Case study e-waste management

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1 Background and objectives

1.1 Introduction

The management of waste electrical and electronic equipment (WEEE), or e-waste for short, has only fairly recently been added to the agendas of organisations responsible for waste management. Experiences around the globe have shown that the usual waste manager, the municipality, is not adequately equipped to handle this complex waste stream. Two new paradigms, however, are the principal drivers of change in the management of e-waste: the **„closed loop economy“** and **„extended producer responsibility“** (EPR). Some countries, mainly in Europe (e.g. Switzerland, Netherland and Belgium) started to experiment with new approaches to managing this hi-tech waste stream more than twenty years ago. A new international framework quickly took shape and the roles of important stakeholders dealing with the ‚end of life' of WEEE evolved: producers accepted the end of life responsibility for their products and initiated **p**roducer **r**esponsibility **o**rganisations (PRO) to manage the material flows and the financing of unprofitable processing steps; the recycling industry went through a rapid evolution where specialists emerged for manual dismantling, mechanical processing, final refining of secondary raw materials amongst other tasks; the legislators carefully developed regulations defining responsibilities and promoting further improvement of the systems efficiency; and last, but not least, consumers, from the big corporate to the small household, increasingly wanted convenient and sustainable options for the disposal of e-waste.

In developing countries and emerging economies this new paradigm shift has not become obvious until recently. Eye opening reports from NGOs such as the Basel Action Network [1], [2], [3] or Greenpeace [4], [5] about pollution from e-waste management in China, India and African countries started to appear in the mass media in the early 2000s. Poor people in the slums of the mega cities in the South tried to recover valuables from the e-waste stream but put themselves and their environment at risk [6]. As a result governments in these countries started to move e-waste up their priority list of environmental issues, which needed special legislative attention. In addition, various international cooperation initiatives were launched, including the Swiss e-Waste Programme, a pioneering project launched by the Swiss State Secretariat of Economic affairs with the aim of building “global knowledge partnerships in e-waste recycling” including China, India and South Africa [7], [8]. Meanwhile e-waste remains a high priority area within the Basel Convention and also within Strategic Approach to International Chemicals Management (SAICM). Furthermore the Stockholm Convention has started to address e-waste for management of polybrominated diphenylether containing material streams. Between 2007 and 2010 various international cooperation projects were launched by multilateral organizations (e.g. the Basel Convention Secretariat, SAICM, producers from the ICT (Information and communications technologies) industry, NGOs and governmental organizations.

1.2 WEEE Definition

WEEE or e-waste is often misunderstood as comprising only computers and related IT equipment. According to the OECD, e-waste is ‘‘any appliance using an electric power supply that has reached its end-of life’’. In this chapter, WEEE and e-waste are used as synonyms, and include all the 10 categories (Table 1) as specified in the EU WEEE directive [9] which has become the most widely accepted classification.

No.	Category
1	Large household appliances
2	Small household appliances
3	IT and telecommunications equipment
4	Consumer equipment
5	Lighting equipment
6	Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
7	Toys, leisure and sports equipment
8	Medical devices (with the exception of all implanted and infected products)
9	Monitoring and control instruments
10	Automatic dispensers

Table 1: Classification of WEE according to EU WEEE Directive (European Union 2003b)

1.3 Objectives of WEEE management

E-waste is usually regarded as a waste problem which can cause environmental damage if not dealt with in an appropriate way. However, the enormous resource impact of EEE is widely overlooked. EEE is a major driver for the development of demand and prices for a number of metals as shown in Table 2. Consequently inappropriate disposal of e-waste not only leads to significant environmental problems but also to a systematic loss of secondary materials [10]. Hence the appropriate handling of e-waste can prevent serious environmental damage and also recover valuable materials.

Besides the positive impact on resources, state of the art recycling operations also contribute to reducing greenhouse gas emissions. Primary production, i.e. mining, concentrating, smelting and refining, especially of precious and special metals, is energy intensive and hence has a significant carbon dioxide (CO_2) impact. "Mining" our old computers to recover the metals they contain needs only a fraction of this energy input [10] but it is important that any recovery is carried out in an environmentally sound manner.

Furthermore end-of-life refrigerators, air-conditioners and similar equipment normally contain ozone depleting substances such as chlorofluorocarbon (CFC), hydrochlorofluorocarbons (HCFCs), fluorocarbons FCs and hydrofluorocarbons HFCs which have a very high global warming potential. The environmentally sound management of these wastes can therefore be significant in mitigating the climate change impact.

Hence the main services a comprehensive WEEE or e-waste management system has to deliver in order to ensure sustainability are (a) collection of e-waste, (b) recovery of valuables such as secondary raw materials and (c) segregation and safe disposal of hazardous waste. Costs for unprofitable processes as well as administration, monitoring and control to ensure quality have to be associated with all of these activities.

Metal	Primary production*	By-product from	Demand for EEE	Demand/production	Main applications
	t/y		t/y	%	
Ag	20,000	(Pb, Zn)	6,000	30	Contacts, switches, solders…
Au	2,500	(Cu)	300	12	Bonding wire, contacts, integrated circuits…
Pd	230	PGM	33	14	Multilayer capacitors, connectors
Pt	210	PGM	13	6	Hard disk, thermocouple, fuel cell
Ru	32	PGM	27	84	Hard disk, plasma displays
Cu	15,000,000		4,500,000	30	Cable, wire, connector ...
Sn	275,000		90,000	33	Solders
Sb	130,000		65,000	50	Flame retardant, CRT glass
Co	58,000	(Ni, Cu)	11,000	19	Rechargeable batteries
Bi	5,600	Pb, W, Zn	900	16	Solders, capacitor, heat sink…
Se	1,400	Cu	240	17	Electro-optic, copier, solar cell
In	480	Zn, Pb	380	79	LCD glass, solder, semiconductor
Total			4,670,000		

Table 2: Important metals used for electrical and electronic equipment [11]

* based on demand in 2006; acronyms: PGM= Platinum Group Metals; CRT= Cathode Ray Tube; LCD= Liquid Crystal Display

2 Current status

Currently the only formally tested e-waste management systems adhering to sustainability and extended producer responsibility principles are found almost exclusively in OECD countries [12]–[14].The European WEEE Directive [9], based on the concept of an extended producer responsibility (EPR) as an environmental policy, has beome the de-facto global standard for e-waste management (Figure 1). The associated RoHS Directive [15] aims to reduce the environmental impact of EEE by restricting or banning specified hazardous material in certain products.

While the WEEE Directive targets the end-of-life the RoHS Directive clearly targets the supply side of the EEE life cycle. Both had to be transposed to national laws which increased the possibilities to accommodate

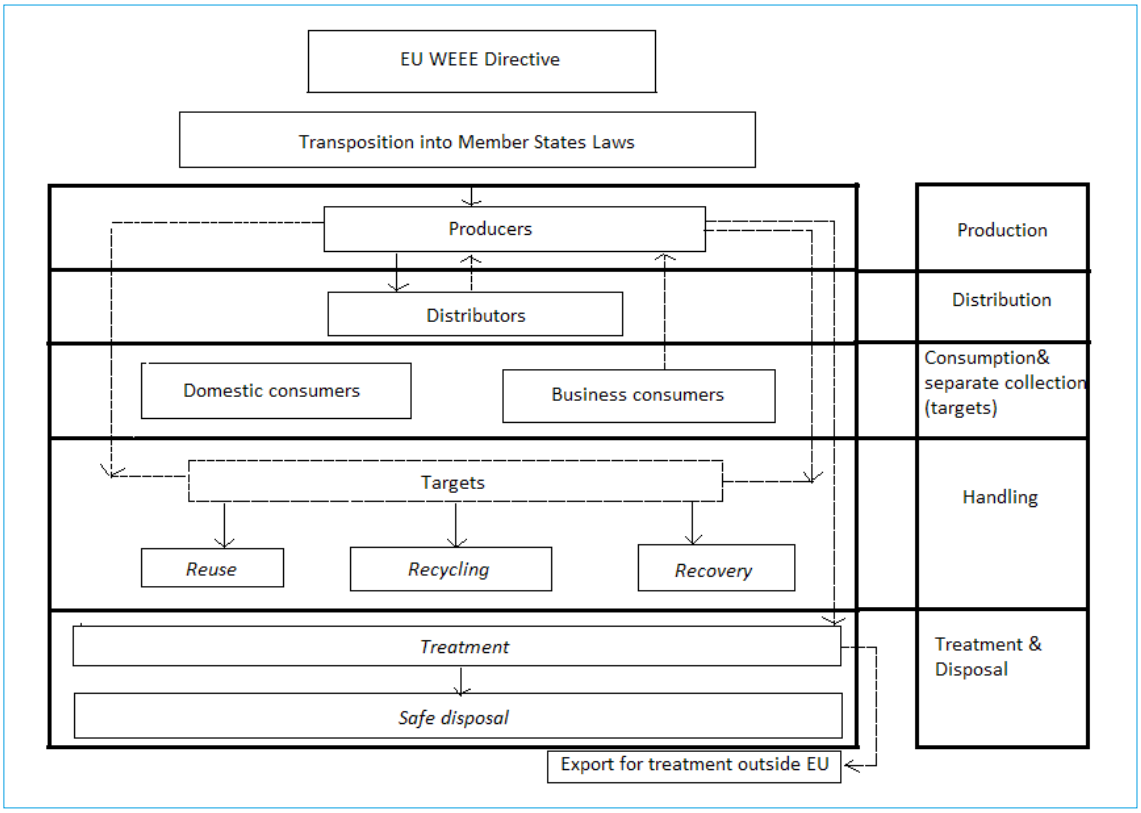

Figure 1: Simplified overview of the EU WEEE Directive [14]

national peculiarities but also increased the complexity for global producers to cope with dozens of deviations in the implemented procedures throughout the EU [16]. Several European countries had started to implement WEEE management policies before the EU WEEE Directive came into force. One of the oldest legislative frameworks is the Swiss "Ordinance on the return, the taking back and the disposal of electrical and electronic appliances" (ORDEA) [17]. It's principles of defining stakeholder's obligation is presented in Figure 2.

In the United States, 23 states have enacted some form of electronics recycling legislation. Some of these state laws established an electronics collection and recycling program and a mechanism for funding the cost of recycling under the EPR principle [18]. In Canada and Australia the implementation of EPR is voluntary. It is more accurately known as extended product responsibility to emphasize that the responsibility is shared – between the producer, the packaging manufacturer, the consumer and the retailer. It is thought that the biggest chal-

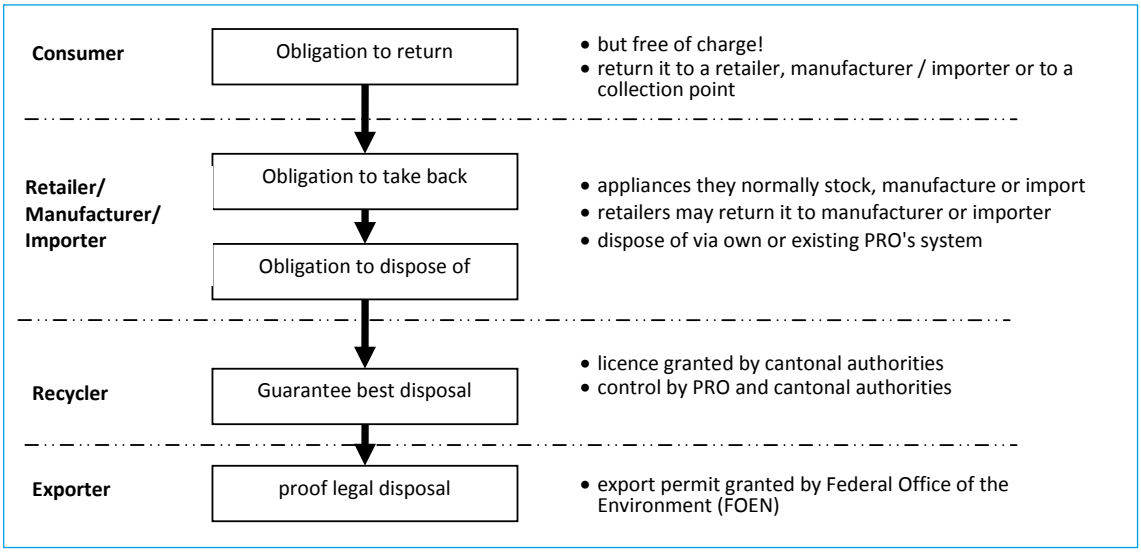

Figure 2: Schematic explaining the various stakeholders' obligations according to the Swiss WEEE legislation ORDEA [8]

lenge for USA, Canada and Australia is legislation and compliance, as current take-back initiatives have either come in late or are not comprehensive enough [14]. Probably the biggest issue is that the current take back systems do not have a comprehensive product view and often only cover a few products.

Although the quantity of domestic e-waste per head is still relatively small in developing and transition countries, populous countries such as China and India are already huge producers of e-waste [11]. These countries also display the fastest growing markets for EEE and are far from saturation [19]. On top of WEEE generated out of domestic consumption, a considerable amount is – intentionally or unintentionally – imported via the trade of used EEE [20].

In these countries a large urban workforce of cheap and unskilled workers is abundantly available. This allows for the creation of many jobs in this partly profitable waste stream but also poses a considerable threat as they often lack the necessary know-how and technologies for safe and sustainable waste management [6]. This problem is often exacerbated by the lack of suitable laws and/or laxenforcement leading to a ‚laisser faire' approach resulting in, for instance, ‚cherry picking' by the recyclers ('get the best - dump the rest') [21]. Most of the participants in this sector are not aware of full extent of the risks and do not know better practices or have no access to investment capital to finance even profitable improvements or to implement safety measures.

Nevertheless in recent years e-waste regulations have been established in a number of developing countries and the situation is changing rapidly. Summaries of developments upto 2012 or earlier can be found as global overviews [14], [22] or in different publications focusing on specific regions: for Africa [23], [24], Asia [25] and Latin America [26]. Most regulations cover up-stream as well as down-stream aspects and refet to sustainability and EPR principles similar to the European WEEE and RoHS directive. However a common feature of most of these regulations is that key elements and principles are still defined in very general terms. This can limit their legal effectiveness, and the lack of subsequent implementation rules and measures makes enforcement difficult.

Figure 3: The informal sector in developing countries often uses inappropriate recycling techniques such as acid leaching of gold (left, India) and burning of cables to recover copper (right, Ghana)

Figure 4: Improved government policies, local initiatives and international cooperation projects in developing countries have created better recycling solutions (left: recycler in Peru; right recycler in South Africa)

Policy & Legislation		The country's political and legal frame-work needs to be understood, by collecting information related to policies and legislations specific or related to e-waste: In addition the Institutional framework need to be known, i.e. the organization of the legislative, the executive and the judiciary systems as well as national and local governmental bodies related to environmental management
Stakeholder assessment	Manufacturers, Importers, Distributors	The purpose of the stakeholder assessment is to identify the actors involved and their role in the e-waste management system by groups of stakeholders, by explaining who they are, what their role is, how they are organized and what may be their impact on e-waste management. Each group of stakeholders is characterized by a set of qualitative and quantitative indicators, which will also provide the necessary data for calculating the e-waste mass flows further in the assessment
	Consumers	
	Collectors, Refurbishers, Recyclers	
	Final Disposers, Most Affected Communities	
Mass flow assessment		The mass flow assessment is a way to describe and quantify flows and stocks of a studied material in a simplified model. The model is characterised by the boundaries of the system it represents, and by fixing variables such as mass and time units (e.g. tons/year), as well as by the flows and stocks which are included in its limits. Finally, once the mass flows are calculated, a graphic representation can be made in a simplified graph (e.g. Figure 5).
Impact assessment		The impact assessment is meant to highlight in a qualitative and possibly in a qualitative way where the priorities are from an environmental and socioeconomic standing point.

Table 3: Structured outcome of an e-waste country assessment.

3 Approaches

3.1 Developing an e-waste management strategy

As outlined in the introductory chapter e-waste management needs to fulfil different objectives which go beyond pure technical implementation. Effective management of e-waste demands a comprehensive and structured approach but developing countries and countries in transition often lack legal and institutional frameworks as well as missing infrastructure. This concern has been raised by various international organizations and initiatives, including the United Nations Development Organization (UNIDO), the United Nations Environment Programme (UNEP), the Basel Convention, the Solving the e-Waste Problem (StEP) Initiative and the Partnership for Action on Computing Equipment (PACE). Several development cooperation projects adopted a three-step approach to help address this:

1. Performing a country assessment in order to understand the current framework conditions, including a review of the current legislation, a stakeholder assessment, a mass flow assessment (inventory) and an environmental & socioeconomic impact assessment.
2. Developing a structured strategy in a multi-stakeholder approach by assigning objectives and main activities to the following five topics: (1) Policy & Legislation, (2) Business & Finance, (3) Technology & Skills, (4) Monitoring & Control and (5) Marketing & Awareness.
3. Implementing the strategy through a roadmap with assigned responsibilities and a timeframe.

3.1.1 Understanding the current framework conditions

In order to define a strategy and implement the most appropriate e-waste management system, it is necessary to understand the local, national or regional conditions. This can be achieved by a comprehensive e-waste country assessment, as proposed in this document.

The first step of an e-waste country assessment usually consists in defining the organizational setup of the study. This not only means structuring the assessment team, but also identifying the local stakeholder(s) to whom the study results will be delivered, and who will take ownership of the e-waste problem in the country. The approach also includes setting up a national e-waste strategy group, comprising representatives of relevant stakeholders related to the e-waste problem. The constitution of such a multi-stakeholder platform ensures that the further implementation of a proper e-waste management system will not be rejected by one

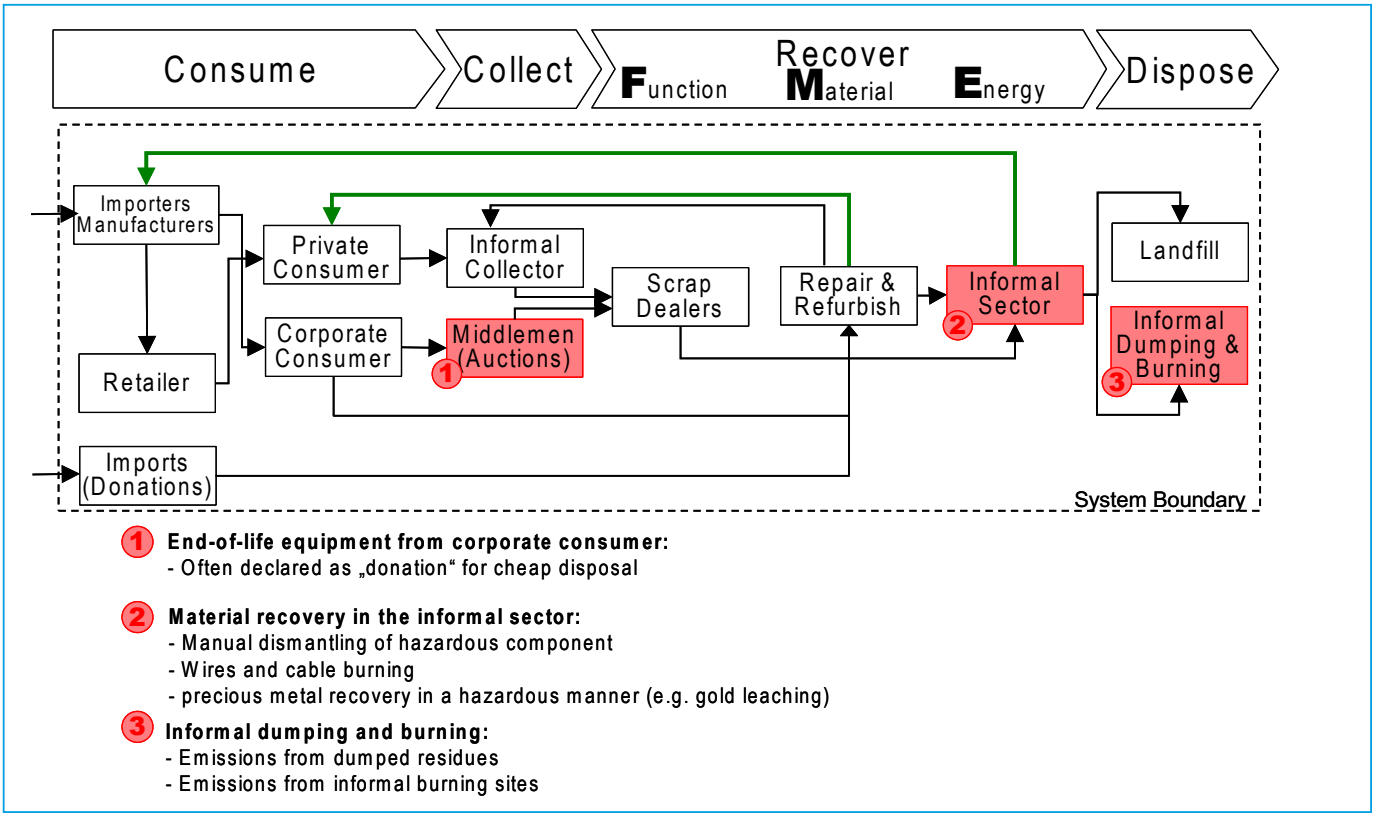

Figure 5: Visualized exemplary outcome of an e-waste country assessment including stakeholder interactions, mass flows and the identification of hotspots.

or another interest group, as all strategic decisions resulting from the assessment study should have been debated and adopted within the group.

The scope of the assessment study has to be defined both by geographical focus and equipment category. The geographical focus defines which cities and/or regions will be included, whether rural areas are considered and if trans-boundary movement should be incorporated in the study. Finally, the modes of data acquisition are also defined and planned, which may include a review of existing literature and statistical data, holding meetings and workshops for additional data gathering, field investigations and stakeholder surveys.

The assessment study eventually leads to a qualitative and quantitative description of the framework conditions related to the content as depicted in Table 3. One of the main results is the understanding of stakeholder interactions, mass flows and the identification of hotspots which need to be tackled in order to achieve a sustainable e-waste management system. A possible visualized outcome is depicted in Figure 5 for a fictitious case.

3.1.2 Structuring the approach

Based on the outcome of the e-waste country assessment and focussing on the identified hotspots which require special attention, a structured strategy is developed by assigning objectives and main activities to specific areas. Experiences from defining and implementing e-waste strategies in various countries suggest to use the following generic focus areas: (1) Policy & Legislation, (2) Business & Finance, (3) Technology & Skills, (4) Monitoring & Control and (5) Marketing & Awareness. The following description contains a proposed formulation of their main objectives and a tentative list of activities to include for each of these areas. However, the details should be established as part of a multi-stakeholder process, e.g. as a subsequent activity to the e-waste country assessment. Corresponding to the visualized outcome of the assessment study the strategy can make use of the same mass flow chart to illustrate where in the system different activities should be applied (Figure 6).

1) Policy & Legislation: activities under this topic aim to develop a legal framework and may include:

- reviewing existing legislations in order to enforce sound e-waste management;
- elaborate requirements for permits or licenses in order to improve compliance to existing legislation;
- promoting policies that meet the minimum of legislative requirements;
- implementing a system of minimum requirements for sustainable e-waste management;

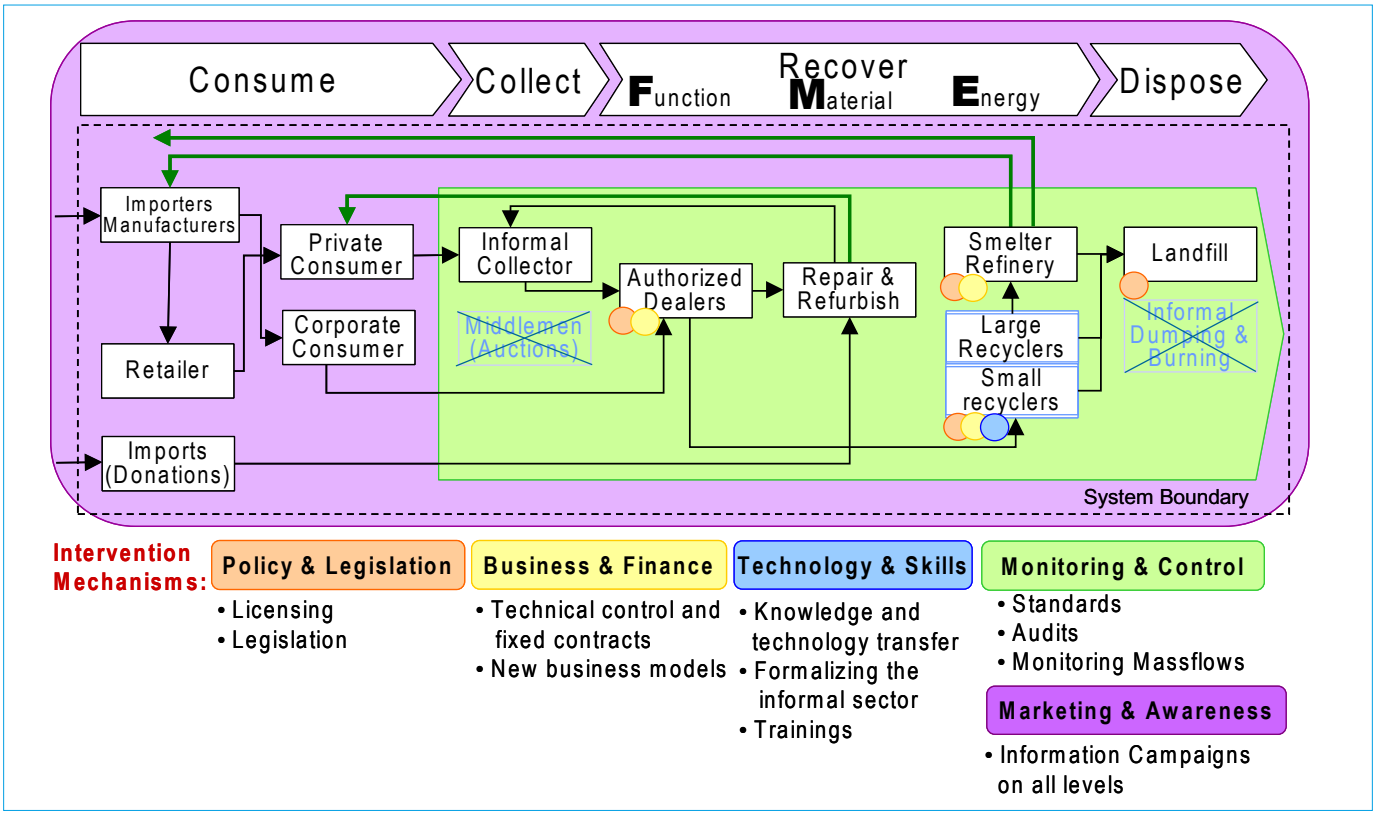

Figure 6: Exemplary illustration of proposed focus areas and activities of the e-waste strategy

- amending existing waste management legislation to allow for specific regulations on e-waste management.

2) Business & Finance: activities under this topic aim to establish institutional frameworks and may include:

- initiating a suitable process that will accommodate negotiations regarding responsibilities and rules amongst relevant stakeholders at local, national, regional and global levels;
- identifying and/or creating appropriate institutions to allocate the responsibilities, objectives and schedules within the e-waste sector;
- developing appropriate systems to ensure long-term financial sustainability of an e-waste management system and fair market conditions.

3) Technology & Skills: activities under this topic aim to develop a qualified and efficient e-waste recycling sector and may include:

- documenting tested and best available techniques and practices;
- identifying, quantifying, and evaluating existing down-stream material markets and alternative material flows;
- connecting existing and new processes in the e-waste stream;
- developing and improving skills and capacities through training;
- satisfying the need for business models to ensure appropriate investments at the appropriate technological and geographical level.

4) Monitoring & Control: activities under this topic aim to ensure a continuous improvement and maintaining compliance of the e-waste sector and may include:

- establishing technical standards and auditing procedures for recycling processes;
- establishing a process for data acquisition which allows for the design, monitoring and control of an e-waste management system;
- setting up a mechanism for continuous update of these data;
- using the collected data for transparent decision making and system improvements.

5) Marketing & Awareness: activities under this topic aim to create awareness at all levels of governance and the general public and may include:

- making information available through appropriate means (e.g. websites, training, campaigns);
- leading the main stakeholders towards sustainable e-waste management by targeting them with tailored solutions (e.g. schools, vocational/technical institutes, the informal sector, governments, and the general public).

		Policy & Legislation	Business & Financing	Technology & Skills	Monitoring & Control	Marketing & Awareness
Pilot Phase				e.g. dismantling facility		
Implementation phase	**Immediate action**	e.g. import ban on refrigerators				
	Midterm solutions	e.g. strict purchasing policies		e.g. master plan for a take back operation	e.g. develop independent auditing body	e.g. awareness campaign on school level
	Long-term solutions	e.g. legislation on e-waste	e.g. sustainable financing scheme			

Figure 7: Possible structure to establish a road-map for the implementation of an e-waste management strategy (including indicative examples)

3.1.3 Implementing a roadmap

The activities described above can usually be defined as having the nature of a pilot phase or an implementation phase. The implementation phase can be divided into immediate actions, mid-term solutions or long-term solutions. The following matrix can be used to establish a road-map for the implementation of an e-waste management strategy.

Such a road-map will need to include a time frame and responsibilities. Responsibilities can be assigned to various stakeholders, such as to governments and OEMs, but also to international co-operation initiatives. Hence this structure should also be the base to co-ordinate bilateral and multilateral development projects in developing countries and countries in transition, i.e. align such initiatives in content and time in order to avoid duplicating efforts.

3.2 Key issues to consider for policy makers (Swiss case study)

In this section five key issues are explored, which are vital in any discussion about implementing e-waste management as required, for example, by the EU WEEE Directive. Each issue is related to EPR as a policy and is considered as an question of how – or what – choices may faced by a policy maker. The analysis is closely related to another study which took the Swiss experience as an example [12]. The five key issues embrace:

1. Getting the system started: how to overcome inertia?
2. Securing financing: how to ensure that the system is financially sustainable?
3. Getting the collection logistics right: what should the scope and logistics arrangement of a system be?
4. Ensuring compliance: how to ensure all actors fulfil their responsibilities?
5. Restricting monopoly: how to prevent anti-competitive practices?

These are by no means the only issues that a policy maker needs to consider but should provide some guidance in evaluating policy alternatives. It is believed that these five issues encapsulate the most relevant questions and provide a broad framework upon which further discussions can be based.

3.2.1 Getting the system started

Policy makers and producers each grapple with the dilemma over who should take the first step. Should the policy be in place before producers are forced to change their practices? Or should the producers pre-empt policy, especially in the context of EPR, because policy deliberations are lengthy?

In Switzerland a producer led take back scheme for WEEE was started before legislation was in place. It began with a small loan from the producers associations to finance the initial year of operations and included only a few major companies as participants. Within a decade this membership has grown to encompass most of the producers operating in the Swiss market. There are similar examples in Sweden, Belgium, Norway and the Netherlands where EEE producers have established take back system in advance of legislation or implementation of the EU WEEE Directive.

The benefit of having a working system in place before legislation was introduced meant that the producers had the chance to develop a system which was both flexible and less expensive. The Swiss experience shows that producers need not wait for the government to force them to take responsibility for the end-of-life disposal of their products. Furthermore it is not practi-

cal to wait until all the producers are on-board before a system starts. The critical mass is reached by a small group of large producers, mainly large multinationals, which dominate the market for EEE.

The key question is whether this can be achieved in other countries as well. Given the global footprint of the EEE industry which is dominated by large multinational corporations, it should be possible to easily transfer operational and system knowledge gained from setting up such voluntary systems in Switzerland or other countries and apply them in other areas.

This approach can work in OECD countries where new systems should be able to hook onto available e-waste management infrastructure. Developing countries generally lack such infrastructure and hence corporate take back systems are harder to implement without the backing of a strong legislative framework. In addition, in many developing countries, OEMs (Original Equipment Manufacturers) are not represented on the ground and often have little control over importing companies and second-hand imports. They therefore have limited possibilities to influence and control the end-of-life management of their branded products. Thus the challenges and mechanisms for the implementation of sustainable take-back systems are different from those in industrialized countries.

3.2.2 Securing Financing

One of the reasons why EPR is becoming popular as a policy measure to manage complex waste streams is because it does not place any financial burden on the local government. However, there are costs involved in the collection, transportation, sorting, dismantling and environmentally safe recycling of the waste. In case the intrinsic recoverable value is not enough to meet these processing costs, additional income streams are required. Moreover, recent studies reflecting the all-time high raw material prices and the economic conditions of developing countries suggest that even when recycling businesses can be run by relying on the intrinsic value of the treated material only, changing conditions can pose risks to the business [27]. Hence some kind of financing safety net, which can be activated once unfavourable conditions prevail, needs to be in place in any e-waste management system. The questions that immediately arise are who should pay, how much, and at which point so that the system is financially stable and can meet its operating expenses.

Recycling fees are one possible mechanism often applied in OECD countries. Fees can be collected at two points – at the time of purchase, or at the time of disposal. In the Swiss system advance recycling fees (ARF) are collected and represent an intergenerational contract between appliances purchased in the past and those that are purchased in the present. This is similar to a pension system. The fees collected in the present are used to pay for appliances purchased in the past and being disposed of now. Similarly, when the appliances purchased today are disposed of in the future, their recycling cost will be met by the fees charged on a new generation of products being sold at that time. A fee can be collected in two ways: (a) as a visible fee, that is explicitly mentioned as an additional component in the price of the product or (b) as an invisible fee, where the product price includes the fee, without explicit publication of it's value.

The Swiss legislation does not stipulate, for example, whether a recycling fee is to be charged or not, or who should pay, how much or when. The advantage of letting market forces dictate the financing of the system is a more responsive system that is able to quickly adapt to shifting market dynamics. Additionally, without financial restrictions, the system is more competitive because it gives producers and PRO's the choice on how to secure financing – how much to charge and when – for the take back and recycling.

Hence policy makers need to be cautious in pre-defining financing mechanism directly in their legislative framework. Complimentary control mechanisms need to be in place to ensure the transparent collection and utilisation of collected funds. If not, there is the danger that unscrupulous agents could abuse the system by charging recycling fees from the consumer for proper disposal, but instead selling the e-waste to recyclers who pay the highest price and who do not necessarily follow sound disposal practices.

3.2.3 Getting the collection logistics right

The logistical implementation of an EPR policy is a hotly debated topic. This is especially true when it comes to whether it should be an individual or collective take back system and what should be done about historical and orphan products whose producers have ceased to exist or which products to bring under the EPR purview. These questions are often raised by both policy makers and producers when formulating EPR based policies.

A collective take back system is an all-inclusive scheme which does not differentiate between different brands of a product type. Individual take back systems are brand-specific and cater only for different products of one particular producer. Both approaches have their advantages and drawbacks. The advantages of a collective system are two-fold. Firstly, this allows for higher efficiency by building economies of scale especially for small countries and/or small WEEE volumes. Secondly, a collective system is often more consumer-oriented and can take into consideration consumers' habits. Many would find it more convenient, for example, to bring all their various e-waste items to one place rather than have to go to different places for different brands.

The main drawback of a collective system is the lack of competition. However competition can also be ensured on alternative levels by regularly tendering the

various tasks of a system (transport logistics, recycling, etc.). Producers usually want to have a choice of how to fulfil their obligations of WEEE management under the given circumstances through either individual and/ or collective schemes as they see fit. For the development of a legislative framework it is therefore suggested that policy makers should concentrate on defining the producer's obligation and leave it open to them how to comply.

3.2.4 Ensuring compliance

One of the biggest challenges of an EPR system is that of producers who evade their responsibility - that is the 'free riders' who enjoy the benefits of the system but without paying for it. Other stakeholders such as retailers and consumers who have a part to play in the smooth functioning of the system can also be prone to shirking their responsibilities. To ensure the continuity of the system,it is therefore essential that all the actors comply so that the chain remains intact.

Avoiding free riders: Experiences from EPR systems (e.g. from Switzerland) suggest that although free riders cannot be totally avoided they can be reduced to acceptable levels through a set of provisions. Firstly, for countries importing almost all EEE, the first point of control is at the customs. This makes free riding difficult for importers/manufacturers, provided that all importers/manufacturers are registered. Secondly, EEE retail chains could insist that their vendors already be a part of the recycling system before carrying their products. Therefore, for the manufacturer/ importer, to gain market access, it becomes imperative that they subscribe to the PROs. In addition, the low cost of participation in the system and the ease of compliance which it offers is a huge incentive for the producers. Thirdly, even though intangible, peer group pressure is a very important means of reducing free riding. Because all producers stand to benefit from fewer free riders, the PROs can use their current members as advocates of the system and encourage reporting of non-compliance. Finally, a legislative backing provided by national legislation is pivotal, as this makes producers legally responsible for the take back and safe disposal of WEEE manufactured/imported by them. In cases of non-compliance they would face penalties.

Avoid rogue recyclers: In an EPR system the legislative framework does not need to stipulate any specific recycling or recovery, but needs to mandate the responsibility of sustainable recycling to the producer thus allowing the industry to decide the best practices that ensure a practical system that balances economic and environmental efficiency. Legislation, however, should be implicit by ensuring that e-waste ideally does not enter landfill and that the collection and associated actors are obligated to ensure proper take back and disposal, and/or lawful export for disposal. Strict requirements are necessary on the materials sent to landfills and incinerators for disposal, including specifications for procedural requirements of licensing, registration and supervision. As a result of the responsibility mandated by an EPR approach, PROs need to ensure that the licensed recyclers appointed by them meet stringent quality procedures and norms. This is usually ensured through technical controls on recyclers by external auditors. Third party auditors ensure greater transparency regarding the quality of recycling. Rogue recyclers such as those who do not follow environmental, health and safety standards and/or illegally ship their waste to other countries for processing or for dumping therefore have the risk of having their contracts with the PROs cancelled thus their material supply cut-off and their licences revoked.

3.2.5 Restricting monopoly

EPR may in certain cases result in firms abusing a dominant position and indulging in price fixing and anti-competitive behaviour which results in inefficiency. The waste management and recycling fields in particular have always been connected with the problem of monopolies. In the case of a collective system, there is the threat of the take back system becoming a monopoly player. Also, a large recycler might corner the entire WEEE waste stream and drive out smaller recyclers, thereby creating a monopoly.

Avoid PRO monopoly: Experiences from Switzerland demonstrate that monopolistic practices of a PRO can be avoided also in collective systems through a set of conditions. One condition is that the Swiss legislation leaves the implementation to the producers who have the choice of either participating in a collective PRO system or setting up a parallel system. Therefore, the producers do not have an obligation to join the collective system and do so only voluntarily as they benefit from economies of scale. This is usually a better solution for small countries or countries with low e-waste generation, such as often found in developing countries, where the economy of scale does not allow for different systems to effectively co-exist in competition. Another condition is that PRO systems should have the status of not-for-profit organisations and as a consequence avoid the goals of a profit-maximising corporation. Furthermore transparency regarding the collection, financing and contracting processes helps alleviate the risks of a PRO monopoly.

Avoid recycler monopoly: Various strategies are possible to avoid a recycler monopoly. In Switzerland one PRO contracts their recyclers themselves and avoids recycler monopoly by giving the rights to the best service offer. As Swiss recycling costs are rather high this means the recyclers who quotes the lowest charges per kg e-waste is generally preferred. In addition to avoid a monopoly of large recyclers the PRO restricts territorial rights to recyclers who are located closer to collection points. The other PRO uses an average system to fix

recycling prices, and leaves the choice of the recycler to the collectors, as all recyclers receive the same rate for the e-waste they process. The experience of e-waste management in Switzerland has shown that it is possible to design a waste management system which overcomes the threat of monopolistic practices. For policy makers, it shows that rigid regulation is not required to create a competitive environment for both the take back as well as recycling services.

3.3 Technological issues

3.3.1 Ensuring an efficient recycling chain

The recycling chain for WEEE consists of three main steps: i) collection, ii) pre-processing (incl. sorting, dismantling, mechanical treatment) and iii) end-processing (incl. refining and disposal) [11]. Usually for each of these steps specialized operators and facilities exist. The material recovery efficiency of the entire recycling chain depends on the efficiency of each step and on how well the interfaces between these interdependent steps are managed. If for example, for a certain material the efficiency of collection is 50%, the combined pre-processing efficiency is 70% and the refining (materials recovery) efficiency 95%, the resulting net material yield along the chain would be only 33%.

Concepts and processes applied in the recycling chain can vary widely in different regions and countries with individual strengths and weaknesses. The main differences can be found between OECD countries with a dominant formal sector and developing countries with a largely informal sector. Figure 8 compares the recycling efficiency between a common formal system in Europe and the informal sector in India for the overall gold yield out of printed wiring boards. While both scenarios indicate similar (low) overall metal recovery efficiencies, both have their weaknesses and strengths in different steps of their respective recycling chain. An analysis of strengths, weaknesses, opportunities and threats (SWOT analysis) for a formal vs. an informal system is summarized in Table 4.

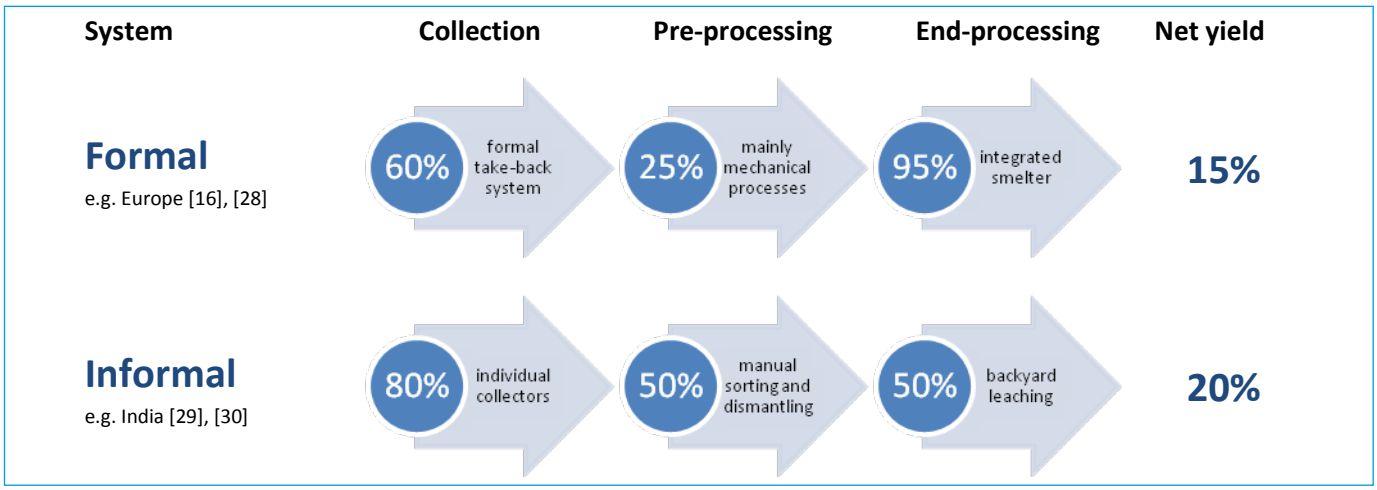

Figure 8: Recycling efficiency between a common formal system in Europe and the informal sector in India for the overall gold yield out of printed wiring boards [31]

	Formal scenario	Informal scenario
Strengths	Access to state-of-the-art end-processing facilities with high metal recovery efficiency [11]	High collection efficiency [11] Efficient deep manual dismantling and sorting [34] Low labour costs gives advantage of manual techniques over mechanical technologies in the pre-processing steps [11]
Weaknesses	Low efficiency in collection [16] Often low efficiency in (mechanized) pre-processing steps [28]	Medium efficiency in dismantling and sorting [29] Low efficiency in end-processing steps [29] coupled with adverse impacts on humans and the environment [6]
Opportunities	Improvement of collection efficiency Technology improvement in pre-processing steps	Improvement of efficiency in the pre-processing steps through skills development for dismantling and sorting [35] Implementation of alternative business models, providing an interface between informal and formal sector [35]
Threats	"Informal" activities in the collection systems	Bad business practice (bribery, cherry picking of valuables only, illegal dumping of non-valuables, etc.) Lacking government support (no acceptance of informal sector, administrative hurdles for receiving export licenses, etc.)

Table 4: SWOT analysis of the e-waste recycling chain in formal vs informal scenarios

Collection: Unlike in Europe – where consumers pay for collection and recycling – waste collectors in developing countries usually pay consumers a positive price for their obsolete appliances and scrap material. As a result, informal waste sectors are often organized in a network of individuals and small businesses of collectors, traders and recyclers, each adding value, and creating jobs, at every point in the recycling chain [21]. As many poor people rely on small incomes generated in this chain, impressive collection rates of up to 95% of waste generated are achieved [23]. This is far above what can be achieved by todays formalized take back schemes [16].

Pre-processing: A comparative study by Wang et al [32] of **pre-processing** scenarios revealed that recovery efficiency improves along with the level of manual dismantling. Purely mechanical treatment options lead to major losses of especially precious metals in dust and ferrous fractions [28], [33]. Labour cost is the main determinant in choosing between manual and mechanical treatment options and so mechanical treatment is mostly applied in developed industries with lower recovery efficiency. In developing countries, where labour costs are usually low, manual treatment is the preferred option. The advantage in these countries is that manual treatment technologies do not require high investment costs, create jobs and lead to higher material recover efficiency [11]. It has been shown, however, that manual dismantling has it's limits and beyond a certain point in the process, semi-mechanical treatment steps for the remaining fractions are a better option from both an economical and eco-efficiency perspective [32], [34]. In addition, the design of products such as the case of composite materials might also hamper manual dismantling.

3.3.2 Applying best available technologies and best environmental practice

Best available techniques (BAT) and best environmental practice have been summarized in various reports and guidelines, such as in the UNEP reports "Recycling from e-waste to resources" [11] and "Metal recycling" [31] for metals, in the Stockholm Convention BAT/BEP guidelines for polybrominated diphenylethers (PBDEs) in plastics [36], the PACE "Guideline on environmentally sound material recovery and recycling of end-of-life computing equipment" [37], the MPPI "Guidance document on the environmentally sound management of used and end-of-life mobile phones" [38] and the Defra report "Battery Waste Management – Life Cycle Assessment" for batteries [39].

A common feature of all these documents is that they address BAT/BEP recommendations based on the recycling chain as described in the previous chapter. It is also a common ground that BAT recommendations can be different under specific socio-economic conditions. Manual processes may, for example, be preferred over mechanical and automated processes or vice versa whilst still complying with international environmental, health & safety standards.

4 Conclusions and lessons learned

As mentioned previosuly, developing and transition countries often face completely different challenges from OECD countries. This requires special attention needs to be given to the main issues related to the implementation of e-waste management systems in developing and transition countries. It is thought, however, that the general goal of e-waste management should not differ from the EPR approaches taken in OECD countries. The five key issues when applying EPR as a policy are discussed above and need to be considered alongside systems needed to achieve the same international standards for sound e-waste management as prescribed under, for example, the EU WEEE Directive.

As a result of experiences made in the Swiss e-Waste Programme [8] and other international collaboration projects, especially in Africa, the main issues related to an improvement of the current e-waste management practices encountered in developing and transition countries were summarized in the Durban Declaration [40]. Stakeholders from various African and European countries classified those issues as sufficiently generic and of equal concern to the other developing and transition countries. The declaration avoids the formulation of ready-made implementable solutions as it was agreed that every country requires its own process to define a road-map related to specific projects. The suggested recommendations are:

- improve co-operation among stakeholders (a) by ensuring the right level of representation in relevant international fora (e.g. Solving the E-waste Problem (StEP), Pacific-Europe Network for Science and technology (PACE-Net), (b) by establishing regional platforms and/or an e-waste forum in cooperation with established regional networks and international bodies, and (c) by identifying with relevant initiatives, learning from them and utilising their expertise;
- establish an institutional framework (a) by initiating a suitable process that will accommodate negotiation amongst relevant stakeholders within local, national, regional and global levels, and (b) by identifying and/or creating appropriate institutions to allocate the responsibilities, objectives and schedules within the e-waste sector;
- create awareness at all levels of governance and the general public (a) by making information available through appropriate means (e.g. web-

sites, training, campaigns), and (b) by identifying and targeting the right audience with tailored solutions (e.g. schools, vocational/technical institutes, the informal sector, governments, and the general public) towards commitment to sustainable e-waste management;

- support markets (a) by identifying, quantifying, and evaluating existing down-stream material markets and alternative material flows, (b) by sharing of information on new technologies for optimized resource recovery, and (c) by promoting fair local e-waste markets wherever possible;
- collect and manage data (a) by establishing a process for data acquisition which allows for design, monitoring and control of e-waste management, (d) setting up a mechanism for continuous update of these data, and (c) by using data for transparent decision making and system improvements;
- develop a legal framework (a) by reviewing existing legislations in order to enforce sound e-waste management, (b) by highlighting permitting or licensing requirements for improved compliance to existing legislation, (c) by promoting policies that meet the minimum of legislative requirements, (d) by implementing a system of minimum requirements, and (e) by amending existing waste management legislation to allow for a regulation on e-waste management;
- develop a qualified and efficient e-waste recycling sector (a) by documenting tested and best available techniques and practises, (b) by developing and improving skills and competencies through training, (c) by satisfying the need for business models to ensure appropriate investments at the appropriate technological and geographical level, (d) by connecting existing and new processes in the e-waste stream in so-called green e-waste channels, and (e) by ensuring continuous improvement of the infrastructure through the establishment of standards and auditing procedures.

5 Guidance materials available

Suggested guiding materials (with Weblinks)

- Information on global WEEE challenges & solution have been compiled at: http://www.ewasteguide.info/ and http://www.sustainable-recycling.org (webpages run by Empa and the World Resources Forum)
- WEEE inventory have been established in a range of developing countries and reports are available http://www.ewasteguide.info/ewaste/case-studies; The related training and reference manual for the assessment methodology is available at http://www.ewasteguide.info/Empa_2012_Assmt-Methodology
- The Solving the e-Waste Initaitive (StEP) has developed a series of white and green papers for e-waste management: http://www.step-initiative.org/index.php/Publications.html
- The Partnership on Computing Equipment (PACE), which is facilitated by the Secretariat of the Basel Convention has developed various guidance document on environmentally sound management of e-waste: http://archive.basel.int/industry/compartnership/index.html
- The European association of electrical and electronic waste collection and take back systems (weeforum) has developed the WEEELABEX standards for e-waste recycling: http://www.weee-forum.org/weeelabexproject
- The Basel Action Network has developed the e-Stewards standard for responsible e-waste management: http://e-stewards.org/ and http://www.ban.org/

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