of e-waste imported illegally into India in the name of second-hand EEE, most of which are nearing their end-of-life and hence become e-waste in very short time
- Low level of awareness among manufacturers and consumers about hazardous nature of e-waste
- Over 95% of e-waste is handled by the informal sector using rudimentary recycling techniques such as acid leaching and open burning resulting in severe environmental and health impacts
- Inefficient recycling processes result in substantial losses of valuable resources embedded in e-waste
- Informal recyclers giving preference to precious metals such as gold, platinum, silver and copper and improperly disposing the rest
- Accessing funds and investment to finance proper e-waste recycling facilities
- Developing appropriate policies and legislation specifically to deal with e-waste
- Implementing mandatory or effective voluntary take-back schemes, such as EPR
- Ability to gather data and inventory on e-waste generation including transboundary movements
- Establishment of proper infrastructure for e-waste collection, transportation, storage, treatment, recovery and disposal
- Improving the working conditions and minimisation of work-related hazardous exposure at e-waste management facilities
- Raising awareness of health and environmental impacts of e-waste
- Adoption of green product design practices by equipment manufacturers
- Development of pool of experts and resources to deal with the e-waste issues
- Development of public-private partnerships to implement e-waste resource recovery and recycling operations

3.0Potential Business and Economic Opportunities in E-waste

3.1 Significance of resource recovery and recycling of e-waste

The use of natural resources in production and consumption has significant impacts on the environment. The processes associated with extraction, processing, transport, use and disposal of materials contribute towards the deterioration of the environment and ecosystems. Recent decades have experienced significant growth in demand for raw materials worldwide mainly driven by the high levels of material consumption in developed countries and rapid industrialisation of emerging economies. According to OECD, the amount of materials extracted, harvested and consumed worldwide increased by 60% since 1980, reaching close to 62 billion metric tonnes in 2008 and expected to reach 100 billion tonnes by 2030. Over the last 30 years, the strongest growth in raw materials demand has been for metal ores. The global metal extraction has more than doubled between 1980 and 2008, increasing from 3.5 billion tonnes to 8.2 billion tonnes or by 133%. [13]

Resource use efficiency which refers to the effectiveness with which an economy uses materials extracted from natural resources to generate economic value is central to green growth. Last two decades have seen a significant increase in waste generation in line with growing consumption of material resources in many countries. As a result, many valuable natural resources are disposed of as waste and are lost to the economy. OECD estimates that about a fifth of materials extracted worldwide ends up as waste. This amounts to over 12 billion tonnes of natural resources lost per year. This is alarming considering the facts that environmental pressures occur not only at the extraction stage of the material consumed but also at the disposal stage.

OCED has noted that recycling rates have increased worldwide for many important materials such as glass, steel, aluminium, paper and glass, with some reaching very high levels. However, recycling activities remain very low for many precious metals, which is a major concern given that these metals are central to number of modern day consumer items.

Although e-waste is usually regarded as a problem due to its environmental damage it is causing if not properly dealt with in an appropriate way, it is easy to overlook the opportunities associated with e-waste, especially at a time where resource use and depletion is also a global issues. Strictly speaking, it can be argued that the problem with e-waste is not due to the materials that are contained in them but due to the inappropriate ways that they are dealt with at the end-of-life. EEE manufacturing consumes many precious metals and therefore an important resource for the world's demand for metals. Some refer to e-waste as a 'above ground mine" ready to be harvested. They argue that mining of used EEE to recover the metals contained in them needs only a fraction of energy required to mine them from natural ores. E-waste contains many valuable materials such as iron, copper, aluminium and plastics and also many precious metals such as gold, silver, platinum and palladium. Table 1 illustrates the important metals used for EEE.

[13] OECD (2013), Material Resources, Productivity and The Environment: Key Findings http://www.oecd.org/greengrowth/MATERIAL%20RESOURCES,%20PRODUCTIVITY%20AND%20THE%20ENVIRONMENT_key%20findings.pdf

Metal	Primary production*	By-product from	Demand for EEE	Demand/ production	Price**	Value in EEE**	Main applications
	t/y		t/y	%	USD/ kg	10^6 USD	
Ag	20 000	(Pb, Zn)	6 000	30	430	2.6	Contacts, switches, solders…
Au	2 500	(Cu)	300	12	22 280	6.7	Bonding wire, contacts, integrated circuits…
Pd	230	PGM	33	14	11 413	0.4	Multilayer capacitors, connectors
Pt	210	PGM	13	6	41 957	0.5	Hard disk, thermocouple, fuel cell
Ru	32	PGM	27	84	18 647	0.5	Hard disk, plasma displays
Cu	15 000 000		4 500 000	30	7	32.1	Cable, wire, connector…
Sn	275 000		90 000	33	15	1.3	Solders
Sb	130 000		65 000	50	6	0.4	Flame retardant, CRT glass
Co	58 000	(Ni, Cu)	11 000	19	62	0.7	Rechargeable batteries
Bi	5 600	Pb, W, Zn	900	16	31	0.03	Solders, capacitor, heat sink…
Se	1 400	Cu	240	17	72	0.02	Electro-optic, copier, solar cell
In	480	Zn, Pb	380	79	682	0.3	LCD glass, solder, semiconductor
Total			**4 670 000**			**45.4**	

Table 1: Important metals used for electric and electronic equipment (based on demand in 2006). [14]

A compressive study undertaken by the United Nations Environment Program and United Nations University [15] have revealed the following facts about the resource availability from e-waste:

[14] UNEP and UNU (2009a), Sustainable Innovation and Technology Transfer Industrial Sector Studies: Recycling – From E-Waste to Resources, Published jointly by UNEP and United Nations University (UNU) http://www.unep.org/PDF/PressReleases/E-Waste_publication_screen_FINALVERSION-sml.pdf

- Mobile phone contains about 40 base metals including copper (Cu), tin (Sn), cobalt (Co), indium (In) and antimony (Sb) and precious metals such as silver (Ag), gold (Au) and palladium (Pd) representing around 23% of the weight of the phone. It is estimated that one tonne of phone handsets (without battery) would contain 3.5kg of Ag, 340 g Au, 140g of Pd and 130 kg of Cu. This is very significant considering that global demand for mobile phones is over 1 billion.

- Electronics make up 80% of the world demand for indium (magnetic properties in hard disks), 50% of antimony (flame retardants), 30% of silver (contact, solders), 12% of gold (circuits), 14% of palladium (capacitors), 30% of copper (wires) and 15% of tin (solders).

- E-waste generated globally in 2007 from mobile phones and computers alone would have contributed to 3% of the world mine supply of gold and silver, to 13% of palladium and 15% of cobalt.

Global Waste Monitor 2014 reports that the gold content of total e-waste generated in 2014 is roughly 300 tonnes, which represents 11% of the global gold production from mines in 2013.

A study conducted on quantifying metal values in e-waste in Australia by Golev and Corder (2017) found that metal parts represented about 51% by weight in total e-waste generated in Australia in 2014, followed by plastics (30%), glass (5%) and printed circuit boards (4%). The study also estimated that potential metal recovery value to be US$370 million with major contributions coming from iron/steel (29%), copper (26%) and gold (24%). An interesting finding of this study is that while waste printed circuit boards only represents 4% by weight in e-waste, it contains around 40% (US$ 150 million) of metal recovery value with a potential revenue around US$21,000 per tonne[16].

3.2 Issues related to resource recovery and recycling of e-waste

Although the resource value of materials such as metals in EEE are well known and availability of technologies to recover these materials are increasing becoming available, only a fraction of e-waste is currently recycled even in developed countries. There are number of reasons why this is the case. Firstly, end-of-life EEE does not reach the recycling process as part of the EEE is stored at home. Secondly, of the collected e-waste, a part is sent directly to recycling for environmentally sound recovery of materials while the rest is reused and then recycled or exported for reuse in developing countries where environmentally sound recycling facilities rarely exist.

Even in environmentally sound recycling facilities materials can be lost in the process as it is not possible recover 100% of the materials. However, rudimentary recycling processes

[15] UNEP and UNU (2009a), Sustainable Innovation and Technology Transfer Industrial Sector Studies: Recycling – From E-Waste to Resources, Published jointly by UNEP and United Nations University (UNU)
http://www.unep.org/PDF/PressReleases/E-Waste_publication_screen_FINALVERSION-sml.pdf

[16] Golev, A. and Corder, G.D. (2017), Qualifying metal values in e-waste in Australia: The value chain perspective, *Minerals Engineering*, 107, pp 81-87

employed in developing and transition economies achieve far less recovery yields especially with valuable metals. These practices employ substandard treatment techniques including open burning to extract precious metals and cyanide leaching to recover metals such as copper, gold and silver. The discharge from these facilities included highly contaminated water and toxic gaseous emissions. Valuable metals are lost due to the inefficiency of the system. Whereas an advanced integrated smelter could recover over 95% of the gold, recycling practices in developing countries could achieve only around 25%.

3.3 Case studies: Resource recovery and recycling of e-waste in India

(1) Case Study
E-Parisaraa Pvt. Ltd – India's First E-waste Recycler

E-Parisaraa Pvt. Ltd, India's first Government authorized electronic waste recycler which started operations from September 2005. The company is engaged in handling, recycling and reusing of e-waste in environmentally sound manner. The aim of the company is to reduce the accumulation of used and discarded electronic and electrical equipment which most end up in landfills or partly recycled in a unhygienic conditions by backyard recyclers and then partly thrown into waste streams damaging the environment. The objective of E-Parisaraa is to create an opportunity to transfer waste into socially and industrially beneficial raw materials like valuable metals, plastics and glass using simple, cost efficient, home grown, environmental friendly technologies suitable for Indian conditions. The company which started in Bangalore now has set up collection and dismantling facilities in or near Delhi, Mumbai, Chennai and Kolkata.

The construction of E-Parisaraa's business model as a large electronics recycling company in India has involved cooperating with large government agencies and seeking global standardization and auditing reviews while also reaching out to the nation's vast "informal network" of scavengers and junk collectors. The company has realised that when informal collectors sell their material to E-Parisaraa, it prevents the material from going to "back yard" recyclers who may use chemicals or small smelters in unsafe and environmentally unsound operations. In addition, access to the material picked up by these scrap collectors, when aggregated to the tens of thousands, helps E-Parisaraa achieve the scale it needs to remain viable. E-Parisaraa is a role model for the entire country for recycling of scrapped electronic materials using techniques suitable to Indian conditions which has economic, environmental and social impacts. Following are some of the features of the company:

- E-Parisaraa is India's first e-waste recycler to obtain both ISO 14001:2004 and OHSAS 18001:2007 certifications
- E-Parisaraa is India's first Ee-waste recycler approved from both Central Pollution Control Board (CPCB) and Karnataka State Pollution Control Board (KSPCB).
- E-Parisaraa handles, recycles and reuse e-waste in an efficient way using unique recycling techniques and processes to recycle and recover resources to about 99% of the material collected and less than 1% goes to adjacent secure landfill.
- E-Parisaraa also conducts regular audits to ensure compliance with the Environment, Health and Safety standards.
- E-Parisaraa is engaged in recovery, refinement and reuse of gold & silver in gold plating and silver plating of watch pails, pen parts, imitation jewellery, temple items, etc.

- Besides precious metals such as gold, silver and palladium, E-Parisaraa also recover other metals such as selenium, indium, cobalt, tantalum and ruthenium in an environmentally sound methods

(2) Case Study
Terrapro - India's first Producer Responsibility Organisation (PRO)

Terrapro is India's first Producer Responsibility Organisation (PRO) set up to assist manufacturers and producers to comply with the new E-waste Management Rules 2016. According to the new Rules, manufactures are required to meet stringent EPR targets but also needs to document and file EPR returns with Central and State Pollution Control Boards providing the details of targets achieved.

Terrapro realises that managing e-waste is a challenging task for a primarily manufacturing oriented company. By providing a total solution to e-waste, Terrapro take away the responsibilities of assists public institutions and private manufacturers. The company has laid down processes that adhere to most stringent of rules and guidelines laid down by the Government of India for managing e-waste.

(3) Case Study
Attero Recycling

Attero is India's one of the largest end-to-end back to back e-waste recycling and metal extraction companies in India operating from Roorkee, a city in Uttarakhand. Attero is now collecting and processing about 1,000 metric tonnes of e-waste a month from over 500 cities in India, and extracting precious metals like platinum, gold and selenium from the trash. Attero buys printed circuit boards from these collectors at a higher price than the collectors would have earned if they stripped metals from the boards using toxic chemicals themselves. The company still makes money because its mechanical recycling process recovers more metal, and the trash collectors pocket more than they would have recycling metals themselves. Their business model is also making India's own e-waste industry somewhat safer. Two-third of Attero's e-waste in India comes from manufacturers such as Samsung and Wipro and outsourcing giants like Genpac and Infosys. Much of the remaining third comes from India's informal sector. The company offers transportation of e-waste from different collection centres to the plant in Roorkee, segregation and dismantling of the different components of the e-waste and recycling 97-98% of the waste.

(4) Case Study
Ecoreco

Eco Recycling Ltd (Ecoreco) is one of the largest e-waste management companies in India that has set industry benchmarks time and again with its innovative & environment friendly disposal practices. As the industry pioneer and market leader, Ecoreco provides an end to end integrated solution for e-waste management to Multi-National Companies (MNC), Indian Multi-National Corporates (Indian MNC), other Corporates, Retailers, Bulk Consumers, Original Equipment Manufacturers (OEM), Government Departments, NGOs, Households, Philanthropy Organisations, Educational Institutions and all other entities willing to discard their e-waste in an environment friendly manner.

Ecoreco, an ISO 9001, 14001 & 18001 certified facility, is led by a professional team at the board and senior management levels, who carries enormous amount of expertise gained over a period of time working as entrepreneur or working with multinational corporates & other reputed companies. To meet the international standards & practices, Ecoreco has developed its in house technologies for recovery of precious & rare earth metals from the complicated e-waste. Data destruction & lamp recycling facilities for on-site & off-site services amongst other value added services. Today, Ecoreco boasts of a unique business model that has evolved to meet changing customer needs and regulatory requirements of the India's e-waste management industry. Ecoreco's end to end services starts from removal of the asset from the client's premise, inventorization, packing, reverse logistic, data destruction, asset recovery, dismantling, e-waste recycling, lamp recycling, precious metal recovery and EPR implementation.

(5) Case Study

Karma Recycling - leading trade-in operator and redistributor of mobile devices

Karma Recycling is a leading trade-in operator and redistributor of mobile devices in India. Karma's consumer and enterprise software and services solutions help consumers, retailers and OEMs manage large-scale buyback and trade-in programs.

Karma Recycling runs an online electronics trade-in service (www.karmarecycling.in/eportal) which allows users across 24 cities in India to sell over 3000 models of used working and non-working smartphones, tablets or laptops of almost all leading brands directly from their home. With a unique pricing algorithm fine-tuned to the Indian market, Karma delivers instant quotes for devices in any condition, providing free pickup and quick payments.Karma also powers in store-exchange programs for electronic manufacturers and retail chains across the country. Mobile device owners can now carry their old devices into the stores they buy new electronics from. Through a backend powered by Karma they get an immediate in-store value against the purchase of new electronic devices.

After purchasing the device, Karma does a full data wipe and software reboot of the device, repairs whatever needs repair, and, post a 50+ step check of the device, re-packages devices for sale at a fraction of their original cost. These refreshed devices are re-sold with a 15-day money back guarantee. All non-repairable devices and spare parts are scientifically recycled back into metals and plastics.

4.0Role of E-waste Inventory, EPR, Private Sector & Manufacturers, PPPs in Transforming E-waste Sector into an Economic Industry

4.1 Role of E-waste Inventory

Previous sections of this paper has clearly identified the resource recovery and recycling opportunities related to e-waste industry. In order to make use of these opportunities it is essential that a reliable inventory is developed for the generated e-waste. Globally, it is recognized that there is a lack of reliable data on the generation, collection, import and exports, and management schemes in general. As a result, number of countries are in the process of initiating surveys to better define the problem, to identify toxic constituents in end-of-life EEE, to develop pilot projects on successful collections, and develop infrastructure to be able to locally refurbish and recycle such used and end-of-life equipment. Proper inventory will also assist the recycling business to evaluate the resource recovery potential of valuable materials contained in e-waste. It can also be used to identify and target those types of equipment that have the greatest potential for impacting on human health and the environment.

IPEN (2013) [17] cites UNEP (2007) [18] following important steps in developing an e-waste inventory:

Step 1: Determine the e-waste item(s) of interest, such as computers, televisions (TVs), mobile telephones, and refrigerators. Compile a list of the brands in the market, the year they entered the market and also whether the items are produced/assembled locally, nationally or internationally. The existence of unbranded / un-named items also needs to be noted for recording in the inventory.

The end-of-life electronic appliances vary depending on the type of products and the technology for which they are employed. In developing countries, some products' life time could be longer than stated in the guarantee or certification card from the manufacturer, such as a refrigerator and a TV set due to the existence of service repair shops and the purchasing power of the users to replace such items. In contrast, the life time of some e-products such as mobile phones, tends to be less than stated by the manufacturers due to rapid changes in the life style and fashion of the users as well as the very rapid development in technology.

Step 2: For each category of interest by item and brand, determine the average weight and size in relation to where they are produced, i.e. locally, nationally and internationally. For example, the capacity of refrigerator (litres)/ washing machine, size of monitor/ TV/ cellular phone. The variation in size of each item should be documented under each brand. Average weight and size along with percentage composition of major categories of materials, such as plastic, glass, etc should be estimated if possible.

Step 3: Determine the range of e-waste items likely to be available from different sources, like service industries such as hotels for TVs, fridges and air conditioners, educational institutions and businesses for computers, etc.

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[17] IPEN (2013) Guide for Conducting an E-waste Inventory in Africa http://www.ipen.org/documents/guide-conducting-e-waste-inventory-africa
[18] UNEP (2007) E-waste Volume 1: Inventory Assessment Manual http://www.unep.or.jp/ietc/Publications/spc/EWasteManual_Vol1.pdf

Step 4: Establish the geographical boundary / system boundary of the inventory area (city/ region). Procure maps of the general area and prepare base maps of the areas to be included in the inventory with physical features marked on them. If detailed maps are not available, procure and use a general city map and fix and mark the municipal boundaries.

Step 5: Identify the different users of the categories of electronic and electrical equipment and other important stakeholders like importers, manufacturers, businesses, government offices, and retailers, all of whom are consumers who would also be e-waste generators, and mark them on the base map, may be on an over-lay transparent layer.

Step 6: Prepare a tentative e-waste trade value chain.

Step 7: Identify e-waste dismantling sites, recycling sites and landfills as well as other uncontrolled dump sites.

Step 8: Identify the data needed to be collected from these stakeholders based on their activity areas and where they come in the trade value chain. These include:
• Production and import data for the identified electrical and electronic equipment
• Sales and export data for electrical and electronic equipment
• Local e-waste generation data
• Imported e-waste data and
• Data of e-waste transferred for disposal/ treatment/ reuse.

As of 2017, there are only very few studies and statistics describing the generation and trends in global e-waste management. In order to fill this gap, the International Telecommunication Union (ITU), the United Nations University (UNU), and the International Solid Waste Association (ISAWA) have formed a 'Global E-waste Statistics Partnership' to improve and collect worldwide e-waste statistics.

4.2 Role of Private Sector/Manufacturers and Public Private Partnerships (PPPs)

The private sector (EEE manufacturers) and public sector (national and local governments) must work closely in order to meet the overall objectives of e-waste management. Governments require the assistance from the private sector to develop proper infrastructure to turn the growing e-waste problem into an opportunity. Environmental sound and economically efficient resource recovery and recycling of e-waste cannot be achieved by public sector (national of local governments) alone. In this regard it is very useful to explore the strengths that private sector can bring in to assist the public sector. Local governments need to explore opportunities to create shared value, where businesses and the community benefit from a product or service provided by the private sector. Private sector firms can derive economic benefits by reducing risk, enhancing productivity and expanding markets, while making a substantive contribution to improved and equitable service delivery by municipalities. Such arrangements are generally referred to as public private partnerships (PPPs). PPP is a long or medium term arrangement between the public and private sectors whereby public sector transfers part of its responsibilities to the private sector. These arrangements are typically formed with clear goals and agreements for delivery of public services or delivery of public infrastructure. In simple terms, PPPs are multi-stakeholder approaches that bring together partners from different sectors with strong interest in service delivery for common public goods. PPPs have proven to be remarkably successful in both accelerating progress in service delivery and areas such as environmental management, including business and value-chain programming. E-waste resource recovery and recycling industry is not an exception.

The above partnerships can only materialise if the enabling conditions are met for both government and private sector. Cheong (2012) [19] has identified following as what to EEE manufacturers need from the government to create enabling conditions for the private sector to enter the e-waste resource recovery and recycling market:

Environmental regulation should provide a framework for reaching environmental standards but not the tools and means how it has to be achieved. It should also aim at high global harmonization, promote free movement of goods and support innovation.

- Regulation should create incentives for voluntary environmental improvements
    - *Voluntary agreements within the industry to be preferred to legislation*
    - *Regulation should recognize and award market leaders*

- Environmental regulation should be fair and reasonable
    - *Different stakeholders have equal rights or obligations*
    - *Rights and obligations understandable and easily verified*
    - *Legislation sets the generic objectives, not the operative means of achieving them*

- Each party should be made responsible only for the part of the value chain which they can directly influence.
    - *Clear definition of responsibilities for different actors in the chain*
    - *Transparency of decision making*

- Effective regulatory initiatives from environmental, economic and health and safety perspectives
    - *Competition between technologies, End-Of-Life solutions and enterprises should be encouraged*
    - *Technological development, rapid R&D cycles and the functioning of the market to be ensured*

- Industry should participate in decision making, especially when fees and exemptions as well as rules for handling of collected material are in question.
    - *End-of-life costs are kept as low as possible (allow competition between technologies and schemes)*
    - *Manufacturers can get enough control over take-back flows at acceptable cost*

- With the current limited recycling / treatment capacity (at international standards) in many countries, manufacturers and importers should be given the option of treating the

[19] Cheong, F (2012) What do electronic manufacturers need from governments? A presentation made on behalf of Nokia at the Multi-Stakeholder Policy Dialogue for Addressing E-waste Challenges and Opportunities through Public-Private Sector Cooperation, Osaka, Japan, 18-20 July

collected wastes in their overseas contracted treatment facilities via the proper Basel Convention export/import permit requirements.

- Legislation should support and advocate the EPR as an environmental policy approach to manage post-consumer e-wastes

- Legislated target for e-wastes collections should be avoided if possible and instead Producer Responsibility Organisation (PRO) schemes should be encouraged.

- Obligations for manufacturers and importers should be based on the actual e-waste arising model, as opposed to products Put on Market (POM) or import volumes or sales of previous year. Different products have different shelf life and perceived values, it will be reasonable to state that different products will also have different 'discard rates'. Therefore, having a universal collection target for all products and expecting the consumers to discard the products purchased in the previous years would be difficult to justify.

- Legislation should reflect the collective responsibility for historical waste

The remainder of this section of the Paper will illustrate some examples of partnerships developed globally and in India for sustainable resource recovery and recycling of e-waste.

Example 1
Solving the E-waste Problem (StEP) Initiative [20]

The Solving the E-waste Problem (StEP) Initiative is a United Nations led public-private partnership hosted by the United Nations University with following mission:

- To foster inclusive solutions-oriented member dialogue, cooperation and consensus by providing a global platform for sharing information, knowledge and recommendations founded on expert scientific research and multi-stakeholder sectoral experience.
- To work internationally with receptive external partners to develop fair and objective policies to stimulate and demonstrate practical, measured and effective responses to e-waste prevention, management and processes
- To lead the e-waste management discussion worldwide by providing a scientific basis from which to inform and actively change the awareness, knowledge, attitudes and behaviour of the international business and consumer public

StEP membership is open to companies, governmental organizations, academic institutions, NGOs and international organizations that commit to actively and constructively participating in StEP's work by signing StEP's Memorandum of Understanding. StEP members are expected to make monetary and in-kind contributions to support the Initiative and its projects. The objectives of StEP include e-waste research and piloting, strategy and goal setting, and training and development. These objectives are achieved through following task forces:

- Task Force Policy
- Task Force ReDesign

[20] http://www.step-initiative.org/

- Task Force ReUse
- Task Force ReCycle
- Task Force Capacity Building

StEP regularly publishes white papers and green paper on e-waste. Following are some examples:

1. StEP White Paper on One Global Definition of E-waste [21]
This publication deals with the issue of how to define e-waste. The intent of this paper is to provide a non-legal definition of the term and clarity about how the term should be used.

2. StEP Green Paper on Differentiating EEE Products and Wastes [22]
This publication discusses the provisions of the Basel Convention that concern e-wastes, and it further examines the potential impact of the Draft technical guidelines on transboundary movements of e-waste and used electrical and electronic equipment.

3. StEP Green Paper on E-waste Prevention, Take-back System Design and Policy Approaches [23]
This publication explores the large variety of e-waste policy options that have been implemented globally and it draws some conclusions about the nature of responses to the e-waste problem and potential policy recommendations.

4. StEP White Paper on Guiding Principles to Develop E-waste Management Systems and Legislation [24]
This publication provides 10 guiding principles to develop e-waste management systems and legislation.

Example 2
Clean E-India Initiative

Clean e-India is a noble initiative by the International Finance Corporation and Attero to help properly manage toxic and hazardous substances in e-waste. Below are some features of the initiative:

- Clean e-India responsibly recycles e-waste to prevent environmental deterioration and destruction caused by the reckless burning of waste.

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[21] http://www.step-initiative.org/files/step/_documents/StEP_WP_One%20Global%20Definition%20of%20E-waste_20140603_amended.pdf

[22] http://www.step-initiative.org/news/step-releases-green-paper-exploring-legal-distinction-between-ueee-and-e-wastes-in-basel-convention.html

[23] http://www.step-initiative.org/news/step-green-paper-explores-policy-solutions-to-e-waste-problem.html

[24] http://www.step-initiative.org/files/step-2014/Publications/Green%20and%20White%20Papers/Step_WP_WEEE%20systems%20and%20legislation_final.pdf

- It protects the health of the people engaged in the illegal and incorrect ways of e-waste disposal.
- It will channelize the unorganized sector which will help improve the living and working conditions of the millions of lives involved in this sector.
- The excellent door-step service provided by Clean e-India is hassle free and provides convenient pick up of your electronics. When requested the e-Captain to pick up the used electrical devices.

Example 3
E-waste: From Toxic to Green

Chintan, an Indian NGO, in cooperation with Delhi's Pollution Control Committee and the city's Department of Environment, created a partnership with Safai Sena, a registered association of waste pickers to improve collection, segregation and storage of e-waste. They then joined forces with companies in India that safely recover metals and plastics from e-waste. The initiative trains waste pickers to collect e-waste using safe e-waste handling practices to reduce their exposure to dangerous toxins. After it is collected, the e-waste is safely stored at Chintan's authorized collection center and sent to recyclers for safe disposal/recycling. Chintan works in partnership with waste pickers, itinerant buyers and small scrap dealers. More than 2,000 waste pickers have been trained on how to deal with e-waste in a safe manner. Electronic waste that is typically burned or dumped in a landfill is now instead collected directly from households, schools and businesses and recycled safely. The initiative negotiates for the best rates from recycling companies so that waste pickers can earn more money, increasing their incomes by 10-30%. The initiative makes the waste pickers more resilient to poverty by providing green jobs that increase their incomes and protect them from the risks of exposure to toxins and heavy metals. The E-Waste: From Toxic to Green initiative can serve as a model to help other countries recycle e-waste and fight poverty. As Chintan's model of handling e-waste is highly replicable due to its low cost, it can be adopted by other cities and countries where e-waste involves significant risk to workers, communities and the environment.

Example 4
Microsoft-GIZ E-waste Partnership

Microsoft embarked on a development partnership with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH as part of the develoPPP.de programme. develoPPP.de was set up by the German Federal Ministry for Economic Cooperation and Development (BMZ) to foster the involvement of the private sector at the point where business opportunities and development policy initiatives intersect.

The objective of the partnership is set up a viable recycling chain for old mobile phones and other electronic waste and raise awareness among the population of a more sustainable lifestyle. The partners' aim was to make recycling of electronic waste in two Indian cities more efficient and more socially and environmentally sustainable. The scheme involved local partners: the Self-Employed Women's Association (SEWA) and the environmental organisation DISHA played a crucial role in the success of the project. Below are some outcomes:

- 200 waste collectors have taken part in e-waste training and are now helping raise popular awareness
- Sustainable relationships have been established with more than 1,100 repair shops
- 264 young people have been trained as ‘e-waste ambassadors
- Many other stakeholders, including municipalities, environmental associations and universities, are learning more and becoming involved.

Example 5
eC2: E-Waste Management Program India

The International Finance Corporation (IFC) of World Bank aims to support the development of an e-waste management solution for the electronics industry to address the challenge of responsible collection and recycling of electronic waste in India at scale and in a cost-effective manner. The goal of the IFC project is to work with private sector entities such as Producer Responsibility Organizations (PROs) and Industry Associations and waste management companies to establish a long-term solution to the e-waste challenges in India that the electronics sector as well as consumers face. The fundamental objectives of the project are:

- Establish an Industry-led Solution for electronic producers to responsibly manage, collect and ensure responsible recycling of obsolete or discarded electronic products
- Raise awareness among the public and other key stakeholders on the need of responsibly collect and recycle e-waste
- Develop a locally relevant system for responsible e-waste management in India and a toolkit for dissemination of learnings from the Project

4.3 Role of Extended Producer Responsibility (EPR)

EPR is regarded an environmental policy approach in which a producer’s responsibility for a product is extended to the post-consumer stage of a product’s life cycle. EPR typically involves a shift in administrative, physical and financial responsibility from governments or local authorities to producers. EPR also encourage producers to take environmental considerations into account during the design and manufacture phases of product development thereby seeking to achieve a reduction in the environmental impact of products, throughout their lifespan, from production through end-of-life.

The European Union pioneered the mandating EPR for management of e-waste. European Union’s Waste Electrical and Electronic Equipment Directive (WEEE Directive) is one of first EPR systems to develop in e-waste field. Subsequently, number of industrialised counties have developed EPR is some form and number of developing countries are currently developing similar schemes with some challenges.

There are four broad categories of EPR instruments at the disposal of policy makers. These typically address specific aspects of waste management, and can be implemented concurrently:

- Product take-back schemes that require the producer or retailer to collect the product at the post-consumer stage. This objective can be achieved through recycling and collection targets of the product or materials and through incentives for consumers to bring the used product back to the selling point. Such schemes are administeted by independent bodies commonly known as Producer Responsibility Organisations (PROs).

- Economic and market-based instruments that include measures such as deposit-refund schemes, Advanced Disposal Fees (ADF), material taxes, and upstream combination tax/subsidy (UCTS) that incentivize the producer to comply with EPR. In South Korea for example, ADFs are imposed on importers and producers of products that are hazardous and more difficult to recycle.

- Regulations and performance standards such as minimum recycled content that can be mandatory or applied by industries themselves through voluntary programmes.

- Information-based instruments that aim to indirectly support EPR programmes by raising public awareness. Measures can include imposing information requirements on producers such as reporting requirements, labelling of products and components, communicating to consumers about producer responsibility and waste separation, and informing recyclers about the materials used in products.

The key objective of EPR is to support improvements in the environmental efficiency of products throughout their life cycle. The following are regarded as possible achievements of EPR:

- Increased collection and recycling rates and increased environmental effectiveness
- Reduction of public spending on waste management
- Reduction in overall waste management costs
- Innovation and implementation related to Design for Environment (DfE)

There are also a number of challenges and constraints to implement EPR. They include unclear and overlapping roles and responsibilities of different actors, a lack of transparency and difficulties in the comparability of data, concerns with free-riding, a lack of enforcement mechanisms, difficulties on deciding fees etc. The detailed analysis of issues, challenges and opportunities related to planning and implementing EPR is described in a issues paper published by OECD [25]. Following is a summary of those challenges:

- Unclear and overlapping roles and responsibilities of different actors (PROs, producers, importers, collectors and recyclers, municipalities and consumers)

- A lack of transparency and difficulties in the comparability of data

- Concerns with free-riding (free-riding occurs when some producers do not finance the collection and recycling of their products up to the level requires or the producers do not provide accurate data about the quantities of products put on the market)

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[25] OECD (2014) Issues Papers on the State of Play on Extended Producer Responsibility (EPR): Opportunities and Challenges
http://www.oecd.org/environment/waste/Global%20Forum%20Tokyo%20Issues%20Paper%2030-5-2014.pdf

- A lack of enforcement mechanisms (issues impacting EPR such as free-riding, competition concerns, illegal landfilling, exports of waste and used products require permanent monitoring and control by public authorities)
- Difficulty to implement differentiated fees and lack of incentives for design for environment
- Informal waste management sector and social challenges
- Waste leakage (e-waste not captured by the EPR scheme but instead collected and treated through other legal or illegal channels)
- Orphan products (these products were put on the market before the introduction of EPR schemes by producers who are no longer in business)

EPR Case Study 1
Samsung Takeback and Recycle (STAR) Progam in India

The program is aimed at generating awareness and educating consumers on the importance of recycling electronic scrap. Through the program, Samsung will encourage consumers to recycle Samsung-branded consumer electronics at no cost at any of the drop-off locations in major cities Samsung has established in India. For larger products, consumers can deliver them to the product collection facility for a nominal payment (if the location is outside the municipal limits) or drop the product at any of the company’s collection centers. To ensure the success of the STAR progra, Samsung has signed contracts with a number of electronics recycling companies in India.

EPR Case Study 2
Xiaomi India E-waste Recycling Progam in India

Chinese technology major, Xiaomi has launched an e-waste management programme in India under the name “Mi India Product Take-Back & Recycling Program”. The initiative involves taking non-operational technology products across multiple brands and categories. Xiaomi will also be giving a discount coupon of Rs 100 against the procured non-operational products, which can be later used on the company's online store against a minimum purchase of Rs 1,000. Xiaomi India has partnered with TES-AMM India for their e-waste recycling process. This program is not limited to their own products.

EPR Case Study 3
LG National E-waste Recycling Program

LG Electronics has developed a partnership Pollution Control Board authorized e-waste recycler for facilitating their customers to enable them to dispose off e-waste products after its end-of-life. In this process, the customer would be interacting directly with the authorised agency meant for handling the e-waste products without involving any 3rd parties.To maximize resource efficiency through LG consumer durable products recycling, LG Electronics works closely with all consumer durable supply chains including authorized service providers, distributors, merchandiser’s customers, and the recycling industry. Electronic waste is to be disposed off separately from the general waste stream via designated collection facilities identified by LG Electronics. The take-back operates folowing way:

- Customers are required to contact LG CIC (Call Center 1800 180 9999) for submitting their request for recycling of LG electronics products.
- LG will send its authorized recycler to home/premise.
- Authorized recycler will inspect the product and calculate the residual value of electronics product.
- As per valuation by authorized recycler, customer will be offered the price of electronic products. On your acceptance of offer, authorized recycler will take the used products after giving the offer price to you.
- The old LG Product will be recycled as per e-Waste disposal guidelines by the LG authorized recycler.

5.0 Role of R&D and Technology Transfer as Key Driver for Harnessing Economic Potential of E-waste Sector

5.1 Role of R&D

In order to understand the role of R&D towards environmentally sustainable resource recovery and recycling of e-waste, it is necessary to understand the current issues that exist in the manufacturing process of EEE. The traditional manufacturing process in the electronics industry has been linear in nature and adheres to the standard "profit" focused approach which can be regarded as "take-make and waste". Currently, many EEE manufacturing companies are attempting to move away from this approach. The EEE manufacturer or other industry player may well have an environmentally certified manufacturing plant and be extremely mindful of its eco-responsibility. However, if the end product is not "clean" in process, then the impact of any improvement through accreditation is weakened. It must be recognised that accreditation is but the first step towards sustainability. It is not an end in itself. Once a product is out on the market, the ability to improve its environmental performance is essentially eliminated. Resources may be expended on attempting to do so but it will be relatively ineffective and environmental impact and degradation will not be reduced.

A product is like a messenger between the acts of production and consumption. They are "the carriers of material's flow, energy usage, functional performance and environmental impacts". The challenge is to ensure that an integrated circular "whole systems design" encouraging a borrow-use-return approach to be taken and the linear method abandoned. This process incorporates design for environment (DfE).

DfE or eco-design, at times also refer to as cleaner production, as a result of major regulatory changes that have and are taking place internationally and together with pressure from end-users, is becoming an increasingly important priority for manufacturers of EEE. DfE is not a compliance activity, but an integrated, cross-functional strategy. DfE is an integrated strategy that has the goal of reducing the environmental impact of a product at the design stage. DfE begins with research and development using environmental impact as the basis for the product whilst procurement and quality assurance work closely with suppliers by ensuring they meet or exceed the criteria for environmental performance. DfE will not only see the elimination of toxic products from the system altogether, better disassembly, lower weight and smaller footprints, it will enable manufacturers to achieve a level of competitive advantage over more conventional manufacturers that do not follow this path. It will also eventually eliminate these conventional manufacturers from the largest markets.

DfE is not only an issue for the manufacturer, the consumer also has a part to play in the process. The consumer is the key to initiation and implementation of DfE at points along the supply chain. The consumer, particularly larger organisations such as government departments, through the implementation of purchasing policies, is in a position to encourage EEE suppliers to implement DfE by specifying criteria in contracts. This is known as environmentally responsible product purchasing (ERPP) or green purchasing.

From a resource recovery and recycling point of view, R&D plays an important role by eliminating the toxic materials in EEE and thereby increasing the efficiency of the recovery processes. Green electronic through lead-free soldering is one such example which is gaining momentum worldwide. EEE contains over 1000 materials of which lead (Pb) has been one of the targets of the regulators forcing manufacturers to adopt lead free products. Industry has come up with several lead free solders with preference given to alloys containing tin, silver and copper but there is no ‘drop-in' substitute to leaded solder.

In order to gain a better understanding of available technologies for e-waste recycling and recovery, the Secretariat of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (SBC), requested World Intellectual Property Organisation (WIPO) [26] to prepare an e-waste technologies patent landscape report. The report, published in December 2013, provides a comprehensive overview of R&D activities related to e-waste recycling and recovery, mainly concentrating on end-of-life mobile phones and computer equipment. It offers a snapshot of innovation in this field, identifies observable trends in patenting activity and provides insights about the technology development cycle, the geographic distribution of innovation, research topics and primary actors, including case studies, within e-waste and related research and development.

The report analyses patent applications relating to e-waste recycling in three main categories, namely: technologies for recycling or recovering materials such as plastics or metals; sources of e-waste and their processing (e.g. batteries, cabling and printed circuit boards); and processes and logistics involved in e-waste treatment, such as magnetic sorting of e-waste. The report shows that bulk of e-waste innovation is taking place in Asia (followed by Europe and the US) with Japanese consumer electronics and metals firms, such as Panasonic, Hitachi and Toshiba, representing the largest and most dominant patent portfolios with over 50 percent of all activity. P.R.China is also emerging as a key player, with domestic e-waste-related patenting activity increasing seven-fold in just six years. The complete details of R&D activities of number of EEE manufacturers around the world can be found in WIPO (2013).

5.2 Role of Technology Transfer

According to (UNEP and UNU, 2009a)[27], the e-waste recycling chain mainly consists of collection, sorting/dismantling and pre-processing and end-processing. All the above steps need to operate in a holistic manner to achieve the following objectives:

- Treat the hazardous compounds contained in e-waste in an environmentally sound manner
- Recover valuable material using efficient processes
- Create economically and environmentally sustainable businesses
- Consider social impact and local context of operations

In order to have a successful e-waste recycling system, it is important to achieve maximum efficiencies in all the components in the recycling chain. The above report cites an example

[26] WIPO (2013) Patent Landscape Report on E-waste Recycling Technologies, Prepared by World Intellectual Property Organisation in collaboration with Basel Convention http://www.wipo.int/edocs/pubdocs/en/patents/948/wipo_pub_948_4.pdf

[27] UNEP and UNU (2009a), Sustainable Innovation and Technology Transfer Industrial Sector Studies: Recycling – From E-Waste to Resources, Published jointly by UNEP and United Nations University (UNU)
http://www.unep.org/PDF/PressReleases/E-Waste_publication_screen_FINALVERSION-sml.pdf

where for a certain metal or device in the e-waste stream the efficiency of collection is 50%, the combined dismantling pre-processing efficiency is 70% and final materials recovery efficiency is 95%, the resulting in final collection efficiency of only 33%.

UNEP and UNU (2009a) identifies number of barriers for the transfer of sustainable e-waste recycling technologies. These are summarised below:

Policy and Legislation Barriers

- Lack of dedicated legislation dealing with e-waste
- Confusion created by attempting to cover e-waste through legislations related to other media such as environment, water, air etc as each of them examine the e-waste issue in different perspective
- Enforcement of laws undertaken by different government departments without any uniform approach
- Players in e-waste being not recognised by the policy and legislative framework
- Existence of strong social programs that exist to support the informal e-waste recycling sector
- High level corruption in law enforcement
- Low national priority for e-waste

Technology and Skills Barriers

- Lack of enforcement of Environmental Health and Safety (EHS) standards among the workers
- Lack of certification of e-waste recyclers and refurbishers
- Lack of a mechanism to separate e-waste from solid waste
- Lack of collection system leading to e-waste being stockpiled in homes and offices
- No infrastructure available for the disposal of hazardous fraction of e-waste
- Recycling business is mainly in the hands of the informal sector
- Current recycling system concentrates on generating good revenues hence no interest in more sustainable technologies

Business and Financing Barriers

- No or limited producer/distributors responsibility
- High cost of logistics especially in transport and hazardous waste disposal
- Exploitation of informal workers in a formalised e-waste recycling industry
- Consumers expect to be paid for broken equipment

Technology Transfer Case Study

The challenge of e-waste management is that it contains not only hazardous materials but also some valuable materials. It is well documented that used electronics are shipped to developing countries for reuse but most of them end up as e-waste in a very short time. The unsophisticated, informal recycling common in many developing countries pollutes the environment. It is now becoming clear that the developing and transition countries have been producing more e-waste than the developed countries where formal facilities exist to properly manage e-waste. Thus, innovative models for technology transfer are needed to tackle the problem until developing countries are better equipped to deal with e-waste by themselves.

This case study describes an innovative model developed by the Solving the E-waste Problem (StEP) initiative where it is argued that affordable and environmentally sound recycling can be achieved in developing countries through the cooperation between local dismantling operations and the global networks of infrastructure that can further refine the materials. The concept referred to as ‘Best-of-2-Worlds” (Bo2W) aims to integrate technical and logistical strengths in advanced end-processing facilities.

Dismantling of e-waste undertaken in developing countries can be a very efficient method to separate materials and components from e-waste due to low labour costs and little need for advanced equipment. At the same time, fractions such as circuit boards require high-tech treatment that is usually unavailable in developing countries. The Bo2W concept connects the best pre-processing already occurring in developing countries (manual dismantling) with the best end-processing (material refinery and disposal) in global treatment network.

6.0 The Way Forward

E-waste is regarded as the world's fastest growing waste stream. The rapid development of the information and communication technology sector has brought with it many life-enhancing advantages and opportunities. The downside, however, is that the scale and speed of technical innovation in this area, fuelled by our limitless appetite for next generation technologies, as well as the global uptake of these low-cost devices. Out of the 41.8 million tonnes of e-waste generated globally in 2014 only 6.5 million (around 15%) was reported as formally treated by national take-back schemes which employ environmentally sound resource recover practices. Much of the remaining e-waste ends up in developing countries where it is often recycled by the informal sector using rudimentary methods that present significant risks to the environment and the health of local populations. In India, only 1.5% of the 1.8 million tonnes of e-waste generated is recycled and over 95% is managed by unorganised recycling sector.

Unlike other types of municipal waste, e-waste involves a complex mix of hazardous, highly toxic materials and economically valuable, noble metals. As up to 60 elements from the periodic table can be found in complex electronic equipment, sophisticated processing technologies are required to maximize the recovery of these valuable resources while minimizing any negative social or environmental impact. This presents both challenges and opportunities for recyclers.

There is a growing perception that e-waste is a valuable resource with huge potential for resource recovery and recycling of valuable materials, especially the metals. Electronic devices are an alternative source of base metals such as copper (Cu) and tin (Sn), special metals such as cobalt (Co), Indium (In) and antimony (Sb) as well as noble metals such as silver (Ag), gold (Au), palladium (Pd) and platinum (Pt). Although the quantities used in each individual device are small, when you consider the global sales of these devices are significant providing the economic benefits of recovering and recycling.

The Asia-Pacific region is the highest contributor to the global e-waste stream. Given that most of the emerging economies are located in this region it is clear that this trend will continue well into the future. India is the 5th largest e-waste producer in the world. The Asia-Pacific region is home to 3 countries (India, P.R.China, and Japan) among the top 5 e-waste producing countries in the world.

In order address the issues and challenges of managing e-waste in the region, the United Nations Regional 3R Forum for Asia and Pacific, launched in November 2009, with an objective to provide strategic policy advices to national government authorities in mainstreaming 3Rs in the overall policy, planning and development, has identified and called action for environmentally sound management of e-waste in the Asia Pacific region during number of meetings held in the past as illustrated below:

Tokyo 3R Statement – Towards the Establishment of the Regional 3R (Reduce, Reuse and Recycle) Forum in Asia – 2009, Tokyo, Japan
Item 2(f)

*"Building adequate **capacity for collection and safe treatment of hazardous waste, including those from household waste and e-waste**;"*

Recommendations of the Singapore Forum on the 3Rs in Achieving a Resource Efficient Society in Asia, 2011 Singapore
Item A (3)

"Large amount of e-waste generated in the world ends up in a few numbers of developing countries for the purpose of reuse, refurbishment, recycling, and recovery of precious materials. E-waste has become an important health and environmental issue, as recycling electronic goods involves exposure to dangerous heavy metals such as lead, mercury, cadmium etc. which can be toxic to human and ecosystems. The countries can consider the following.

- *Establish proper institutional infrastructures for collection, storage, transportation, recovery, treatment and disposal of e-waste at regional and national levels. Such infrastructure should be integrated into existing waste collection schemes. Develop public-private-community partnerships to encourage the establishment of formal e-waste recycling and disposal enterprises.*

- *Establish appropriate regulatory procedures to control illegal exports of e-waste and to ensure their environmentally sound management. In this regard, proper testing of used or end-of-life electronics and electrical equipment prior to export should be encouraged to declare the presence of hazardous components as well as the functionality of the equipment.*

- *Introduce awareness raising programmes and activities at all levels on issues related to health and safety aspects of e-waste in order to encourage better management practices.*

- *Establish formal standards, certification systems and licensing procedures for recycling and disposal enterprises to ensure safety and environmentally sound processing of e-waste.*

- *Implement 'extended producer responsibility' (EPR) mandating producers, importers and retailers with the cost of collecting, recycling and disposal of e-waste. Thorough investigation into the problems and challenges of implementing EPR should be conducted to overcome any obstacles."*

Ha Noi 3R Declaration – Sustainable 3R Goals for Asia and the Pacific for 2013-2023, Ha Noi, Vietnam
Item III 3R Goals for New and Emerging Wastes (Goals 13, 14, 15)

*"Goal 13: Ensure **environmentally-sound management of e-waste** at all stages, including collection, storage, transportation, recovery, recycling, treatment, and disposal with appropriate consideration for working conditions, including **health and safety aspects** of those involved.*

Goal 14: Effective enforcement of established mechanisms for preventing illegal and inappropriate export and import of waste, including transit trade, especially of hazardous waste and e-waste.

*Goal 15: Progressive implementation of **"extended producer responsibility (EPR)"** by encouraging producers, importers, and retailers and other relevant stakeholders to fulfill their responsibilities for collecting, recycling, and disposal of new and emerging waste streams, in particular e-waste."*

Surabaya Decalaration on Promotion of Multilayer Partnerships and Collaboration for the Expansion of Reduce, Reuse and Recycle (3Rs) in Asia and the Pacific, 2014, Surabya, Indonesia

***"Recognizing** the complex and daunting nature of waste management challenges faced by local authorities and municipalities in today's world in view of the diversification of waste streams region-wide, the growing presence of chemicals and hazardous and toxic elements, including e-wastes, in the general waste stream, the increasing presence of waste, in particular plastics and disaster waste in coastal and marine environment that increasingly demand science-based decision-making and solutions within multilayer partnerships and collaboration,*

On-going discussions and resulting reports concerning post-2015 development agenda categorically mentions the importance waste management and 3R towards achieving the goals [28]. Some of the goals related to e-waste are illustrated below:

"11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment

12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse"

The efficient management of our natural resources and the way we manage and dispose of toxic waste and pollutants are important targets of Goal 12 Responsible Consumption and Production of Sustainable Development Goals (SDGs). In particular, goal targets the following:

- By 2030, achieve the sustainable management and efficient use of natural resources
- By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
- By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse

[28] UN (2015) Report of the Open Working Group of the General Assembly on Sustainable Development Goals
http://www.un.org/ga/search/view_doc.asp?symbol=A/68/970

The campaign of Swachh Bharat launched by the government of India is aimed to accomplish various goals and fulfil the vision and mission of "Clean India" by 2nd of October 2019 which is 150th birth anniversary of the great Mahatma Gandhi. The Swachh Bharat Abhiyan puts focus on awareness and aims to ensure 100% collection and scientific processing/disposal reuse/recycle of municipal solid waste. Since over 95% of the e-waste is handled by the unorganised informal sector using non-scientific processing techniques, e-waste is one of the waste streams that need lot of consideration to achieve these goals.

India is experiencing a major problem with the ever-increasing amount of e-waste, as it lacks the policies and infrastructure to deal with the issue in a sustainable way. Although e-waste is a problem because of its hazardous components, it is also a solution to the depletion of the natural resources that manufacturers of EEE depend on. Proper recycling of e-waste is of great importance in order to harvest these secondary sources. The e-waste recycling chain consists of three main steps: collection, sorting/dismantling, and pre-processing and end-processing. In developing countries like India these three activities are undertaken predominantly by the informal e-waste recycling sector, with little presence of the formal recycling sector. Although the first two of these steps can be undertaken by the informal sector without much environmental impact, the last step of end-processing, when undertaken by the informal recycling sector, could result in severe environmental impacts.

The transfer of appropriate technology to India to manage their e-waste problem should be undertaken, keeping in mind their social, environmental and economic boundaries. Direct transfer of technology without any consideration given to inter-linked, non-technical aspects has led to failure in a number of cases. The collection of e-waste by the informal sector is quite efficient in a number of developing countries. Furthermore, the informal sector is quite active in the pre-processing stage of recycling operations. For example, deep level manual dismantling of used EEE in developing countries may be preferred over high-technology, automatic processes as a result of an abundant workforce and low labour costs. Deep-level manual dismantling also results in good preparation of feedstock for the subsequent steps in the recycling process. However, there is lot of room for improvement in all other informal recycling activities through technology transfer. Even with such improvements, an optimal level will be reached whereby it will no longer be feasible for informal recyclers to process materials efficiently. State-of-the art end-processing facilities, such as integrated smelters, will be required to recover precious materials in an efficient way.

The future success of technology transfer to countries with dominant and successful informal e-waste recycling sectors will depend on innovative models whereby the informal sectors are still allowed to participate in safe recycling practices while hazardous operations are transferred to state-of-the-art formal recyclers. Such models would require giving a high priority to further improvement of collection and pre-processing by the informal sector through technology transfer to benefit state-of-the art formal recycling operations towards the end of the recycling chain.

EPR is considered globally as one of the most powerful policy mechanisms in dealing with the e-waste problem. Most developed countries have had a lot of success implementing EPR related policies. Due to the urgency of the issue, a number of developing countries are planning or have already adopted EPR related policy mechanisms based upon the templates used in developed countries. If possible, developing countries should take care to avoid this path and try and attempt to design their own EPR schemes based upon their capacity to implement such schemes. Whichever scheme is adopted, managing e-waste is a major challenge to an individual country in the developing world due to the limitations and challenges already discussed. As such, serious consideration should be given to a regional approach, where economies of scale may be more appropriate.

In order for developing countries to move forward on EPR regulations, (Akenji *et al.*, 2011) [29] have proposed that developing countries should move gradually towards EPR in phases. They have identified competition with the informal waste management sector, poor infrastructure for waste collection and treatment, perception of e-waste and poor international governance of import and export of e-waste as key challenges facing the governments. Therefore, they have recommended that instead of following an EPR template or generic recommendations, developing countries should commence the process by setting up a multi-stakeholder panel, referred to as a 'National E-waste Expert Review' (NEWER) consisting of experts, policy makers, researchers, relevant industrial associations and consumer groups.

This review should be entrusted with following tasks:

- Review specific national situation regarding e-waste
- Extracting lessons from experiences in developing and implementing EPR systems in other countries
- Consulting with various e-waste stakeholder groups that would be affected by an EPR system, including informal waste collectors and recyclers
- Evaluating national infrastructure for e-waste management, related policies already existing, new ones needed, and the capacity to implement EPR-based policies.

Then they have recommended the following phases for implementing EPR in developing countries:

- Phase 1: Focus on improved waste management and resource recovery (establish an interface organisation to mediate with informal sector, certification of proper recyclers, licensing repairers)
- Phase 2: Focus on integration of externalities into consumption and production (eg. product take-back, recycling fund)
- Phase 3: Focus on design for environment (design for environment)
- Phase 4: Regional/international collaboration towards better governance for resource circulation

The Institute for Global Environmental Strategies (IGES) has an Issues Brief on Applying EPR in Developing Countries. [30] This paper describes very useful policy concepts for implementing EPR in Asia-Pacific countries based on the above mentioned Phases. They are summarised below:

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[29] Akenji, L., Hotta, Y., Bengtsson, M. & Hayasi, S. (2011) EPR policies for electronics in developing Asia: ad adapted phase-in approach. *Waste Management & Research*, **29**, 919 930.

[30]

http://pub.iges.or.jp/modules/envirolib/upload/3553/attach/rio_issue_brief_vol3_EPR_mar2012.pdf

Phase 1 Policy Concepts

- Public awareness campaigns
- Development of basic waste separation and collection infrastructure
- Creation of interface organisation to mediate between the informal sector and resource recovery facilities
- Licensing for proper repairers
- Certification for recyclers and recycling centres

Phase 2 Policy Concepts

- Introduction of take back scheme
- Recycling Fund
- Minimum sustainability quality standard for recyclables
- Eco-industrial parks

Phase 3 Policy Concepts

- Greening the supply chain
- Green purchasing
- Restrictions on throwaway products
- Introduction of virgin material tax

Phase 4 Policy Concepts

- Multilateral financial mechanism for sustainable resource management and resource circulation

To manage the emerging threat from e-waste, and due to the urgency of the issue, number of developing countries are looking into adopt policies and technologies that are already been implemented in developed countries where proper infrastructure is in place to manage e-waste. However, the economic, environmental and social situation in number of these developing countries (mainly located in Asia and Africa) are different to the developed world, hence, the need for adapting, implementing, and scaling up appropriate technologies that are more suited to the local conditions. One of the key areas that developing countries need to concentrate relates to how to deal with the informal e-waste recycling sector. It is important to note here that in many developing countries the informal sector is very active in activities related to the e-waste recycling chain. These informal recyclers are motivated by the precious materials contained in the e-waste stream and its market value. In countries such as India and P.R.China, where significant amount of e-waste recycling is taking place, informal collectors achieve very high collection efficiencies. In fact, informal collection of e-waste does not have any major adverse impacts on the environment. Instead they lead to high collection rates and many economic and social benefits to the poor section of the community. The informal sector is also involved in the second stage of the e-waste recycling chain - dismantling pre-processing. Even here there are no major impacts on the environment instead more economic and social benefits to poor community. The last stage of the e-waste recycling chain where processes/techniques are necessary to extract the valuable components such as metals is where the current environmental impacts are. Most of the informal recyclers utilise low efficiency processes resulting in major health and environmental impacts. For example primitive technologies utilised by informal recyclers to extract raw materials from printed wire boards, wires and other metal bearing components have very low material recovery rates and also result in major environmental impacts. The challenge for the policy makers in developing countries is how to achieve efficiencies in the informal sector at the same time taking into account the environmental and social aspects of their operations.

Prohibiting and imposing fines on informal recycling have not helped in countries like P.R.China and India. This is due to the fact that informal recycling is undertaken by the poor people and as such the government is unable to impose heavy fines as they cannot pay it. These governments then tried to regulate the informal e-waste recycling sector by licensing them. However, the effectiveness of such a scheme depends a lot on the responsibility of the disposer of e-waste. The challenge is how to deal with the e-waste disposer who receives more money from unlicensed informal recyclers than from the licensed recyclers. The emergence and growth of the informal sector in developing countries is the result of intricate interactions between economic incentives, regulation gaps, industrial interdependence and the social reality and it can be argued that informal sector may remain an influential recycling force for years to come. The whole informal recycling chain must be thoroughly investigated on which steps are environmentally harmless and should remain and which steps of the material mass flow should be changed for better downstream environmental and recycling performance.

The United Nations have recently developed a process to map a country's system for e-waste management based on four types of systems below[31]:

Type 1: Advanced mechanism
In a Type 1 system, a strong legal framework for e-waste is backed by strong enforcement. In addition to legislation, there is also an established and functional collection and recycling infrastructure, with high environmental health and safety standards.

Type 2: Voluntary initiative
In a Type 2 system, the private sector (mostly international manufacturers and recyclers) take the initiative to implement a take-back and recycling programme for e-waste that may or may not be in collaboration with or bestowed with recognition by the government. As it is entirely voluntary, the system usually operates based on commercial imperatives rather than regulatory requirements, and it therefore operates even in the absence of a legal framework for e-waste.

Type 3: In transition
A system in transition is a Type 3 with a nascent legal framework that is still being tested. As the legislation is being developed and implemented, the collection and treatment mechanisms may be in the process of being established, with collection and processing infrastructure involving a mix of formal and informal actors, and EHS standards in the low to medium range of sophistication.

Type 4: Informal initiative
When the informal sector is predominant in the collection, recycling and disposal of e-waste, the system is considered a Type 4. Countries with a Type 4 system typically have no

[31] Honda, S., Sinha Khetriwal, D and Kuehr, R. (2016), Regional E-waste Monitor: East and Southeast Asia, United Nations University ViE-SCYCLE, Bonn, Germany http://ewastemonitor.info/pdf/Regional-E-Waste-Monitor.pdf

established legal frameworks for e-waste yet, and they mostly lack formal recycling facilities or high environmental health and safety safeguards.

India could be considered under Type 3 above as it is currently in the process of strengthening the e-waste regulatory framework through the new E-waste (Management) Rules, 2016. One of key developments in the new Rules is statuary requirement of the e-waste collection targets defined on the basis of products sold. Each manufacturer, producer and importer is now required to fill an EPR Plan based on its sales. Generally, manufacturers have agreed to support the new requirements, however, the question is how they will internalise or externalise the additions costs involved in complying with new regulations.

E-waste should be included under the Swachh Bharat Abhiyan to ensure scientific processing/disposal reuse/recycle of e-waste and to develop potential business and economic opportunities in e-waste towards creating employment and wealth. In addition, a formal operational review on a regular basis of the E-waste (Management) Rules, 2016 involving key stakeholders to identify and address the issues and obstacles of implementation should also be initiated.

The Eighth Regional 3R Forum in Asia and the Pacific, under the theme of "***Advancing Clean Water, Clean Land and Clean Air through 3R and Resource Efficiency – A 21st Century Vision for Asia-Pacific Communities***" calls for innovative, effective and smart solutions in the areas of policy, institution, technology, infrastructure, financing and partnerships towards effective implementation of Ha Noi 3R Declaration (2013-2023) and SDGs. In this regard, the Asia-Pacific countries could strengthen their 3R and circular economy policy and programmes towards effective management of e-waste by implementing following activities to create enabling conditions for enhancing the business and economic potential of resource recovery and recycling from e-waste:

- Well defined national e-waste management strategy based upon 3R concepts. Such strategy should not only address the environmental and health impacts of e-waste (end-of-pipe) but also look at the reduction of e-waste through green design (up-the-pipe). It should also create enabling conditions for relevant stakeholders to develop business and economic opportunities to recover the materials from e-waste. The strategy should take into account the financial, institutional, political and social aspects of e-waste management, in particular, incorporating the activities of informal e-waste recycling sector
- Well defined regulatory procedure adequate enough to control illegal exports of e-waste and to ensure their environmentally sound management.
- Identify the factors that determine the responsible e-waste disposal behaviour of consumers
- Improve country's ability to gather data and inventory on e-waste generation including their transboundary movement and to access appropriate and cost effective technologies to manage e-waste within their own borders. Such inventory should clearly identify the key players in the e-waste recycling value chain
- Establishment of proper institutional infrastructures for collection, storage, transportation, recovery, treatment and disposal of e-waste at regional and national levels.
- Development of scientific resources such as experts and laboratories to conduct environmental and human health impacts of e-waste
- Improving the working conditions and minimisation of work related toxic exposure at e-waste collection, processing, recovery and disposal facilities.

- Awareness raising programmes and activities on issues related to health and safety aspects of e-waste in order to encourage better management practices.
- Develop public-private-community partnerships to encourage the establishment of formal e-waste recycling and disposal enterprises.
- Require the countries that export used EEE to developing countries to formally test the equipment prior to export.
- Prohibit import of e-waste if the receiving country does not possess adequate capacity to manage these wastes in an environmentally sound manner.
- Identification of organisations or institutions with potential to develop innovation hubs and centres for excellence for developing and promoting environmental sound e-waste recycling technologies. These centres of excellence should conduct R&D on innovative technologies and should be able to assess the applications of relevance of technology transfer.
- Develop standards for collection, storage, transport, recovery, treatment and disposal to ensure environmentally sound management of e-waste.

Three Policy Questions

Policy Question 1
The Asia-Pacific region is experiencing a major problem with the ever increasing amount of e-waste as they lack the policies and infrastructure to deal with the issue in a sustainable way. Although e-waste is a problem due to its hazardous components, it is also a solution to the depletion of the natural resources which the manufacture of EEE depends upon. Proper management of e-waste requires innovative, effective and smart solutions in the areas of policy, institution, technology, infrastructure, financing and partnerships, which are lacking in many countries in the region. In particular, 3R technologies that drive towards resource security and circular economic development are essential for the region to cope with the challenges of e-waste. In this regard private sector could play an important role supporting the public sector agenda. Thus, the question for policy makers in countries in the Asia Pacific region is how an enabling environment could be created for the private sector to harness potential business and economic opportunities in recycling and resource recovery e-waste in the region?

Policy Question 2
One of the key challenges and difficult to solve the problems related to e-waste management in the Asia Pacific region is the existence of informal e-waste recycling sector. Although, the informal e-waste recycling sector plays an important role in collecting and dismantling the e-waste ready for recycling, their recycling standards are typically sub-standard and result in severe environment pollution. The existence of the informal sector is also one of the key barriers for attracting the formal sector for e-waste recycling. In contrast, the formal e-waste recycling sector is equipped with advanced 3R technologies that could drive circular economic development without any adverse impacts on the environment. Thus, the question for policy makers in the Asia Pacific region how can the strengths and capabilities of informal and formal e-waste recycling sectors are combined to develop a sustainable e-waste management system in the region?

Policy Question 3
Sustainable e-waste management in any country will largely depends the level of awareness and behaviour in relation to hazardous nature as well as the economic potential of the used EEE. Such awareness and behaviour is unique to a country as it depends on their complex

socio-cultural and economic conditions. For the formal e-waste recycling sector to invest and implement innovative 3R technologies, they need to be assured that sufficient supply of used EEE is reaching their facilities. Thus, the question for policy makers in the region is how the consumer's e-waste disposal behaviour and awareness are addressed in the context of complex socio-cultural and economic conditions in the country so that the implementation of innovative 3R technologies could be sustainable in the longer term??