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Chapter 3

The e-waste development cycle, part II—impact assessment of collection and treatment

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CHAPTER OUTLINE

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3.1 INTRODUCTION AND READER'S GUIDE

Chapter 3 includes the second part of the e-waste development cycle, describing the assessment of collection and treatment and the environmental, economic, and social impacts forming the factual basis for the next steps. A key question for this part is:

- Step 2: how to collect more and treat better?

In Chapter 2, a rather qualitative approach was followed. The next stage includes a more quantitative assessment. This provides a factual basis for describing the key issues in the development process, enabling later interventions to be more targeted. The primary objectives of e-waste development are to "collect more and treat better" (Wang, 2014). The second stage of the development cycle, the quantitative assessment stage, analyzes the current collection and treatment situation in more detail. This also includes substantiation of e-waste treatment in formal and informal sectors and focuses on areas of concern identified in the previous assessment of country status. The quantitative description includes an overview of technologies available and (simple or more complex) estimates and flow analysis of e-waste streams. Both main elements combined, being **collection** (Section 3.2) and **treatment** infrastructure (Section 3.3), constitute a baseline description of e-waste amounts collected and treated properly versus substandard or out-of-sight collection and treatment. In turn, the analysis provides the necessary e-waste volume information for the **environmental** (Section 3.4), **economic** (Section 3.5), and **social** impact assessments (Section 3.6) that follow.

It is a matter of preference whether the analysis is performed subsequently after or jointly with the previous qualitative stage. The results of the assessment phase contribute to the setting of priorities later in the next stage in Chapter 4, which are related to policy development and implementation.

Table 3.1 Key development questions posed (covering Chapter 3 of this handbook)

Development areas	Starting countries	Emerging countries	Established countries
Step 2: how to collect more and treat better? (Sections 3.2 and 3.3)			
Assessment of collection	3.2.1 What basic data on e-waste volumes are available?	3.2.2 How to get better data for complementary flows?	3.2.3 What is the quality of collected and reported volumes? How much scavenging takes place?
Assessment of treatment	3.3.1 How to improve formal and informal treatment?	3.3.2 How to optimize dismantling vs. mechanical treatment?	3.3.3 How to economically reward innovation in technology?
Step 3: what are the societal impacts (environmental, economic, and social)? (Sections 3.4, 3.5, and 3.6)			
Environmental impacts	3.4.1 What are the most pressing environmental issues?	3.4.2 How to maximize the environmental performance per collection category?	3.4.3 How to improve the environmental performance of complementary recycling?
Economic impacts	3.5.1 How much funding is needed to set up the initial infrastructure?	3.5.2 How to direct financing to treat complex fractions efficiently?	3.5.3 How to realize a level playing field? 3.5.4 How to optimize the eco-efficiency of the system?
Social conditions	3.6.1 How many jobs are involved and what are the working conditions in the informal sector?	3.6.2 What are new job opportunities? How to improve health and safety?	3.6.3 How to enhance consumer education?
(Continue to step 4: Policy and Legislation, Business and Finance, and Technologies and Skills)			

Specific questions are highlighted in the following Table 3.1 and for the full reader's guide covering the Chapters 2–5, see Table 2.1:

Like in Chapter 2, to support tackling these key development questions, for each step in the development cycle proposed in Section 2.3, the following approach is taken for "starting," "emerging," and "established" countries (as defined in Section 2.1.2):

1. **Aim of the step in the development cycle:** a description of why the step is needed, the rationale and focus behind it, and its position in the development cycle in relation to other parts.
2. **Characterization, key questions (per type of country):** characterization of the status in a country by means of elaborating on the above key questions rather than simply providing "precooked" answers.
3. **Common issues, experiences, and recommendations:** a description of the most observed common issues and of the probable tasks ahead.

4. **Possible tools and information sources:** a short listing of potential tools, experiences, and information sources available in the national and international domain.

3.2 COLLECT MORE—E-WASTE QUANTIFICATIONS

Evaluation of the collection pathways and size of the EEE products placed on market (POM) and the amounts of e-waste generated, collected, and treated is relevant. This includes describing the market of EEE and WEEE in more quantitative terms as far as trading and recycling flows, e-waste in residual waste, and import and export amounts. There are obviously very different infrastructures and knowledge levels per country or region. Most starting countries may completely lack formal and sometimes even informal collection infrastructures, Other countries mainly collect through informal channels, whereas others have sophisticated logistics arranged, and highly detailed research methodology and outcomes available, regarding total flows of e-waste (Huisman et al., 2012; Magalini et al., 2012; Wang et al., 2013; Wielenga et al., 2013; ADEME, 2013; Magalini et al., 2015). In principle, more than 900 different product types that can potentially be classified as e-waste exist (Baldé et al., 2017; Huisman et al., 2017) and constitute a wide range of values, average weights, and typical life spans streaming together in e-waste flows originating from households, businesses, and public space. The concepts, definitions, and methodology to quantify e-waste globally and nationally are summarized into the E-waste Guidelines (Balde et al., 2015; Forti et al., 2018).

For emerging and even many established countries, usually little understanding about the whereabouts of e-waste flows exists. Basic or more advanced fact-finding is a key investigation activity irrespective of whether a first, second, or third loop is taken through the e-waste system development cycle sketched in Fig. 2.3. The advantages of having better information are numerous: it is a key ingredient for measuring environmental performance; it improves financial planning and investment decisions; it results in improved monitoring and control; and it helps in finding the most cost-effective collection interventions. Data on the e-waste volumes are essential for setting the baseline for policy development. Hence a common key question for all types of countries is:

- What collection data are available, which e-waste volumes have unknown whereabouts, and how can more tangible information be gathered in due course?

3.2.1 Starting countries

For starting countries, there often is hardly any statistical information on the size of the e-waste problem. In practically all cases, distributed second hand product streams from more saturated markets enter a country via rail, road, or sea, dependent on the geographical location. As a result, the qualities and quantities of the various streams mainly entering a country are difficult to determine. Hence a key question for starting countries:

- How can one get a first estimate of the e-waste volumes entering (and leaving) the country?

The aim of the investigation is to derive a first sketch of the main flows and connected values. In this case, looking for scientific precision is not at stake. Countries that import significant volumes probably already have an organized but largely informal domestic e-waste market. Here is it important to understand the mechanisms and values of importation in order to intervene properly. Actual trade flows are commonly a mixture ranging from waste products with very low values to significant product volumes with substantial remaining lifetimes (Huisman et al., 2017). Here an initial investigation at key entry points at the country's ports and main roads, in cooperation with customs and port officials, is a possibility (Odeyingbo et al., 2017). Analysis of the Countering WEEE Illegal Trade project (Huisman et al., 2015) illustrates that logistics costs are key and are driven on one hand by avoiding sorting and purchasing costs at the source, and on the other by maximizing product resale value, including the possibility of repairs, at the destination. Nevertheless, the net result is often too much importing of low-quality products and an indirect contribution to waste generation after the product's short last use in the destination country.

Developing a first factual basis is helpful for gaining a better grasp of the situation. This can be started with a relatively simple national stock-and-flow model that can include three parts of what is essentially the first version of a country study:

1. Develop simple mass balances starting with the net domestic consumption of new products. Here the *UNU Global E-waste Monitor* (Baldé et al., 2017) provides an initial assessment for almost all countries in the world. This can be complemented by and compared with basic sales data for a limited number of products such as computers, mobile phones, TVs, and refrigerators. Sources of information also include data from

producers, market analysts, and international organizations that focus on IT products and general economic development, such as the ITU, World Bank, IMF, and sometimes the country's own trade statistics.

2. To develop collection systems, a useful approach is to start with small pilot projects in, for instance, dense population areas and/or simultaneous collection from government offices, schools, and academic institutions. For one of the earliest examples, see the work of Ploos van Amstel (1997). In many countries these projects, with the financing of collection above market value or with agreements to voluntarily hand over specific product volumes, provide great insights into the types of products that will return, and importantly they also generate the first volumes for testing various dismantling and mechanical recycling processes on a small scale to be established later at larger facilities. These pilot projects are instrumental in moving away from theoretical discussions about the level of financing needed for collection and recycling to a more fact-based and informative situation.
3. The size and routing of import flows, for instance second hand trade via ports, can be assessed. Here also, existing approaches such as the Person in the Port project involve port authorities in monitoring the size and qualities of imported volumes (Odeyingbo et al., 2017). Where any import data are missing, another possibility is to conduct a rather simple assessment of the product stocks in use and hibernated at households by means of simple questionnaires for a limited number of types. Here identifying suitable researchers or market intelligence companies is a good step toward developing a small but dedicated research basis at knowledge institutes interested in taking up this challenge in the future.

The qualitative information and updated market and stakeholder descriptions of Section 2.7 concerning the actual functioning of the informal collection system, when it exists, can be included. This provides insights for understanding why certain products are traded away and against what prices. The outcome of the analysis is relevant for measures to be taken later and the costs associated with their implementation.

3.2.2 Emerging countries

The majority of emerging countries have not yet constructed any "mass balances" regarding possible volumes. Typically, although some e-waste is collected, it is nowhere close to potential volumes. Information regarding amounts flowing in and out of the country is usually scarce. Moreover, reported collection volumes are commonly for the lowest value materials, or only a limited number of product types are collected. Hence, a second more elaborate type of assessment is at stake here for emerging countries.

Therefore, the following key question could be answered for emerging countries:

- How can one get better data for all complementary e-waste flows?

The next steps are specifically recommended (when not done already):

1. One can set up national research consortia, with researchers taking a lead on first developing a more comprehensive e-waste stock-and-flows model. Here Wang et al. (2013) describes various model setups dependent on available data. Some emerging countries have already performed elaborate studies. Hence some examples (Huisman et al., 2012; Magalini et al., 2012, 2015) provide valuable lessons on how to approach this in the context of an emerging system and how to find interested researchers to develop this and take use of the tools and basic methods, as described by Wang et al., (2013), to a national level.
2. One can develop a more elaborate stock-and-flow model. Here the discussion can also be connected to plans for expanding the scope of products from the first limited scope. It is advised to use more "harmonized" e-waste classifications, such as those developed by Baldé et al. (2015) and Forti et al. (2018) from the beginning. This simplifies the assessment of waste generation potential and makes the input data and output results compatible with those of other countries; it also allows for structured monitoring of collection performance over time. In cases where life span information is missing, life span parameters from other countries with similar economic and trade situations can be used as proxies to construct a national stock-and-flow model. For model choices, one can find more detailed information in the work of Wang et al. (2013).
3. It can be complicated and time-consuming to find more detailed information beyond what is available from emerged collection channels. For determining the quantities involved, more elaborate consumer surveys in a reproducible format are likely needed (see also Schluep, 2012) as well as the determination of POM data from national statistics, producer or branch organizations, and trade statistics (Baldé et al., 2017). Regarding collection data, age information for equipment in stock or in the collected waste stream provides data for determining equipment life spans.

4. The most complex task is to gather information on the whereabouts of equipment collected outside of designated systems. Due to the widely distributed nature of e-waste volumes traded, one will find it impossible to track the fate of all volumes. However, targeted market assessment of the most representative items allows one to derive a rough quantitative assessment. In particular, receiving collection data for complementary channels may require substantial effort in reaching out to and building trust with metal waste traders and recyclers who are operating outside of designated channels (Huisman et al., 2012). It is highly advised that the assessment is started in a cooperative manner to ensure that the most relevant actors are thinking about how to increase reported volumes and improve transparency in the end-of-life chain. Specific cooperation with reuse organizations, waste traders, recyclers and their organizations, and professional e-waste handlers is instrumental for receiving information. The task may provide an opportunity to start establishing improved stakeholder discussions or even a national monitoring council with the most crucial members represented. The quantitative focus can be accompanied by semiquantitative assessment of the values of different products and components, and ideally the qualitative drivers behind complementary trade.

3.2.3 Established countries

For established countries that lack a national monitoring council, that have no country assessment, or are in need of better information than currently available, the steps of the previous section can still be implemented, provided that one additional key question is tackled:

- What data are available regarding the quality of collection amounts, and the scavenging of products and components in particular?

1. When stock-and-flow modeling from the previous round exists, a more comprehensive and reliable version can be created. In particular, measuring the stocks in society again can significantly increase the confidence in waste generation numbers. This forms the basis for determining the percentages collected and reported versus the share that is not. When a pool of established researchers already exists, the focus of such a round can also be on the quantities residing in businesses. This also counts for more professional types of equipment that are even

more distributed and generally present in small amounts in a wide range of dedicated applications. One can also benchmark market inputs, waste generation, and collected volumes internationally when similar models and product classifications are used and applied, for example, in the *Global E-waste Monitor* (Baldé et al., 2017), the EU's *WEEE Forum Key Figures* report (WEEE Forum, 2010–2017), and the common methodology for measuring the collection target developed for the European Commission—DG Environment (Magalini et al., 2016). This enables the transfer of valuable lessons from one country to others in the same region.

2. Especially where multiple compliance schemes and organizations are responsible for collection, it is recommended that one national monitoring council or working group is formed. When not done already, such a council preferably also includes government officials, recyclers, and trade organizations in developing a joint monitoring framework. More important, the identification of main leakages and types of undesired trade, export, volumes discarded with other municipal solid waste, and high-value items in low-value mixed scrap allows for better intervention in collection channels. When collection amounts can be tracked in relation to individual municipalities, monitoring and benchmarking of these volumes (normalized in kg per inhabitant to compare per capita; see Huisman et al. (2012) for an example) supports identification of other trade channels. This in turn supports interventions and the banning of illicit trade by means of enforcement. Examples and recommendations for developing such monitoring, including the exchange of information between enforcement agencies, is available in the recommendations section of the *Countering WEEE Illegal Trade* report (Huisman et al., 2015).

3. In addition, sometimes clearing houses exist for assigning individual shares of collection to compliance schemes and recyclers. Here ad hoc tools can be used and linked to national monitoring to determine the share of individual compliance schemes to the national totals to fairly assign collection targets and cost shares to individual schemes. By jointly providing data for and analyzing the results of a national complementary e-waste flows model, one can identify actual volumes to a much higher degree.

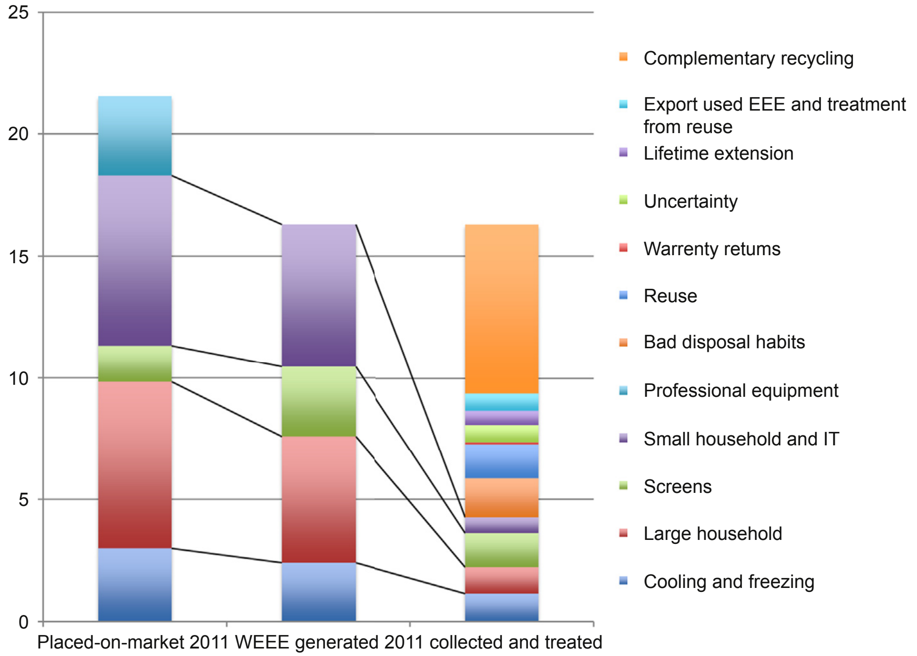
4. It also advisable to develop a specific scavenging index for the country for tracking the removal of valuable and environmentally relevant items, in particular the scavenging of refrigerator compressors, which lead to significant environmental pollution and climate warming in the very early stages of collection (Magalini and

Huisman, 2018). This also significantly affects the value of contracted collection volumes, thus feeding economic market distortion as will be discussed later in Section 3.4.

3.2.4 Examples of e-waste quantifications

A first example of such fact-finding for various EU countries can be found in the UNU country studies for the Dutch (Huisman et al., 2012), Italian (Magalini et al., 2012), Belgian (Wielenga et al., 2013), French (ADEME, 2013), and Romanian (Magalini et al., 2015) collection systems. As an example of the fate of e-waste in Italy, the following Fig. 3.1 is presented.

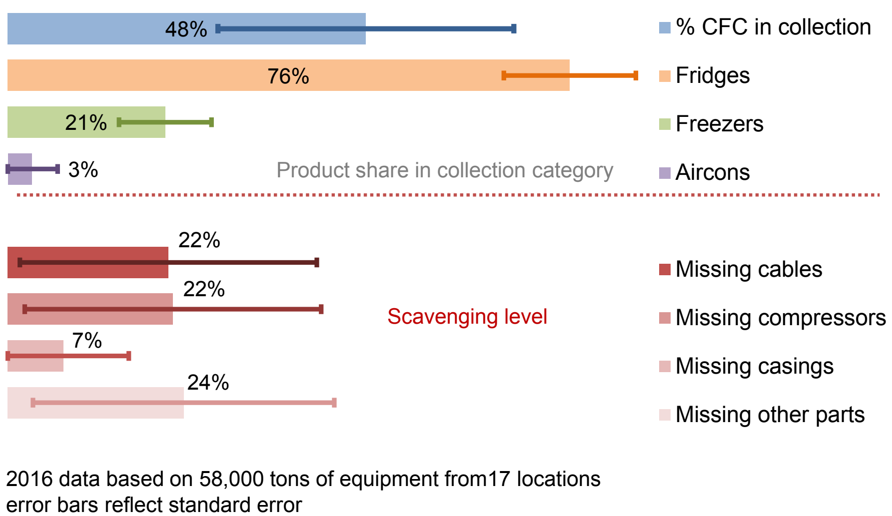
The left side of Fig. 3.1 shows the quantities placed on market, which add to the stock of consumers and businesses. The middle bar shows the waste generation potential, and the right bar shows collection amounts in both reported and complementary channels for a selection of countries. Highlighted on the right side is the magnitude of reported and nonreported quantities for Italy in particular. The results clearly show the role of the consumer at the beginning of the trading and collection chain for WEEE



■ **FIGURE 3.1** Example e-waste quantification, Italy 2011, in kg per inhabitant (Magalini et al., 2012).

not collected and ending up in residual solid waste and all sorts of reuse and export destinations. Based on such fact-finding approaches, respective producer responsibility organizations, recyclers, and governments are considering collection intervention options that improve national performance. Results from the studies behind Fig. 3.1 are improving stakeholder cooperation in changing the reporting conditions and ultimately improving control over collection and treatment. For example, in the Netherlands the mechanism of paying for e-waste collection has changed into a more efficient and less market-disruptive payment mechanism for reporting treated quantities outside the system when they are processed according to standards. More information on this "all actors report" approach is presented in Section 4.2.3.

A second example showcases the large differences between regulated and reported parts of national e-waste systems and the nonregulated/nonmonitored sections related to the scavenging of products, materials, and components from the reported collection stream. Based on research by Magalini and Huisman (2018), the scavenging of both products and components "missing" is measured based on 13 companies that provided sampling information for 465 ktons of collection volume was well as collection details for 51 collection category−country combinations that are well distributed throughout Europe. An example of the result for the scavenging of cooling and freezing (C&F) appliances is presented in Fig. 3.2. The graph shows significant volumes of



■ **FIGURE 3.2** Scavenging of cooling and freezing appliances, 2016. *From Magalini, F., Huisman, J., February 2018. WEEE Recycling Economics, Study Commissioned by EERA, Bonn, Germany.*

CFC refrigerator compressors being removed prior to treatment, leading to significant ozone-layer depletion and global warming impacts and thus the clear need to continue intervening in the trade of such compressors in established countries.

The above example demonstrates, first of all, that although CFC-containing C&F appliances were phased out from entering the market decades ago, the share in later waste generation is still significant. This ratio, as illustrated by the error bar, ranges from roughly 35% for richer countries to 70% for relatively poorer countries. The average EU share has dropped with roughly 10% compared with 4 years earlier (Huisman et al., 2015). From the volumes reported, around 20%–25% on average is entering treatment facilities without the compressors. Unfortunately, this percentage is higher for poorer countries with a relatively higher CFC share. The example is not only economically relevant, as the scavenging of cables further reduces the material value of the reported flows, it also illustrates that reporting only in weight does not reflect the underlying environmental priorities. In this EU example, besides ozone-layer depletion, the global warming effect of the CFC emissions is substantial. It equals an amount equal to roughly eight million tons of CO_2 equivalent, or the annual emissions of six million passenger cars on the road.

3.3 TREAT BETTER—RECYCLING INFRASTRUCTURE AND INNOVATION

Appropriate treatment of e-waste can contribute to both the prevention of serious environmental damage and to the recovery of valuable materials, especially for metals. The actual treatment steps usually comprise two stages: (1) preprocessing, which includes sorting and dismantling, and (2) mechanical separation and end-processing of fractions obtained from preprocessing into commodity materials again, such as individual metals produced by smelters and refineries and plastics from specialized facilities. In Section 4.4, as well as in work from the SRI project (2018), more information is provided on the various forms of preprocessing and end-processing technologies for different fractions.

Generally speaking, improving the recycling infrastructure has multiple aims: gain control over potentially toxic components in an environmentally sound manner; recover valuable material maximally; prevent health and safety concerns for workers; and compliance with various social aspects that have impacts in local and national contexts. Obviously, countless configurations of treatment practices exist in different parts of the world, ranging from relatively simple manual work to more automated mechanical treatment to very advanced automated end-processing of metals, plastics, and complex or toxic materials. A country's entire configuration of processes and the logistic flows between them, referred to as the combined recycling infrastructure, thus ranges from basic, scattered, and informal in starting countries, toward greater automatization in emerging countries, to advanced and well-configured processing with significant economies of scale and investments that provide high environmental and economic performance for established countries.

3.3.1 Starting countries

One obviously cannot abruptly transform a basic treatment infrastructure into an advanced one overnight. It takes considerable time to acquire the necessary capital, building, and human resources and deploy them in practice. Hence the aim of this step is to determine how treatment can be improved gradually under country-specific conditions. Therefore, the specific goals that depend on development status are rather distinct and are thus also the key questions. For starting countries, specific key questions are:

- What are current treatment practices for e-waste, both formal and informal?
- How can fractions be steered to end-processing locally, nationally, regionally, and internationally?

Many sources describe all kinds of technologies available for e-waste treatment. However, the beginning for starting countries is to organize and upgrade existing, scattered dismantling operations into a more structured configuration. This creates, on one hand, better health and safety protection for workers but also some initial economies of scale for **both valuable and toxic fractions at the same time**. Following the UNU-initiated Best-of-2-Worlds (Bo2W) approach (Wang et al., 2012), the right balance needs to be found between funding slowly professionalizing dismantling activities that steer value recovery from e-waste, to secondly funding control over the most environmentally relevant rest fractions simultaneously. These fractions, such as CRT glass, mercury-containing components, and batteries, commonly have negative economic values. Therefore, a key challenge is to find local, national, regional, and international markets and buyers for both components at the same time. Groups of smaller countries or regions can alternatively team up to achieve economies of scale. A key step in the assessment phase is to search for these outlets and determine what the logistical challenges are in getting these materials to the right end destinations. Here collection pilot trials can provide a first physical stream as test case material for determining national cost levels, logistical needs, and administrative challenges when sending out test batches of, for instance, printed circuit boards and batteries to destinations outside their country of origin.

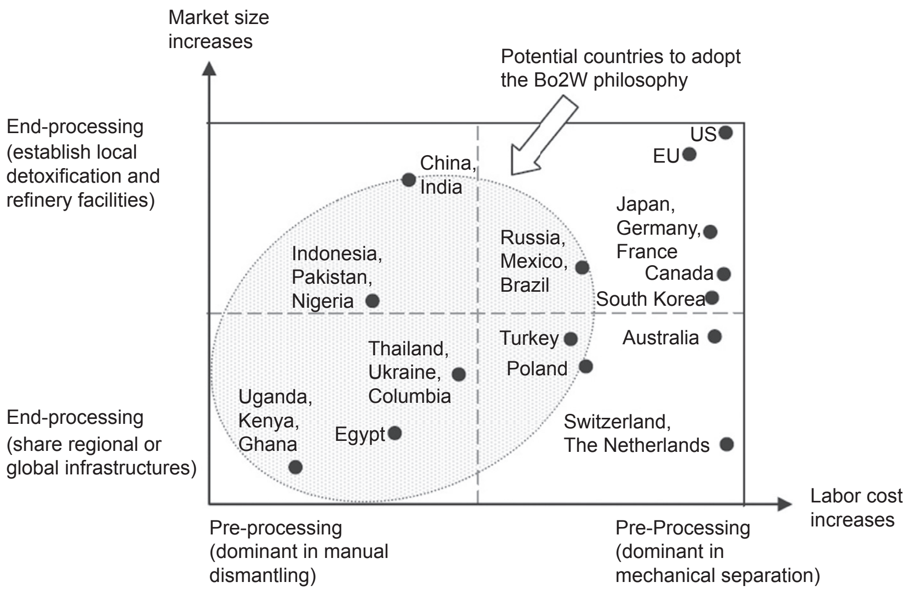
Specific tools, recommendations, and experiences can also be found from the UNU-coordinated e-waste academies for academia, managers, and policy-makers in the field (UNU, 2018), in particular the toolkits developed. In addition, the Bo2W original publication notes various applications in countries; for instance, by NGOs such as Worldloop (Worldloop, 2018) and the Oko-Institut (Manhart, 2015) with more elaborate organizational activities in concept implementation. Moreover, various development projects from the German GIZ contain experiences from transforming large informal sectors into more organized sectors to allow for better health and safety protection, increased values from better organizing trade, and improved workers' rights in general (Gunselius, 2017). More technical guidance on what technology options are available for separation are described in Section 4.4 under Technologies and Skills.

3.3.2 Emerging countries

For emerging countries, a key question with regard to developing treatment infrastructure is:

- How does one find the right mix between dismantling and mechanical processing?
- How does one efficiently organize the trading and logistics system in such a way that the critical fractions land at the proper end-processing facilities?

The below Fig. 3.3 shows, on the vertical axis, the possibility for developing larger-scale end-processing stages dependent on sufficient nearby volumes, logistics, and economic investment capacity. The horizontal axis shows the possibility for more manual dismantling-oriented processing versus more mechanical treatment, which is also largely dependent on country labor costs.



■ **FIGURE 3.3** Use of preprocessing and end-processing in various countries. *Wang, F., Huisman, J., Meskers, C.E.M., Schluep, M., Stevels, A.L.N., Hagelüken, C., 2012. The Best-of-2-Worlds philosophy: developing local dismantling and global infrastructure network for sustainable e-waste treatment in emerging economies. Waste Management 32 (11), 2134—2146.*

The above Fig. 3.3 from Wang et al. (2012) gives a first idea for various countries with respect to the current types of preprocessing and end-processing. The UNEP report “Recycling: From E-waste to Resources” (Schluep et al., 2009) shows specific evaluations for different groups of countries as well as barriers to the successful transfer of sustainable e-waste recycling technologies. As the treatment of e-waste is the core physical activity for achieving higher sustainability levels, it is noted that for emerging countries, some important boundary conditions require attention.

There is an inevitable limit to economic value for some e-waste categories, meaning that formal treatment is not automatically reaching breakeven economically. In some cases, the value of treatment can also cover some financing of fractions with negative values related to the purchasing, logistics, and storage, removal and control of toxic materials, and recovery of materials with relatively little value such as plastics. However, revenues from secondary materials often are not sufficient to cover all costs accruing through the entire treatment chain. Secondly, the main risk when implementing the Bo2W approach is that when not applied integrally as intended, it only leads to optimized cherry-picking activities. Therefore, the risks for stakeholders engaging in proper recycling are still high without a financing system and policy support as a safety net to cover systemic deficits. In societies, environmental policy and recycling standards can facilitate the e-waste streams to proper channels for safe treatment. In addition, environmental value recovered from proper handling is to be encouraged or compensated for by policies that will avoid such cherry-picking. Without these preconditions, practicing Bo2W in developing countries will only have temporary success and lead to insufficient economic performance at a limited treatment scale in the long run.

As experienced in pilot projects, a significant challenge to setting up an eco-efficient treatment system is to create trust between stakeholders. This is highly relevant for the relation between various end-processors at the end of the treatment chain toward dismantlers at the beginning of the chain. The latter are free to determine the destinations for their secondary streams. Alternative outlets in the informal market can offer higher prices due to inferior environmental performance at the same time. Selling valuables to the informal market, or not properly considering the waste after treatment, harms the flow to environmentally preferred state-of-the-art end-processors. A direct way to strengthen cooperation is to file formal contracts between (groups of organized) dismantlers and end-processors with explicit stipulation of material delivery and treatment quality while excluding informal recipients for the same fractions. Hence a key part of the assessment is to invest in the upgrading of fractions from secondary origin and find better connections for larger volumes into national industries and international trade networks in case they are more efficient for more complex materials.

The Bo2W philosophy aims at a net stream of hazardous and precious metal fractions to the best state-of-the-art end-processing facilities available. Here the Basel Convention and the administrative load related to transboundary shipments, in particular for flows of hazardous fractions from dismantling facilities in developing countries to dedicated end-processing facilities in developed countries of such fractions, needs to be streamlined (Huisman et al., 2015). Economically, these costs are not that high in comparison with total system costs due to relatively low volumes with only a small portion of the fractions going to advanced end-processing. However, due to the administrative load, the costs per ton for the few containers involved are likely to be very high. Here it is not against the principles of the Basel Convention (Basel Convention, 1989), which exclusively restricts the shipment of e-waste from OECD to non-OECD countries. The Bo2W approach is therefore to be regarded as a transitional and complementary solution for developing and emerging countries and for countries that are just too small and lacking capital-intensive refineries and hazardous waste treatment facilities (Wang et al., 2012).

Often, the monitoring of collection and treatment processes is developed over time in emerging countries. However, there is a structural difference between mandatory reporting of compliance by the recycling sector, and monitoring for the purpose of tracking national performance over time in a more comprehensive manner. For individual compliance checks, the advice is to develop reporting, control, and auditing tools—for instance, like the WEEE Forum REPTOOL—to track the destinations of fractions, the actual level of control, and recycling efficiencies (WEEE Forum, 2018). At the same time, it is recommended that a national (and where needed anonymized) aggregation of such results is started to track progress, realize comparison of treatment performances, and measure the effectiveness of the policies and interventions that will be further discussed in Chapter 5.

3.3.3 **Established countries**

Not only in developing countries, but also in established ones, the e-waste recycling industry is, generally speaking, rather immature. Schluep et al. (2009) states: "*The main barriers originate from the lack of specific legal frameworks, low national priority for the topic, conflicting existing legislation and uncoordinated enforcement of the law. With regard to technology and skills, barriers are primarily defined through the lack of EHS standards, the strong influence of the informal sector, the lack of collection infrastructure, cherry-picking activities and low skills and awareness. Additional barriers assigned to business and financing topics include limited industry responsibility, high costs of logistics, possible exploitation of workers from disadvantaged communities, crime and corruption and false consumer expectations*." These barriers underwrite the need for a more holistic e-waste development cycle as well as much more attention to the sophistication level of the treatment infrastructure itself. The development of infrastructure and technical knowledge is an important element in overall take-back system performance. The outcomes are relevant for enabling key priorities for policy development and ways to improve toward more eco-efficient recycling.

For established countries, a rather different key question applies:

- How can we reward higher quality of treatment and stimulate innovation, in particular for recovery of hazardous and critical raw materials?

Most established countries have many technological options and usually rather optimized configurations for economic value recovery. At the same time, minimum treatment standards and protection levels for depollution are implemented. However, there is rarely an innovation and improvement agenda that goes beyond these minimum levels, and financing for additional efforts is rarely provided. Hence it is recommended to look into improved depollution and recovery of critical raw materials via alternative financing mechanisms and rewards (Magalini and Huisman, 2018). One example here is, for instance, to build in more direct technical performance requests in procurement contracts between recyclers and producer organizations. Obviously, in order to establish this, both the quality and the volumes need to be understood (from the previous step) in relation to the technical capabilities of the recyclers present. This topic of more focus for increasing recycling levels is further elaborated in Section 3.5, after the next environmental impact assessment part. This is because technical capabilities and environmental priorities need to be combined before elaborating on the economic impacts and thus the efficiency of the options available.

3.4 POLLUTE LESS—ENVIRONMENTAL IMPACTS

Impact assessment is an important step in identifying the societal consequences of e-waste and specifically for finding improvement potential and priorities for (re)defining policy objectives and where to interfere or not.

Hence, a key question for all three country types is:

- Step 3: What are the societal impacts (environmental, economic, and social)?

3.4.1 Starting countries

For starting countries, impact assessment can be rather basic. Here, following the problem analysis from the initiation phase, it basically focuses on getting additional basic facts and figures beyond the already known issues from the country assessment, in a more structured way. Hence a key question is:

- What are currently the most pressing environmental issues associated with e-waste?

Commonly for starting countries there are two core issues. One is the presence of already polluted sites requiring remediation. The second is to stop the continuation of such pollution by arranging collection and effective toxic control in treatment. Assessment of polluted sites is often requiring substantial effort. An inventory of the sites and determination of remediation actions requires the mapping of locations, volumes, and types of pollution. Important here is to distinguish the remediation and cleanup of existing sites from diverting flows and professionalizing recycling activities to less polluting levels. For the latter, depending on government priority-setting towards very local pollution, the first resources should be spent on banning the most harmful practices such as acid leaching of circuit boards and burning of copper wire. Secondly, finding the right and first outlets for further treatment of, in particular, the complex and hazardous fractions from treatment belong here as well. Many practical experiences and training materials can be found in the UNU e-waste academies toolkit (Magalini et al., 2012).

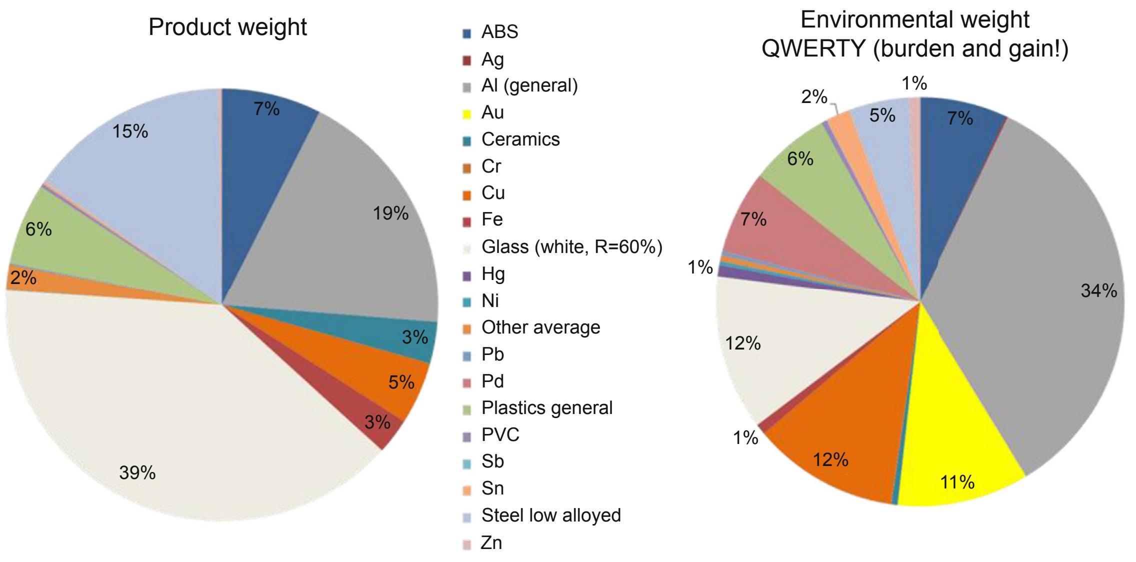
3.4.2 Emerging countries

For emerging countries, assuming more directly polluting activities are already reverted, the role of environmental impact assessment is somewhat different. Here a key question is:

- How does one set priorities beyond basic treatment for the various e-waste collection categories?
- In which channels should preprocessing fractions end up to achieve maximum environmental performance and economic value recovery?

To enable improvements in collection and treatment, a more elaborate environmental impact assessment can either be performed in the country itself, or outcomes from existing studies representing similar conditions can be learned from. The key is to focus on improving the destination and treatment of the environmentally most relevant fractions that are different per collection category. Secondly, various technical improvements can be evaluated from an environmental point of view, supporting and also setting initial sets of standards for logistics and treatment. The impact assessment framework is advised to be conducted not just as one-off studies, but also to keep track of performance over time, especially in terms of a weighted index for the level of control over toxic substances.

In this regard, various approaches and sector-specific impact assessment tools have already been developed for Europe and can be mirrored elsewhere. The QWERTY/EE tool is a software tool developed at TU Delft that evaluates the environmental and economic impacts of electronic products in the entire end-of-life chain (Huisman, 2003; Huisman et al., 2003). QWERTY stands for quotes for environmentally weighted recyclability. The EE stands for eco-efficiency. The general idea is based on environmental and economic quantification of three values. The minimum impact values (environmental and economic) correspond with the theoretical scenario of "all materials being recovered completely without any environmental impact or economic costs of end-of-life treatment steps." The maximum values are defined as the theoretical scenario of "every material ending up in the worst possible (realistic) end-of-life route." And finally, actual recycling scenario values are based on the environmental and economic performance of the end-of-life scenario under consideration and are compared with the prior two boundary values. The outcome can be expressed as percentages or in absolute numbers and be tuned to the national conditions or impact assessment themes desired as highlighted in Fig. 3.4 below. The outcome for either individual products, collection streams, or even all e-waste in the national territory can be used as weighted and thus prioritized indices tracking past and ongoing performance over time. An example outcome for a flat-panel TV is displayed above. It can illustrate effectively the priorities of different



■ **FIGURE 3.4** Weight vs. environmental weight of a first-generation LCD TV (Balkenende et al., 2014).

materials such as trace amounts of precious metals, not just according to physical weight but rather as environmental weight to total product and even complete collection flows. In addition, the calculations describe the main causes of environmental losses and recoveries related to the materials present and thus form the basis of prioritization in the case of material substitutions.

Based on the QWERTY/EE tool modeling the entire end-of-life chain (Huisman, 2003), an important shortcoming of general weight-based approaches as applied in traditional weight-based recycling targets is revealed. The approach allows for alternative prioritizing of different improvement options in the system. Moreover, due to weight-based targets, a substantial amount of documentation and reporting effort is focusing on what is entering treatment facilities, whereas actual performance is mainly determined by final end-processing efficiencies. Therefore, the QWERTY methodology, based on large-scale modeling of the e-waste collection, logistics, preprocessing, and end-processing chain, is later also applied, for example, in the EU revision of the WEEE Directive. A key lesson from this application for Europe is the considerable variety in environmental themes per treatment category due to different occurrences of the substances of environmental concern identified in the study (Huisman et al., 2008):

- toxicity effects most dominant in various environmental impact categories for flat-panel TVs and monitors as well as for energy-saving lamps due to their mercury content;
- avoid ozone-layer depletion and global warming potential due to the presence of CFCs in C&F appliances;
- resource depletion aspects, in particular for richer products such as small IT, laptops, tablets, computers, and mobile phones.

This rather condensed description of outcomes illustrates the role that structured impact assessment work can play, ultimately directly and indirectly proving essential guidance for options related to collection targets, separate treatment, and development of standards. Over the course of years, many of the options underpinned by the impact assessment have been adopted in the revision process of the WEEE Directive.

For other emerging countries, dedicating resources to environmental impact assessment also helps to set more targeted goals such as material-specific requirements per collection category and to avoid general policy tools such as using generic weight-based recycling targets for all e-waste types that do not reflect the actual environmental priorities. Also, in relation to the next economic chapter, a better balancing between economic costs and environmental benefits is then made possible.

3.4.3 Established countries

For established countries, despite all knowledge and implementation efforts, weak points and suboptimal solutions remain. Very commonly, environmental impact assessments are not made or updated, despite significant expenditures in running take-back systems. Thus a key question is:

- How does one optimize the environmental performance of the formal e-waste system?
- Where is progress possible by incorporating complementary collection and recycling channels?

A common weak point is the impact of scavenging, complementary cross-border flows, and lower than desired actual levels of depollution when reported on a national level. Despite this, not many countries investigate with a more structured impact assessment that evaluates societal benefits against the costs of the system at large. Research can be costly but also can lead to significant benefits and savings. Assessment can support the removal of unnecessary requirements or changing more generic ones such as the aforementioned weight-based targets to more sophisticated material-related ones, in turn also supporting the development of reporting and treatment standards. For instance, in case of a product scope that is too elaborate, collection and recycling can also economically and ecologically function for certain types of equipment without legal requirements; for instance, in cases where toxicity levels are reduced drastically by product designs that have substituted hazardous materials with other (valuable) materials. This also counts for other cases where the principle of proportionality is violated, such as for certain professional equipment produced in very low numbers with long life spans and very high reuse and social value, such as specialized medical equipment moving to hospitals in developing countries. Here, keeping such products in scope leads to adverse societal effects. For more established systems, optimizing the balance between environmental aspects and costs is more relevant, and hence more information on eco-efficiency approaches is provided in the following section.

3.5 PAY ADEQUATELY—ECONOMIC IMPACTS

Economic impact assessment runs similar to the environmental one and contains the same sophistication levels. Determining economic value related to e-waste and reusable EEE flows supports options to reduce costs, including administrative burdens for actors involved, and promotes more collection and higher quality of treatment.

3.5.1 Starting countries

For starting countries, usually very little to no information is available on the level of financing needed to get started, and hence a key question is:

- How much funding is needed for setting up an initial basic collection and recycling infrastructure?

In the very early stages of e-waste system development, access to funds for initiating the first activities is crucial. Therefore, the key questions posed here purposely do not include the kind of financing system needed or who should pay for what, nor who in the long run should control the funds collected. System development starts better with actual funding to test and start up some basic collection and treatment infrastructure and the collection of the key facts on the actual costs of various operations. Generally speaking, widespread discussion on these questions between key stakeholder groups as a first activity is frequently observed to be negatively contributing to actual solutions. As proposed in Section 3.2.1, ideally one could directly start with a collection and treatment pilot with relatively well-defined and representative volumes and practices. From such a pilot project, initial cost figures can be derived for the key factors: cost of acquiring the waste, residual value of components and materials with reuse values, costs for logistics at and from collection points, capital costs for simple processing steps, costs for dismantling by measuring average times per step by workers including depollution, values for the actual prices of valuable (metal) fractions, costs for nonvaluable (like plastics) and hazardous fractions (like CRT glass, batteries), and initial estimates for the share of these in total tonnages as well as the costs of export to more advanced facilities when not available in the country itself. Finally, management and reporting costs should be roughly determined and can be corrected assuming larger economies of scale in the near future.

Again, in the e-waste academies toolkit (UNU, 2018) and various development projects mentioned on the StEP Initiative website, some particular initial information is available on the (reuse) value of various equipment types, which is a key threshold for collection. Here it should be attempted to discriminate between such residual reuse value versus the material value of actual waste products, fractions, and components. Removing some first barriers to steering existing collection is needed for establishing e-waste dismantlers. Regarding dismantling, small technology investments can provide large improvements, such as assisting in buying better equipment such as cable strippers to avoid (less and less widespread) burning of cables and more pure copper recovery. In other cases, financing is needed for banning the most pressing pollution types such as acid leaching of circuit boards and the burning of plastic residues by means of more on-site monitoring and enforcement.

3.5.2 Emerging countries

For emerging countries, financing should increasingly focus on payments for both scaling up volumes and providing funds for fractions that are not economically viable for collection and recycling. Hence a key question here is:

- How do we steer the financing more efficiently to the parts in the chain that are cost negative, in an eco-efficient manner?

In the starting phase, funding should be addressed toward the collection and treatment of smaller (pilot) quantities in order to get an initial understanding of the total chain. In a second development cycle, this should be changed toward moving away from financing profitable steps when economies of scale are slowly realized. For emerging countries a balance should be realized in time between local initiating actions versus realizing higher economies of scale via more mechanical treatment and upgrading of secondary streams. This also allows those parts of the markets to mature where possible without financial intervention. At the same time, however, the quantities of fractions with negative values need toxic controls to receive more structural payments. Here again, without assessment, updates to financing cannot be made due to a lack of key economic data. Specific attention should be given to further optimizing the level of dismantling versus mechanical processing over time, as often labor costs are increasing and economies of scale can make mechanical processing more attractive. Hence more continuous assessment is recommended, including shifting the focus from making the system effective toward making the national system eco-efficient. Hence a close connection to the environmental impact assessment is next.

3.5.3 **Established countries**

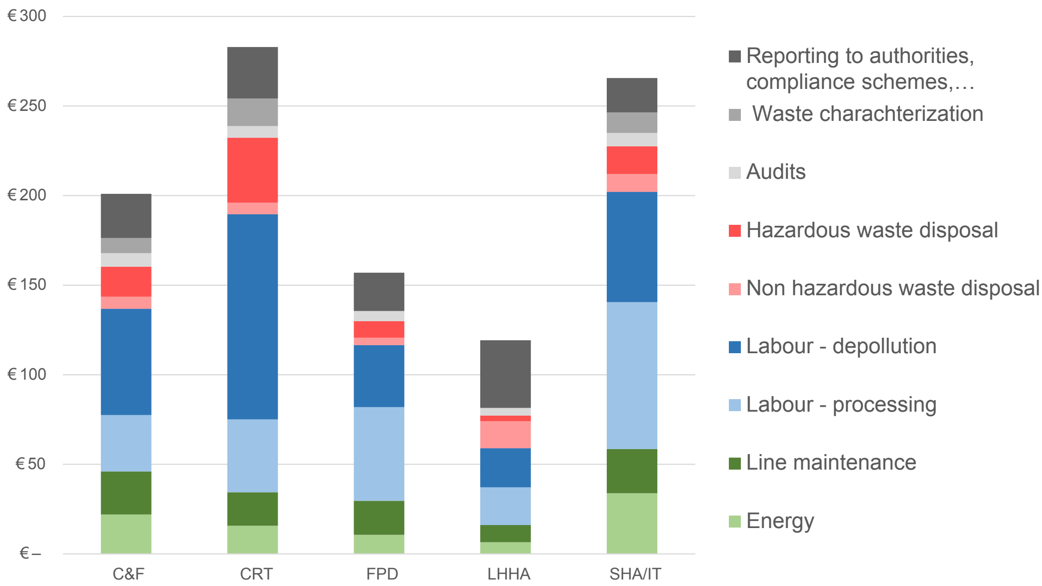
For established countries, not many comprehensive studies exist on the actual costs of compliance and the functioning of the financial system at large in relation to the delivered quality of collection and treatment performance. Usually very little attention is paid to the quantification of compliance costs in reality, and how noncompliance can be avoided when monitoring is not there or only occasional.

Hence a key question here is:

- How do we determine country-specific compliance costs and financing mechanisms to overcome an uneven playing field, in particular for the highest-quality preprocessors?

Although several benchmarks exist with regard to total prices for e-waste treatment in Europe (WEEE Forum, 2010–2017), more attention is usually needed to determine whether finances are indeed directed toward the realization of compliance (Huisman et al., 2006; Huisman, 2013). In particular, when substantial competition exists between multiple compliance schemes in one country and/or recyclers without much monitoring, the economic driver to maximize profits on one hand and cutting compliance corners on the other are created. To illustrate this, the following example is made with cooperation of the European Electronics Recyclers Association recyclers in Europe (Magalini and Huisman, 2018):

Fig. 3.5 is based on 20 confidential and anonymous responses from recyclers, allowing UNU to conduct the survey and to have insight into direct operational costs and their ranges across Europe. These values are direct cost components and not prices, which are determined also by other market conditions, overhead, and capital investments that are excluded here. The initial cost ranges provided were extended when a significant number of responses indicated higher or lower values than presented in a follow-up questionnaire conducted in 2018. The average costs (representing 2016 as the base year) have been calculated considering the mean of each cost interval, multiplied by the number of respondents that confirmed their company costs as belonging to the interval. The results indicate that, for example, for C&F appliances and CRTs, the costs of all reporting combined contributes about 20% of the total operational costs for full compliance, and the costs for full depollution and hazardous waste disposal make up roughly

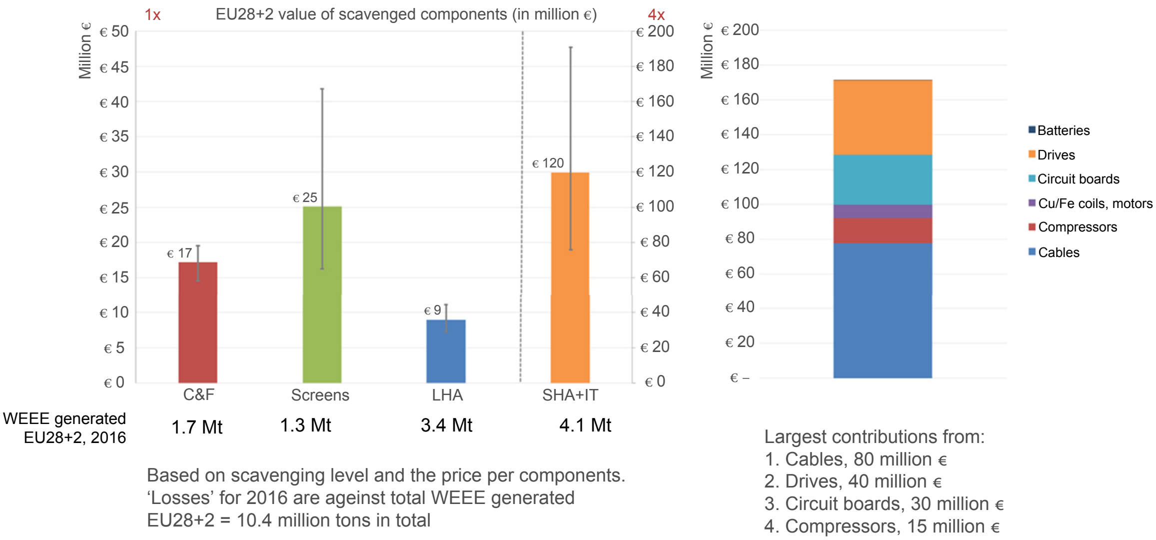


■ **FIGURE 3.5** Cost components of fully compliant recycling in € per ton, 2016 (Magalini and Huisman, 2018). *Presented costs are not total treatment costs per category. Excluded are capital, depreciation, other staff, office costs, etc.

50% for CRTs and 60% for C&F. This illustrates both the attractiveness of avoiding compliance in badly monitored systems and thus that driving costs down by EPR schemes should be capped by understanding better on a national level what a viable cost level is. More conclusions on financing mechanisms and ways to prevent a race to the bottom are presented in Section 4.3.

When collection quality results of Section 3.2 are combined with the outcomes of the other collection categories, the following results are obtained regarding the diverted material value of components being scavenged for the EU as a whole. For the limited number of components quantified, this added around 200 million EUR of material value that is supposedly in the reported side of the WEEE treatment market, which becomes a significant competition distortion element (Magalini and Huisman, 2018). Finally, not all types of scavenging are computed yet. An even larger economic effect is related to the absence of the most valuable products in the return channels. Due to the absence of EU-wide data for all collection categories, this kind of product scavenging index is not yet computed. What is known, though, is that for the Screens collection category compared with waste-generated volumes (Magalini et al., 2016), only 5%–15% of all laptops and tablets, and about 30%–50% of flat-panel monitors and TVs of the supposed volume, are present in the return channels, whereas the so-called relative presence of negative-value CRT TVs would be about 125%−175% if the share of products was similar to the e-waste generation; see (Magalini and Huisman, 2018) for more details (Fig. 3.6).

As illustrated, a common weak point is the impact of scavenging, complementary cross-border flows, and lower-than-desired actual levels of depollution in case this is reported at all on a national level. Despite this, not many countries conduct a more structured impact assessment that targets societal benefits against the costs of the system at large. Research can be costly but also can lead to significant benefits and savings. It can support the removal of unnecessary requirements. For instance, in the case of a product scope that is too elaborate, collection and recycling can also economically and ecologically function without legal requirements—for instance, in cases where toxicity levels are reduced drastically by product design. This also counts for other cases where the principle of proportionality is violated, such as for certain professional equipment produced in very low numbers, with long life spans, and very high reuse and social value, such as specialized medical equipment moving to hospitals in developing countries. Here keeping such products in scope leads to adverse societal effects. That also leads to the next section on eco-efficiency relevant for established countries.



■ **FIGURE 3.6** Total intrinsic material value of scavenged components, 2016, EU total (Magalini and Huisman, 2018).

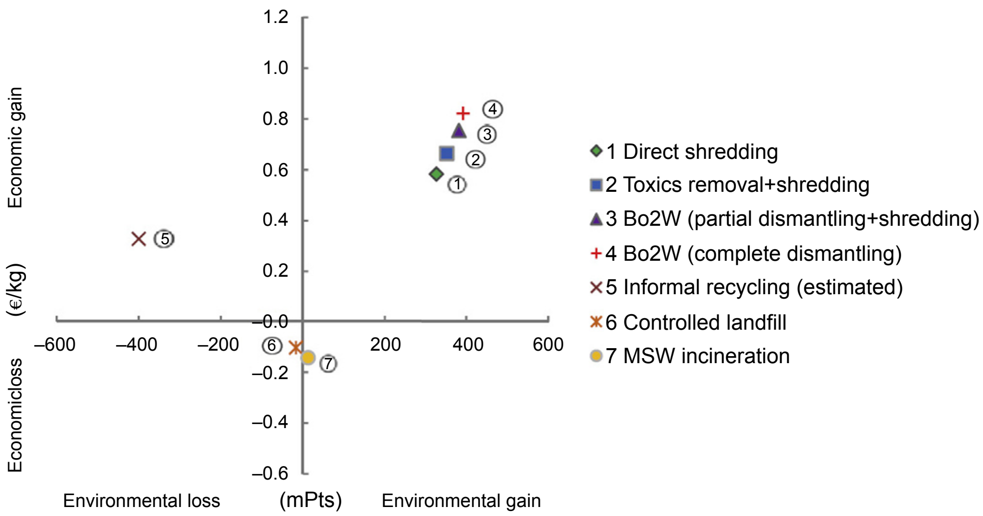
3.5.4 Eco-efficiency: optimizing the ratio between environmental impacts and costs

For established countries, despite all knowledge and implementation efforts, weak points and suboptimal solutions remain. Also for these countries, when both environmental and economic data are available, an additional key question is posed:

- How do we maximize the eco-efficiency of the e-waste system by linking environmental and economic impacts?

By combining the environmental values and costs in one eco-efficiency approach, it is possible to link environmental effectiveness with cost efficiency. This helps answer a central question from a societal point of view: what environmental improvements can be achieved for the money invested? An example of this is presented below in reviewing various options for preprocessing and end-processing under a Chinese context from the Bo2W project (Wang et al., 2012). It shows the various environmental and economic outcomes of various levels of mechanical treatment versus more dismantling as well as disposal scenarios.

Fig. 3.7 shows the basic idea behind the eco-efficiency calculations of the QWERTY/EE approach. The Y-axis represents an economic indicator (in this case €) for total costs along the recycling chain. The X-axis represents the environmental indicator. There are different end-of-life scenarios for the same product relative to a certain starting point (the origin in the figure). Such scenarios or options describe certain changes in end-of-life treatment or the application of certain technological improvements such as redesigned products, other preprocessing options, and separate or increased collection and treatment. In order to achieve higher eco-efficiencies, improvement options should lead to a change from the reference or starting point in the direction of the upper right part. However, options with a direction toward the down-left should be avoided (higher costs and higher environmental impacts), because from the point of reference, a lower eco-efficiency is realized. Fig. 3.7 shows clearly and unambiguously that the various recycling possibilities score much better than disposal and informal recycling options as well. For this particular case in China for 2012 for computer recycling, a full dismantling scenario is the best option among the more formalized options. From this, clear lessons and priority setting can be derived as illustrated for many scenarios developed by Huisman (2003). The application of



■ **FIGURE 3.7** Eco-efficiency of WEEE treatment scenarios in China (Wang et al., 2012).

such eco-efficiency evaluations is a crucial activity in the development and implementation of e-waste policies. It quantifies where taxpayers' money ultimately could be spent best, and where a low return on investment can be expected.

However, theoretical values and eco-efficiency potential are not always exploited. In the case of the Bo2W approach in China, significant export of these critical and valuable fractions did not materialize due to administrative, management, and economic hurdles. The latter effect is mainly due to higher values of, for instance, reusable printed circuit board components compared with the raw material value.

From the application of the Bo2W approach in India (Wang et al., 2012) and other countries (Worldloop, 2018), it is extracted that specific country business models that arrange for efficient payments and shipment of critical fractions to the right destination are desired. This contains both an organizational element to arrange for the administration and logistics and a dedicated financial clearance element. For instance, for fractions sold abroad such as printed circuit boards, one needs control over the quality of the bought materials to avoid cherry-picking of components of cherry-picked remainder board types as well as on-time payment, since informal collectors usually are in demand for direct cash. The logistic advantages originate from having an organization that acts as an intermediary between smaller semi-informal recyclers and integrated smelters abroad. These approaches should include not only circuit boards but also less valuable critical fractions like batteries. Partial implementation of the Bo2W philosophy without taking care of all hazardous fractions leads to undesired "cherry-picking." Hence an organization on the receiving end that takes care of hazardous content is needed, as participating end-processors are not in a position to set up a fully monitored material delivery system.

3.6 WORK SAFER - SOCIAL IMPACTS

Social impact assessment, although rarely executed, is relevant for identifying the link between e-waste and the creation of jobs, of local health and safety issues, and the issue of digital divide. Also, increasing knowledge levels of the general public in general and especially of the need to collect and recycle more, is quite relevant for the long-term success of the e-waste system. In the end, it is the consumer who has to return e-waste and will also pay, no matter how the initial financing has been arranged. The role of consumers in the system and their awareness and willingness to separate and collect e-waste from other waste is therefore crucial. As indicated in the introduction to Section 2.1, development of e-waste systems not only contributes to responsible consumption and production and less waste—UN Sustainable Development Goal (SDG) 12—but also contributes directly or indirectly to almost all of the other SDGs and thus to the multitude of social dimensions behind them.

3.6.1 Starting countries

For starting countries, usually concerns about the health and safety of e-waste (and repair) workers are high on the agenda. A key question here is:

- How many people are currently earning a living in the e-waste domain?
- What are they earning typically now? How many new jobs will be created if e-waste handling is improved?
- What can be improved regarding working conditions?

The meaning of e-waste domain in this regard should also include repair and dismantling activities, which are a substantial part of the economy for many countries. When creating the basic collection and dismantling infrastructure, the challenge is to **involve** these informal sectors in development instead of pushing them outside. Nevertheless, some transfer of jobs will happen when certain undesired and polluting informal practices are banned. Therefore, assessing as quantitatively as possible how many workers may lose their jobs when informal practices are eliminated needs attention. Positively, development means more organization is needed, possible creating additional higher-level jobs and more income for workers. Various organizational forms uniting workers and traders are possible in the form of small SMEs and cooperatives as well as dedicated public–private partnerships. A good source for more information related to the formalization of informal sectors, specific solid waste streams, and worker conditions is available via GIZ (2011) and Bonner (2009).

3.6.2 Emerging countries

For emerging countries, usually worker protections have evolved over time; however, they often still require attention. Secondly, when increasingly more manual work is converted into mechanical processing, the development of a more skilled workforce requires attention. Hence the key questions here are:

- What jobs should be kept, and what new job opportunities are possible?
- What skill developments are needed for this?
- How can health and safety conditions be improved as well as the organization of workers?

Specific assessment of worker safety can be conducted in particular via the starting of auditing and training on the job for e-waste workers. Various tools also exist here, again in the UNU e-waste academy series (UNU, 2018). Such training can be applied from the working level and also toward management, monitoring, and the enforcement domain.

For both emerging and developed countries, information gaps still exist. In most cases, many consumers do not know what an e-waste collection point is or where to find it. In cities, often container parks are far away and difficult to reach for those without a car and who rely on public transport. In the long run, consumer education is an important element for the acceptance of e-waste systems and for proper disposal behavior in particular, as well as for reducing the scavenging levels of components and products to nonreported sections of the metal scrap trade.

3.6.3 Established countries

As a follow-up for developing countries, key questions are:

- How can consumer education be optimized to realize better (quality of) collection?

In surveys conducted for the FP7 project "Countering WEEE Illegal Trade," the recommendation to enhance consumer education in various ways ranked number one among e-waste experts and enforcement agencies (Huisman et al., 2015). Also, in the StEP Whitepaper on guidance principles, this aspect is clearly on the radar screen for successful long-term development (StEP Initiative, 2016). Therefore, it is also recommended to not only conduct awareness campaigns, but also measure which means are most effective by repeatedly surveying the general public regarding their attitude, potentially incorporated in the e-waste quantifications as proposed in Section 3.2 (Schluep 2012; Schluep et al., 2012).

It is important to identify the societal consequences (i.e., economic, environmental, and social aspects) of e-waste take-back and recycling, and specifically to find improvement potential and priorities for (re)defining legislative and other interventions. These are described in the next Chapters 4 and 5, focusing on the second part of the development cycle: the actual drafting, selection, and implementation of policy, financial, and technology interventions, for which the assessment of this Chapter 3 forms an important factual basis.

3.7 CONCLUSIONS

The assessment of **collection** (Section 3.2), **treatment** (Section 3.3), and the related **environmental** (Section 3.4), **economic** (Section 3.5), and **social** (Section 3.6) impacts forms the necessary **factual basis** for understanding the heart of the development cycle with the three key development areas presented in Chapter 4, with Policy and Legislation in more detail in Section 4.2, Business and Finance in Section 4.3, and Technologies and Skills in Section 4.4. After this, the factual basis ideally forms a solid starting point for a national action plan for practical implementation by listing all key intervention options in Section 5.2, the Selection and Prioritization in Section 5.3, and converting this into an implementation roadmap that includes the description of timing and resources needed in Section 5.4. In all these subsequent chapters, the factual basis from this Chapter 3 assessment is a crucial ingredient. Finally, important direct and indirect conditions for successful implementation are listed in Section 5.6 related to Monitoring and Control, Section 5.7 regarding Awareness and Education, and Section 5.8 on the topic of Design Feedback.

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