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Environmental Technology & International Affairs

Material Flow Analysis and Application of LCD Monitors in Peru. A Case Study of Waste Electrical and Electronic Equipment (WEEE)

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **NATHALIE GHAZARIAN**, hereby declare

1. that I am the sole author of the present Master's Thesis, "MATERIAL FLOW ANALYSIS AND APPLICATION OF LCD MONITORS IN PERU. A CASE STUDY OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)", 62 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The management of waste electrical and electronic equipment (WEEE) leads to an environmental as well as to a resource profusion problem in Peru. Thus, the issues are lack of financial support, limited economic capacity and lack of commitment to complex recycling regulations, and the release of hazardous substances from electrical and electronic equipment (EEEs). The environment and people involved have to deal with the exposure of POPs, such as Brominated Flame Retardants (PBDEs), and heavy metals such as mercury and copper. WEEE requires an effective regulatory framework for the management of recycling facilities, which challenges the Peruvian recycling system. Particularly, the Basel and Stockholm Conventions provide regulations and guidelines at the international level. Among Latin American countries, the Peruvian government is one of the few, which have introduced comprehensive legislative measures for the management of WEEE. However, the progress of formalization the WEEE system is limited to a certain extent in Lima. Therefore, the handling, treatment and disposal of LCD monitors are analysed by the Material Flow Analysis (MFA), showing strengths and weaknesses of the Peruvian WEEE management framework. The MFA also demonstrates the environmental impact assessment of the monitors by the informal sector. The evaluation of MFA with the provision of three different scenarios provides the following solutions for the problem. Firstly, the enhancement of awareness-raising campaigns has to be supported, secondly, the population needs to be attracted to the collection and recycling process by the donations of lottery tickets, thirdly, the inclusion of the informal sector is necessary to improve the formalization of the system, fourthly, a reuse culture as a new economic niche should be implemented to encourage people involved in the informal sector and ultimately, product based recycling fees should be implemented for additional financial support for the management of WEEE.

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List of Abbreviations

CCFL	Cold Cathode Fluorescent Lamp
CFL	Compact Fluorescent Lamp
CRT	Cathode Ray Tube
DIGESA	Health Ministry's General Health Bureau
EEE	Electrical and Electronic Equipment
EC-RS	Commercial Marketing Company for Solid Waste
EMPA	Swiss Federal Laboratories for Materials Science and Technology
EPS-RS	Certified Solid Waste Service Provider
EPR	Extended Producer Responsibility
ICT	Information and Communications Technology
IPES	NGO for Promotion of Sustainable Development
MEF	Ministry of Economy and Finance of Peru
MFA	Material Flow Analysis
MINAM	Ministry of Environment of Peru
MTC	Ministry of Transportation and Communication
PAH	Polycyclic Aromatic Hydrocarbon
PBDE	Polybrominated Diphenyl Ethers
PBDD/Fs	Polybrominated Dibenzodioxin and Dibenzofurans
PCB	Printed Circuit Board
PCDD	Polychlorinated Dibenzodioxin
PCDD/Fs	Polychlorinated Dibenzodioxin and Dibenzofurans
POP	Persistent Organic Pollutants
PUCP	Pontifical Catholic University of Peru
SUNAT	National Superintendency of Tax Administration
Swico	Swiss Economic Association for the Suppliers of Information, Communication and Organizational Technology
WEEE	Waste Electrical and Electronic Equipment

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1. Introduction

1.1 Problem

Waste electrical and electronic equipment (WEEE) is a growing waste stream. The technology of new electrical and electronic equipment (EEE) increases the demand for it and contributes to the worldwide generation of WEEE. These EEEs are mainly items, such as computers, mobile phones, TVs, printers, ACs, washing machines, refrigerators, among others.

WEEE requires a regulatory framework for the management of precise recycling processes in Peru. These substantial resources and capacities are not completely available and accessible in Peru. On the one hand, the WEEE issue in Peru is based on the lack of financial support, limited economic capacity and lack of commitment to complex recycling regulations. On the other hand it is a problem due to the release of hazardous substances from EEEs, for instance, POPs (Persistent Organic Pollutants), PBDEs (Polybrominated Diphenyl Ethers), and heavy metals such as mercury and lead. The inappropriate recycling of WEEE results in a harmful exposure to the environment. Therefore, the collection, handling, treatment and disposal of WEEE have become important in the Peruvian agenda.

The lack of financial capacities and support are related to the expansion of WEEE in terms of volume and complexity. Each new generation of EEE results in prematurely discarded electronics even before the lifespan expires. Since Peru experiences accelerated economic and development growth, it occurs even faster there. The capacities of Peruvian recycling authorities are limited. As a result, many recycling companies do not meet the requirements of the WEEE regulations.

The recycling companies, for instance Coipsa, San Antonio Recycling, Peru Green Recycling and Comimtel (which are the main Peruvian WEEE entrepreneurs), pay and proceed a part of the treatment and handling of WEEE. However, on the one hand the agencies are not able to finance the whole recycling procedures of EEE, and on the other hand it would not be profitable for them. Thus, the majority of recycling firms, which pay for WEEE, commercializes the electronic components and does not take the social and environmental responsibility, which indicates to export the materials with low market values to other countries in order to be preceded appropriately (Peru Green Recycling, 2012). The Peruvian government does not financially contribute to the management, collection, treatment and disposal of WEEE.

However, EEEs contain various hazardous materials, such as mercury and cadmium which pollute the nature, if not properly treated. In particular, up to 60 elements from the periodic table can be found in a PC. The toxic components are of low risk during the use of the equipment. They become harmful to the environment and to people in the end-of-life process. For example, lead in CRTs (Cathode Ray Tube), mercury in flat screens, and cadmium and flame retardants in plastics can be emitted to the environment if not properly handled (Boeni, 2008).

Furthermore, in the case of Peru where the provision of economic and financial resources for the recycling process of computers is not sufficiently implemented, WEEE may end up in not well-managed landfills. This in turn has a negative effect on the environment. Especially, the accelerated growth of industry, information technology and communication taking place in the country contribute to the WEEE problem.

Nevertheless, from an economic and resource point of view the expenditures by the recycling companies are not sufficient to cover all operating costs. The lack of financial support and limited economic capacity, lack of commitment to the WEEE legislation and release of hazardous substances from EEEs are closely related to each other and can be tackled by comprehensive policies, enhanced recycling and dismantling infrastructure.

Since there have been few MFA (Material Flow Analysis) studies about Latin American countries and particularly no MFA of Peru, the contribution of this work is to provide the first MFA of LCD monitors in Peru and recommendations of policies, local initiatives and recycling procedures.

1.2 Literature Review

There have been various conducted MFAs around the world. MFAs are of high scientific interest and have major inputs on the development of policies. In addition, they provide crucial information of flows and accumulation within economies and for the management of hazardous substances. Especially, researches of the European Union member states and Asia, including Japan (which counts to one of the first case studies) and China, were conducted to measure the impacts of human activities on the environment (Balat, 2004).

These methodological approaches are neither widespread in African nor in Latin American countries. In particular, there have been several analyses of the Nigerian case of WEEE. The WEEE model of Nigeria was applied by using data, such as sales data, transfer coefficients and usage time of EEE. The study concluded that storage and reuse of obsolete computers are preferable rather than direct disposal (Ibrahim, 2013). However, for Argentina, Chile and Mexico MFA has been analysed and applied. The MFA of Argentina was focused on the biophysical aspects of the economy between 1970 and 2009. They compared the results with Spain and other countries. During the analysed period of time the quantity of materials consumed and extracted in Argentina increased above 77% (Brun et al., 2014). The Chilean study included the state of the recycling infrastructure of computers, and the governmental, industrial and consumer impacts and came to the conclusion that today's Chilean formal recycling management receives less than 3% of the annual quantities of WEEE, particularly of computers (Steubnig et al., 2009). The MFA of Mexico deals with the understanding of the system of used computers. The study shows that the geographical location and perceived value play a determining role towards the amount of disposed computers. Especially, the legislation has an influence in Mexico and the change of communication and technology contributes to the state of disposed computers (Estrada/Kahhat, 2014).

However, there is no MFA of LCD monitor in Peru. The engineer Professor Ramzy Kahhat of the PUCP (Pontifical Catholic University of Peru) works on topics and issues of different types of WEEE in Peru. The studies are mainly dealing with computers, monitors and cathode ray tubes (PUCP, 2011). These reports are essential for the data collection of a Peruvian MFA.

1.3 Objectives

The objective of the thesis is to evaluate the international documents of the Basel and Stockholm Convention, the national regulations of WEEE in Peru and the data of the recycling of LCD monitors by the MFA analysis in order to find legal gaps and overlaps in the recycling management of WEEE in Peru. Peru is discussed as a case study because of its constant industrial progress and because of the fact being one of the few Latin American countries with comprehensive legislative measures for the management of WEEE. Additionally, the non-existence of many WEEE studies in Latin America is another reason for analysing Peru.

The evaluation of MFA and the given international and national regulatory frameworks will show the current status of WEEE and LCD monitors in Peru. Moreover, the analysis shall demonstrate to which extent the laws do not or do consider the protection of the environment at the national and international scale and which financial and environmental measures should be taken into account. The material flow analysis, which has important policy relevance, is a useful instrument to assess the flows and life cycle of monitors within the system. It is used to estimate the industrial in- and outputs of computers to the natural ecosystem capacity. All these analyses are crucial to elaborate suggestions for the resource and environmental issues of WEEE in Peru. The suggestions are related to policies, local initiatives and regulations.

1.4 Research Questions

The paper focuses on the following research questions:

1. How far does the legal framework of Peru include the regulations of the Basel and Stockholm Convention?
2. To which extent do they or do not overlap in the main processes of recycling (collection, dismantling, treatment systems and final disposal)?
3. Which measures should be taken by Peruvian authorities to improve the recycling life cycle of LCD monitors?
4. Which effects will the proposed measures have in comparison to today's situation?

2. WEEE Facts

2.1 International WEEE Generation

The international situation of WEEE has significantly changed in the recent decades. There is a remarkable acceleration of WEEE at the international level. The transition from analogue to digital technologies and to flat-screen monitors contributes to this situation. At the same time the demand for EEE leads to a higher production, recycling and disposal rate of these items. Many countries face the legal and environmental issues, for instance, the implementation and control of a regulatory framework for WEEE, provision of appropriate recycling equipment, financial support for recycling procedures and development of well-managed final disposals. The issue is increasingly growing the interest of political, economic and natural science actors (Kuehr, 2012). The recycling of WEEE is a small fraction of the overall recycling products. Nevertheless, its importance is growing with the continuous demand for EEE.

The rising presence of WEEE also contributed to a wide range of definitions, regulations, guidelines, decrees, projects and policies (Kuehr, 2012). However, the more common used guidelines and classification of WEEE are from the WEEE EU Directive, where WEEE is divided into the following 10 types:

1. Large household appliances: refrigerators, freezers, washing machines, electric stoves, etc.
2. Small household appliances: vacuum cleaners, toasters, coffee machines, irons, etc.
3. IT and telecommunications equipment: printers, personal computing, Laptop computers, telephones, etc.
4. Consumer equipment: radio sets, video recorders, television sets, musical instruments, Hi-Fi recorders, etc.
5. Lighting equipment: Fluorescent lamps, discharge lamps, etc.
6. Electrical and electronic tools: drills, sewing machines, saws, tools for gardening, etc.
7. Toys, leisure and sports equipment: video games, electric trains, computers for biking, running, etc.
8. Medical devices: radiotherapy equipment, fertilization tests, cardiology, dialysis, nuclear medicine, etc.
9. Monitoring and control instruments: thermostats, smoke detector, heating regulators etc.
10. Automatic dispensers: for hot drinks, cold and hot bottles, for solid products, etc (WEEE Registration, 2008).

Each category is characterized by its corresponding weight, size, function and material components. Since the items differ in waste quantities, toxic composition and economic values, the classification should be taken into consideration. Moreover, the categorization is particularly crucial in the end-of-life phase of EEE in order to take them for the appropriate collection, treatment, handling and final disposal (Baldé, 2015).

Furthermore, the ratio of EEE for purchases in the international market was 19.5 million tons in 1990, rising to 34 million tons in 2000. According to estimates the peak was 76.1 million tons of EEE in 2015, which is almost the fourfold of EEE supply since the last 25 years (Kuehr, 2012). Consequently, the worldwide generation of EEE was over 40 million tons in 2014. In 2014, around 6.5 million tons of WEEE were reported to be properly and formally treated based on the information of national take-back systems. The EU Member States are reported to dispose 0.7 million tons of WEEE into the waste bin, but for other regions there is no accurate data. In addition, the global amount of WEEE, such as screens and monitors reached more than 6 million tons in 2014. In 2018, it is forecasted to have almost 50 million tons of WEEE (Baldé, 2015).

However, the geographical distribution of WEEE generation and disposal differs per continents. The majority of WEEE took place in Asia, having 16 million tons in 2014. Thus, each inhabitant generated 3.7 kg WEEE. The Americas follow after Asia, reaching 11.7 million tons of WEEE in 2014. While North America is the main generator (7.9 million tons) of WEEE among the Americas, Central America is the smallest one with 1.1 million tons. South America forms 2.7 million tons of WEEE, and as a result, every inhabitant is related to 12.2 kg of WEEE. Europe counts to the highest per inhabitant WEEE producer with slightly over 15 kg per inhabitant. Ocean produced the lowest amount of WEEE with 0.6 million tons in 2014. Nevertheless, the inhabitant quantity of WEEE was 15 kg per inhabitant, which is almost as high as the European ratio. Africa produced nearly 2 million tons of WEEE, and had the lowest per inhabitant WEEE generation (1.7 kg/inhabitant) fraction (Baldé, 2015).

Nonetheless, another aspect of WEEE is the growing informal sector, where the amount of shipped and disposed WEEE is unknown and can hardly be estimated. The informal sector corresponds to the increase of WEEE generation and supply. The more EEE with economically valuable components, for instance, gold, indium or copper, the higher is the interest for the informal sector to be part of the recovery phase. The most famous and criticized informal sector is located in Guiyu, China. It has gained global media presence among informal recyclers. The factory receives through transboundary trade of products and raw materials of WEEE from all over the world. Their work is focused of the extraction of valuable resources, especially gold and copper, without proper technology and protection conditions for the workers. By that the informal recyclers release harmful and toxic materials of EEE, causing negative effects on the environment and public health. The common recycling practices are open burning of cables for copper recovery, destroying CRT monitors

for the recovery of copper, and soaking of PCB (Printed Circuit Board) in acidic liquid. These are highly toxic practices where soil concentrations, PCDD (Polychlorinated Dibenzodioxin), PCDD/Fs (Polychlorinated Dibenzodioxin and Dibenzofurans), and PBDD/Fs (Polybrominated Dibenzodioxin and Dibenzofurans) are being produced (Estrada-Ayub/Kahhat, 2014).

The tremendous rise of WEEE supply and generation and the effects of the informal sector stress why the topic of proper WEEE legislation, collection, treatment, handling, and final disposal is of high importance for regional, national and international agendas.

2.2 WEEE in Peru

Peru is in an economic and technological process of development, being able to provide a higher level of living conditions. On the one hand the country still suffers from the majority of the population living in poverty, and on the other hand it experiences a rising consumption rate of EEE because of the economic improvements (IPES, 2011).

The ICT (Information and Communications Technology) sector of Peru records high growing rates, which lead to resource and environmental issues. In particular, the WEEE actors have to deal with lack of financial support, financial capacities, commitment to complex recycling regulations and the release of hazardous substances from EEE. Moreover, the sales data of EEE show constant increases, which will be transformed to more WEEE in the near future. Additionally, the technological advancement indicates progress of the quality of life in Peru.

The Peruvian WEEE market has as well experienced a significant increase. The volume of WEEE rose 26 times in the last 15 years. An estimate indicates that more than 100.000 tons of EEE have entered the Peruvian market in 2014. The biggest imported part is of category 1, having 40%, followed by the WEEE category 4 with 30%, 20% of category 3 and the 10% consisted of tools for the construction and textile industry. (Sustainable Recycling Industries, 2015) The computer market reached the quantity of monitors for approximately 30.000 US dollars. A rise of computer monitors and desktops to 70% is expected. There are 4 million computers and items used in Peru (ITU et al., 2016). According to estimates 0.13 million tons of computers and its components were disposed in 2015 (IPES, 2011).

Peru is one of the few among Latin American countries that has made substantial improvements in the WEEE regulatory framework, having several legal regulations. Besides Peru, also Argentina, Bolivia, Colombia, and Ecuador have national regulations. Additionally, Brazil, Mexico and Costa Rica introduced the R2-certified recycling facilities. In Central

America, Costa Rica is the only country with an implemented national legislation of the WEEE management. However, a lack of legal framework incentives, environmental awareness of EEE exposures and lack of WEEE training for recycling practices marked the last years in Peru and other Latin American countries (Baldé, 2015).

Since there are no industrial production factories of EEE in Peru, all the EEE are imported to the local product offices. Companies with certificates and licenses of disassembly of EEE can be found in the computer market. They import or purchase recycling equipment from foreign countries to adjust them in Peru and commercialise the disassembled items. Even though these offices comply with the requirements and norms, which are imposed by the government, they pursue their individual capacities, programmes and criteria in regard to WEEE. However, the companies do not yet completely have environmental responsibility for the treatment, handling and final disposal of EEE (IPES, 2011).

The Peruvian government and recycling authorities are aware of the increasing number of computers and monitors in the country. As a result, several initiatives were implemented in certain districts of Lima. MINAM (Ministry of Environment of Peru) started public campaigns for the collection of EEE and they collected 21 tonnes of WEEE in 2010 and 2011 in Lima. In addition, collection initiatives in Lima, Callao, Huancyo and Trujillo came to a result 14 tonnes WEEE in 2012. All the collected WEEE was recycled and treated in an appropriate manner by licensed recycling companies (ITU et al., 2016).

Furthermore, the promoted project “Corporate Social Responsibility for the Management of Waste of Electrical and Electronic Equipment in Peru – PERU e-waste” is conducted in collaboration with MINAM, the Swiss State Secretariat for Economic Affairs and EMPA (Swiss Federal Laboratories for Materials Science and Technology). The purpose of the project is to foster the living standard of the population by the management of formal WEEE mechanisms, to improve sustainable economic activities and to mitigate the effects on the environment (MINAM, 2014).

However, the informal sector of EEE in Lima also has to be considered. The informal purchasers work without any safety protection conditions and commitment to regulations. The main markets of used computers and monitors are located in the areas Jíron Leticia, Las Malvinas y Wilson (Galerías Wilson). Jíron Leticia has its focus on the purchase of monitors, PCU, components and printers, while Las Malvinas is concentrated on used cell phones. Additionally, these markets provide services of acquisition of spare items, and of services of repair. There is no accurate date of the sold EEE in the informal sector.

2.3 Regulatory Framework of WEEE

2.3.1 Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal is a global treaty, which entered into force on 5 May 1992 and is ratified by 53, signed by 182 parties. Its objective is to minimize the international movement as well as the generation of hazardous wastes and ensure their environmentally sound disposal thus protecting human health and the environment from the adverse effects. One of the major concerns was the transfer of hazardous wastes from industrialized countries to less developed countries for cheap disposal. With the introduction of a controlling system for the export, import, final disposal and trade of this type of wastes at international level, the Convention aims the reduction of the volume of hazardous waste to protect human health and the environment (EUR-lex, 2006). Furthermore, there are provisions that specify the categories of waste classified as hazardous regarding toxicity and flammability (UNEP, n.a).

The Convention states that transboundary movement of wastes from the party of generation to any other party is only allowed under the condition of not harming human health and the environment. Additionally, a prior informed consent has to be applied before any export or import takes place. In particular, the exporting state requires a prior written approval of the importing state ensuring compliance with regulatory requirements for movement of hazardous wastes. All parties of the Convention are able to ban exports or imports of such wastes. The states might enter into bilateral or multilateral agreements with parties or non-parties, in conformity with the terms of the Basel Convention (Basel Convention/UNEP, 1992).

The Convention provides for the full ability of the parties to protect their own environment and to decide whether the transboundary movements of hazardous wastes might have negative impacts on the environment. The parties must cooperate with each other to achieve a sustainable and environmental-friendly transboundary transfer of hazardous wastes (Basel Convention/UNEP, 1992).

Peru ratified the Basel Convention on 23 November 1993 and entered it into force on 21 February 1994 (Basel Convention, 2011).

2.3.2 Stockholm Convention

The Stockholm Convention on POPs is an international legally-binding agreement, which has been ratified by 180 countries. The Convention entered into force on 17 May 2004 and has the objective to protect human health and the environment from POPs including by-products, pesticides and industrial chemicals (IPEN, 2016).

POPs have a long-range transport capacity in the environment and are therefore geographically widespread. These chemicals accumulate in the tissue of living organisms and are highly toxic. As they can travel long distances they are found throughout the world causing heavy damage to humans and the environment. The aim of the Convention is to take measures for the elimination or reduction of production, use and release of 12 POPs, the so called “dirty dozen” (UNIDO, n.a).

The following 12 types of POPs are listed in annexes of the Convention:

- Aldrin
- Chlordane
- Dieldrin
- Endrin
- Heptachlor
- Hexachlorobenzene
- Mirex
- Toxaphene
- Polychlorinated biphenyls
- DDT
- Dioxins
- Furans (Secretariat of the Stockholm Convention, 2004).

The Convention also aims to support the transition to safer alternatives to POPs and to look for further POPs to eliminate. Another goal is to clean up old stockpiles as well as industrial equipment that contain POP components. The parties of the Convention are required to take action to reach the goal of eliminating or restricting the production and use of POPs and PCBs.

Peru ratified the Stockholm Convention on 14 September 2005 and entered it into force on 13 December 2005 (Stockholm Convention, 2008).

2.3.3 National Regulation on the Administration and Management of WEEE

In 2012, Peru adopted a national law, i.e. "Supreme Decree No. 001-2012-MINAM" (Reglamento Nacional para la Gestión y Manejo de los Residuos de Aparatos Eléctricos y Electrónicos) in 2012. Additional provisions were applied under Ministerial Resolution No. 200-2015-MINAM in 2015 (RAEE, 2016).

The 2012 Peruvian WEEE decree is based on the EU WEEE Directive, including the EPR (Extended Producer Responsibility) principle. EPR is a legislative approach that gives the manufacturer of the product the responsibility for the recycling or final disposal of the post-consumer product. The objective is to reduce toxicity and prevent risk to the health of the population and to the environment. As stated in Article 2 the WEEE decree applies to anyone in Peru involved in the management of WEEE (RAEE, 2016).

In addition, the Decree clarifies conditions and requirements for the submission of the ten WEEE categories. Manufacturers are required to design management plans to ensure environmental-friendly recycling mechanisms and processes. The procedures aim to start with IT and consumer equipment, as they form the main part of WEEE. These plans include basic information about the producer and waste life cycle. The WEEE plans have to be approved by either the Ministry of Production or the Ministry of Transportation and Communication (MTC) of Peru. Producers have up to six months for the implementation of their plans and they are obliged to report annually on the progress made. Currently, there are 48 plans for the WEEE management in Lima (Ott, 2013).

The 2015 Ministerial Resolution requires that manufacturers of equipment in WEEE categories 1, 2 and 5-10 to submit their WEEE management plan within 12 months of adoption. The submission of revised plans is required by manufacturers of the categories 3 and 4 within six months. It incorporates collection targets of 4% in year 1, aiming a rise of 16% in year 5. The purpose of this regulatory framework is to ensure solid WEEE recycling management and to monitor the weight of EEEs and the development of the plans (RAEE, 2016).

Furthermore, there are two technical standards ("Normas tecnicas"), NTP 900.064 and NTP 900.065. They focus on the collection, transport and treatment of WEEE and provide measurements for the control of different types of EEE, which are appropriate for the environment. The ultimate goal is to prevent, reduce and mitigate the environmental impacts

possibly generated impacts during the recycling process on the environment (INDECOPI, 2014).

3. Methods

The used methods are based on the MFA and the research field trip to Peru, Lima in February 2016. During the research stay interviews were conducted with experts of MINAM, NGOs, private and public sector; and visits were taken to the informal recycling sector (See detailed information in Appendix I). The MFA is the central mean for providing the situation of the processing of LCD monitors in Peru and to analyse possible recycling policies and initiatives.

3.1 Material Flow Analysis

The Material Flow Analysis is applied according to Brunner and Rechberger, using the software programme STAN. The aim here is to demonstrate the strengths, weaknesses, sensitive environmental areas, and political and legal insufficiency of the recycling processes of LCD monitors in Peru. The MFA evaluation provides the development of potential legal policies and the status quo of environmental challenges associated with this issue.

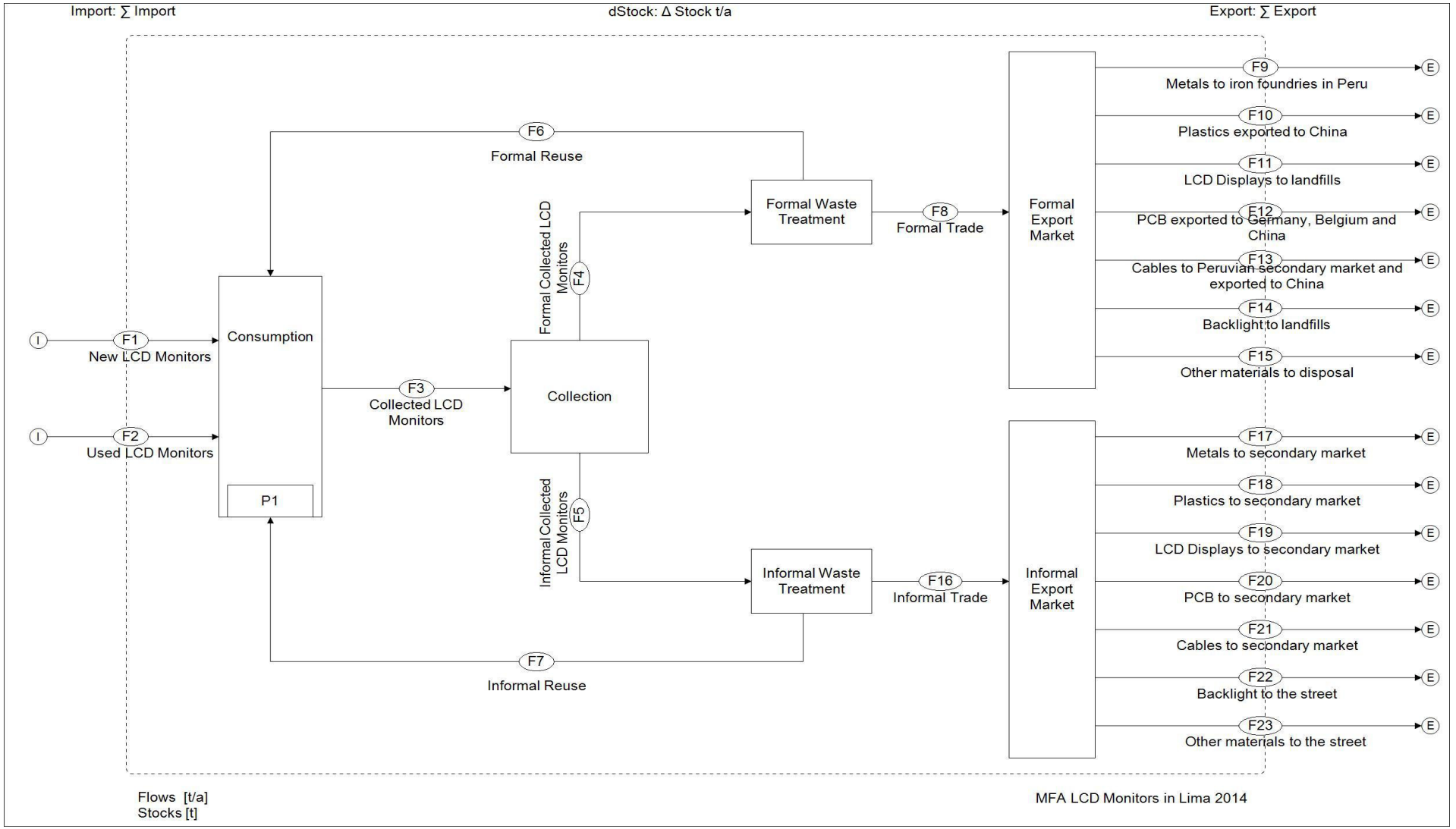

Figure 1: MFA LCD Monitors in Lima 2014
Source: Author

3.2 Definition and Description of Processes and Flows

The following chapter explains the processes, stock and flows for reasons of clarification. There are 6 processes and 23 flows used and they are described according to the structure of the MFA.

Consumption Process (P1)

The MFA starts with the flows of new (F1) and used LCD monitors (F2) in Lima (imported in 2014), which flow to the consumption process. The process of consumption does not distinguish between different types of consumers. It is rather the overall consumption of these monitors by the population. Both monitors are used from different consumers, for example, households, the public and private sector. Obsolete and end-of-life monitors are transferred by the flow F3 (Collected LCD Monitors) to the collection process (P2). In addition, the consumption process has a stock, because not all imported LCD monitors are disposed for treatment and handling purposes. A part of the monitors is still in use and as a result, the stock increases by tonnes per year (t/a).

Collection Process (P2)

The collection process includes LCD monitors, which are handled, dismantled and treated in the next steps by the formal and/or informal recycling sector. It shows the general amount of collected computer monitors in the system. After the consumption process, recycling companies, and/or municipalities and informal recyclers collect the products. (See detailed information in Appendix 2)

Formal Waste Treatment Process (P3)

The formal waste treatment process indicates that authorized operators with the licenses EPS-RS and EC-RS (further information in chapter 3.4.2) handle, dismantle and treat the collected LCD computer monitors. The flow formal collected LCD monitors (F4) delivers the amount of LCD monitors, which are intended for further treatment. The biggest WEEE recycling firms are San Antonio Recycling, COIPSA, Peru Green Recycling and Comimtel in Peru, which collect, transport or receive various types of WEEE for further processing.

Informal Waste Treatment Process (P4)

The informal waste treatment process is based on handling, dismantling and treatment mechanisms of LCD monitors. The flow informal collected LCD monitors (F5) provides the

monitors for processing. It occurs by informal collectors and recyclers. The operations are not undertaken by formal registration, equipment, facilities and working protecting conditions in this process. There is no accurate data about the quantity of LCD monitors collected, handled, dismantled and treated. The people involved in this process pursue unsophisticated operation performances.

Formal Export Market Process (P5)

The formal export market process is composed of dismantled and treated components of the LCD monitors. It receives the ingredients of the monitors by the flow formal trade (F8) for export and disposal purposes. The materials and substances of the monitors are distributed according to their final disposal destination. The formal WEEE recycling companies are obliged to record quarterly reports about the monitors in this process.

Informal Export Market Process (P6)

The informal export market process includes the monitors after their handling, disassembly and treatment. The items for the export activities are delivered by the flow F16 without authorized means. The purpose of the process is to export the different materials of the LCD monitors for economic reasons.

There are a total of 23 flows in this MFA.

New LCD Monitors Import Flow (F1)

The flows of the new (F1) and used LCD monitors (F2) stand for the imports at the beginning of the system. The new LCD monitors are imported to Peru for consumption use to the system. It is an import, which experience the entire WEEE recycling processes within the system. These monitors are transformed by human activities into wastes and harmful emissions, such as PCB, mercury, and arsenic, among others.

Used LCD Monitors Import Flow (F2)

The used LCD computer monitors are also import flows to the system and undergo a transformation into wastes. The flow is from the used LCD monitors to the consumption process. They are delivered for the Peruvian population's consumption. The imports to the system end up either in sanitary well-managed sanitary waste disposal/not-well-managed final waste disposals or in exportation.

Collected LCD Monitors (F3)

The collected products are the flow from the consumption to the collection process, whereby the recycling companies or municipalities collect the used monitors. These are monitors that are obsolete, in their end-of-life phase or broken. They are accumulated in order to flow to the overall collection process.

Formal Collected LCD Monitors Flow (F4)

This flow stands for the number of collected LCD monitors that are linked from the collection to the formal waste treatment process for formal handling, disassembly and treatment.

Formal Reuse Flow (F6)

The formal reuse flow is linked from the formal waste treatment process to the consumption process, identifying the monitors that advance to reuse products. Additionally, it illustrates the collected amount of products at the waste treatment plants, which is delivered for reuse. This flow is accumulated directly to the stock of the consumption process. The reuse flow is constituted by the collection and formal waste treatment and addresses households and/or second and third users.

Formal Trade Flow (F8)

Flow 8 indicates the link between the formal recycling processes and export process. These disassembled LCD monitors of flow 8 are delivered to the formal export market process for economic and sanitary reasons.

Metals to iron foundries in Peru (F9)

Flow 9 shows the quantity of metals of disassembled LCD monitors, which is delivered to iron foundries in Peru for operation.

Plastics exported to China (F10)

The flow 10 indicates the amount of plastics after the handling and dismantling that is exported to China for specialized work procedures. Many of the plastics are flame retardant grades, such as PBDEs, and they can cause harm to the environment. Therefore, they need to be treated by appropriate mechanisms. Since this type of technology is not given in Peru, plastics are sold to foreign parties.

LCD Displays to landfills (F11)

The magnitude of LCD displays is shown by this flow. LCD displays are transmissive and contain various hazardous substances. Mercury is found within the CCFL (Cold Cathode Fluorescent Lamps), which is highly toxic. As a result, LCD displays count to be harmful during the dismanlting and disposal phase. These items stay in the country, but are disposed in sanitary and well-managed final disposals to reduce their potential risk of hazardous releases. The sanitary landfills, where the formal waste treatment process disposes the components of LCD monitors, are approved by DIGESA (Health Ministry's General Health Bureau).

PCB exported to Germany, Belgium and China (F12)

The flow of PCBs illustrates the quantity of PCBs exported to Germany, Belgium and China. PCBS are of environmental concern due to its chemical ingredients. They contain valuable substances, for instance, gold, silver and palladium, but they also consist of lead. PCBS might expose toxic emissions, such as furans, dioxins, and acids, if not properly treated (Williams et al., 2008). Peruvian recycling firms do not have the appropriate equipment and technologies for the treatment of PCBs. Therefore, they export them to Germany, Belgium and/or China.

Cables to Peruvian secondary market and exported to China (F13)

This flow indicates the tons of cables dismantled from the LCD monitors. Their content is based on copper, which requires appropriate facilities for further treatment. Thus, they are sold to secondary markets within Peru for reuse means or exported to China. The copper part has an environmental implication, if not treated in an appropriate manner and can be harmful for a person's health during the dismantling process.

Backlight to landfills (F14)

The magnitude of backlights in the system is shown by the flow 14. The LCD displays are not able to generate energy and demand backlights for the production of colours. The backlight structure of LCD monitors is based on CCFLs. Besides producing high power, CCFLs contain mercury for the generation of vapour discharges (Tyagi/Chatterjee, 2013). Mercury has a liquid phase and counts to the only metals within the periodic table with a liquid state (Swico Recycling, 2011). As a result, backlights are disposed in sanitary landfills in the region of Lima to avoid the highly complex dismantling phase of backlights.

Other materials to disposal (F15)

Other materials are considered to be other not useable wastes. In particular, it does not have any value for export or recovery.

Informal Collected LCD Monitors Flow (F5)

The informal collection flow indicates the amount of monitors being relocated to the informal waste treatment process for operation activities.

Informal Reuse Flow (F7)

The informal reuse flow shows the magnitude of LCD monitors delivered from the informal waste treatment to reuse means, as they have potential for reuse. During the collection phase several LCD monitors that are in still good condition may be transferred to the stock. Particularly, they are often sold to reuse markets where the monitors are either sold as whole or disassembled for resale in parts.

Informal Trade Flow (F16)

This flow is a connection from the informal waste treatment to the informal export market process. It consists of the dismantled materials and components of LCD monitors, which are delivered to the export process for economic and business reasons.

Metals to Secondary Market Flow (F17)

The amount of metals of the informal sector is shown by flow 17. Since there are no formal facilities for metals, they are sold to the secondary market.

Plastics to Secondary Market Flow (F18)

The plastics of the monitors are illustrated by flow 18 and they exit the system to secondary markets. However, their dismantling and handling might release hazardous substances (PBDEs), as mentioned earlier. PBDEs are highly toxic for the surrounding area of treatment and for the workers involved. Especially, the informal sector faces these issues due to a lack of financial capacities, facilities and technologies.

LCD Displays to Secondary Market Flow (F19)

Flow 19 stands for the quantity of LCD displays treated by the informal sector in the system, leaving it by purchases to the secondary market. Their disassembly requires detailed work and expertise. However, generally the entire LCD displays are sold in secondary markets.

PCB to Secondary Market Flow (F20)

The amount of PCBs of the informal sector is demonstrated by the flow 20 in the system. The informal waste treatment process performs without protectoral equipment, exposing themselves under hazardous emissions. The PCBs include valuable materials, which encourage informal collectors to extract them. The extraction of gold and silver is related to toxic exposures to the environment due to the handling mechanisms. Their recovery and continuous existence is of significant economic interest in the informal sector. The remove of gold and silver is managed by acid leaching, taking place next to rivers. During this activity heavy metals are released to the waters (Williams et al., 2008). In addition, they contain PBDEs, which have negative impacts on the environment, if it is disposed in not-well-managed landfills, such as on the street or in some gardens.

Cables to Secondary Market Flow (F21)

This flow is a mean to show the amount of cables exiting the system to secondary markets. The informal export market has an economic interest in the cables due to its copper content. They are burnt in open piles, achieving the remove of the casings and the extraction of copper, which is sold to secondary markets (Williams et al., 2008).

Backlight to the Street Flow (F22)

The backlight to the street flow indicates its quantity leaving the system. They are disposed on the street, not considering their harmful impact in not well-managed final disposals. Due to its hazardous substances, such as mercury, the backlights have potential to leach to soil and water areas. As a result, eutrophication might be a negative side effect (Tyagi/Chatterjee, 2013).

Other Materials to the Street Flow (F23)

The flow of other materials indicates not usable wastes and it is not of environmental concern. After the informal export market process in the MFA, it is not as important as the other flows. The flow 23 is disposed on the streets.

3.3 System and Data considered

The scope of the study considers LCD monitors, and not only the screen, display or other components. The entire monitor equipment is analysed in the MFA. The system refers to the capital of Peru, Lima and evaluates the period of 2014.

The CRT has been the dominant application technology of television and computers for the last 80 years. However, the LCD display and monitor technologies have evolved rapidly and introduced 10 years ago the full colour display technology. The change from CRT to LCD has led to an almost complete extinction of CRT supply. At the same time, the amount of CRT recycled has experienced tremendous increase. Especially, its older technology differs from the one in regard to the materials used in each type of display (Goosey, 2012).

Since LCD monitors are the most widely used types in Lima and comprised of several different layers and complex recycling operations, it is interesting to analyse their collection, recycling, treatment, disassembly and final disposal in the system. The imports to the system end up either in sanitary well-managed sanitary waste disposal/not-well-managed final waste disposals or in the recovery process. The waste disposal processes are not divided as such. Due to their chemical ingredients, majority of the LCD monitors is found in the exports for further processing or recovery means and/or in landfills. The recovery process aims to extract the valuable substances from the formal recycling process for industrial and economic purposes. In particular, the system demonstrates the pathways from new and used LCD monitors in use to obsolete and end-of-life monitors to their handling and dismantling treatment by the formal and informal sector, to their disposal, export or sale to secondary markets.

The data of the system of LCD monitors in Lima in 2014 is mainly based on statistics and reports of SUNAT (National Superintendency of Tax Administration), IPES (NGO for Promotion of Sustainable Development), EMPA, MINAM, Swico (Swiss Economic Association for the Suppliers of Information, Communication and Organizational Technology), academic studies and conducted interviews during the research trip to Lima. SUNAT is the Peruvian customs agency and provides data about imported and used LCD monitors. It publishes annually figures related to the above mentioned products. However, SUNAT is not responsible for the WEEE management operations, namely collection, handling, dismantling, treatment and disposal.

IPES is a local NGO, specialized in sustainable development of WEEE, urban agriculture, urban forestry and green areas, water and sanitary facilities and environment studies (IPES, 2016). It works closely with EMPA and plays an observer and mediator role in the entire WEEE management process towards the Peruvian legal framework. Nevertheless, IPES has a crucial position in the WEEE management. EMPA initiated the WEEE project in Peru in 2007. They conduct research studies in cooperation with IPES, in particular about monitors, refrigerators, cell phones and the informal sector, among others. The information about the informal waste treatment process is partly used from IPES sources. Moreover, MINAM has some data about the imports of monitors, but their information also comes from SUNAT.

As mentioned earlier, the four main licensed companies perform the formal recycling process. They are obliged to record and provide a quarterly report of the numbers of their handled, dismantled and treated WEEE products, which is delivered to MINAM. The Peruvian WEEE recycling management is considered to be one of the more advanced among Latin American countries. Nevertheless, the inventory of the delivered, disassembled and recycled LCD monitors is not accessible for the public. There are only estimates available on the collection, reuse, formal waste treatment and final disposal processes. For example the recycling infrastructure of WEEE categories 3 and 4 is based on the formal recycling capacity of approximately 15- 20% and the estimates of the informal sector capacity varies from nearly 50-70% of WEEE. The latter percentage relates to the general amount of WEEE and not specifically to LCD monitors. Since there is no obligation to keep track of the number of LCD monitors in the informal waste treatment process, there is no accurate data about the monitors handled in the informal process. Additionally, it is estimated that 40% of WEEE is stored either in households and/or second and third use. The level of data uncertainty is high.

In general, SUNAT is the main provider of concrete data to perform the MFA of LCD monitors in Lima. The import flows of new and used LCD monitors are based on numbers of SUNAT. The flows of reuse of the formal and informal sector are included to illustrate the quantity of LCD monitors being handled in the waste treatment process and being delivered for reuse purposes. The materials considered are chosen to figure out the legal weaknesses and strengths and the potential harmful environmental exposure.

The division of the collection process into formal and informal is necessary to present the significant amount of LCD monitors, which are not processed under the formal legal framework. A higher amount of monitors in the informal sector also means an uncertain level of various hazardous substances release, such as mercury, to the environment. In addition, the

both waste treatment processes are divided into the consisting materials of LCD monitors in order to analyse the management of the disassembled components. The structure of the flows of the different ingredients, which are disposed in the export market processes, is based on a study by Swico. Considering the Swico report, the materials of LCD monitors were chosen for the MFA. Some of these components pursue strict recycling manners, while others are exported to China, Belgium or Germany, or stay in Peru in sanitary landfills. It is important to evaluate which harmful substances of LCD monitors might have a negative impact on the environment and which substances should be regulated by legal authorities. All the considered materials in the system are precisely taken in order to recommend certain WEEE policies, local initiatives and means of recycling enforcement.

3.4 Three Scenario Analyses

The three scenario analyses focus on different amounts of waste to demonstrate the impact of several flows on the environment, capacities of the formal recycling technologies and the influence of the informal sector.

Peru has a population of slightly more than 30 millions and Lima has approximately 8.5 million inhabitants (World Population Review, 2016). The scenarios consider only waste management of LCD monitors in the capital Lima. The following analyses are based on a combination of impressions gained during the research trip, legal facts and situational assumptions of the Peruvian economy, which do not relate to the current status quo of Lima. The first scenario focuses on the enforcement of the reuse sector, the second scenario on the promotion of the take-back system and the third scenario deals with environmental issues.

3.4.1 Scenario 1 – Little Waste

The first scenario assumes that there is little waste produced by LCD monitors in the formal and informal recycling sector due to increased capacity building efforts of the government, financed particularly by MEF (Ministry of Economy and Finance of Peru) and MINAM.

MEF and MINAM implemented the pilot project “Let’s reuse it! – WEEE and EEE” and promote several reuse initiatives at schools, universities and the informal sector. Generally, the purpose of the capacity building project is to change the process of recycling, handling, dismantling and disposal in order to foster the reuse process of LCD monitors. The project has a time frame of 20 years. The intention is to create a solid reuse culture among citizens and recycling companies of WEEE in Lima. The baseline of the reuse culture automatically initiates a new type of business. The provided financial contributions provided by the stakeholders to the project and initiatives will annually adapt the outcomes to the circumstances.

MEF provides its expertise related to business start-ups, project management and new economic niches by holding training programs and workshops at schools, universities and the informal sector on a quarterly basis. They explain the value of several dismantled materials from LCD monitors emphasizing the benefits of a reuse culture and the prosperous business opportunities in this sector. The reuse start-ups are financed by the MEF and the MINAM. The responsibility to promote the purchase of used LCD monitors lies with the companies. However, MEF works directly with the WEEE recycling companies and informs them about the reuse options of their products. The firms are able to develop a reuse niche of LCD

monitors and/or to cooperate with reuse start-ups. Cooperation with the start-ups that purchase the monitors is a significant source of finance.

While MEF works with the recycling companies, while MINAM's main target partners are schools, universities and the informal sector. In addition to offering training programs and workshops, MINAM focuses on information exchange about sustainable and environment-friendly recycling techniques promoting the reuse culture. Another area of their concentration is clarification of negative effects of disposed POPs, PBDE and hazardous substances, if not properly treated. MINAM is keen on transferring knowledge about the environmental impacts of certain disposed materials in not well-managed landfills in Lima. They also emphasize that reuse of EEE should be considered as part of the recycling culture.

The project "Let's reuse it! – WEEE and EEE" aims mainly to attract the attention and interest of young people. Therefore, various training programs and workshops are held at schools and universities. The informal sector is important in this case, as it is responsible for the release of uncertain amounts of substances that are harmful to the environment. The targeted audience is considered to be greatly interested and willing to adapt to the reuse culture.

The project has the substantial purpose of providing knowledge, expertise and information about environmentally sound management of disposal. However, the reuse culture might be debatable for the WEEE recycling companies, because of uncertainties about their revenues. Nevertheless, the project ensures that the authorized recycling firms do not have any financial and economic losses. MEF, with its project management training programs and support for start-ups, secure appropriate prices for the provided used EEE. Depending on the decision of the recycling companies how many LCD monitors to treat, the treatment and handling work might change and/or be reduced to a certain level. Ultimately, there is little waste produced, disposed to landfills and exported to Germany, Belgium or China.

At the same time the purpose of the reuse pilot project and initiatives is to reduce the waste of LCD monitors in the formal and informal sector and to promote the reuse culture. The development of "Let's reuse it! – WEEE and EEE" has an influence on the system of the MFA. It is assumed that the formal sector's collection accounts for 60%and the informal collection for 40%. It is further assumed that both sectors separate the collected LCD monitors for reuse and recycling. Particularly, 75% of the collected LCD monitors are reused and 25% of the monitors are being treated and disassembled in the formal and informal treatment process.

As a result of the project's initiatives, the formal and informal collections split their collected LCD monitors for reuse and treatment processing. Since three quarters of the monitors are directly provided as entirely reusable products, MEF and MINAM achieved their goal of enhancing and promoting the reuse culture. The changing cycle of the final disposal in well-managed and not well-managed landfills encourages the opening of new business opportunities. MEF and MINAM were able to arouse interest in the establishment of a reuse culture. The targeted population of the project was encouraged to take part in the reduction of LCD monitor wastes. The reuse culture among citizens of Lima was developed, showing that people are aware of the harmful effects on the environment and identify opportunities of reuse businesses. Consumers are willing to buy and use second hand monitors. During the training programs and workshops it was also stressed that only well-functioning LCD monitors are being sold for reuse purposes. The recycling companies are responsible for the provision of such products.

Nevertheless, the cooperation between MEF, MINAM and the recycling companies was successful, as the firms purchased their collected LCD monitors for reuse, contributing to the rise of the consumption stock. Companies did not record any significant losses, because the reuse process offered a profitable area. Additionally, they continue to handle 25% of their collected LCD monitors. They keep working with their recycling team, co-workers and partners and use their recycling technology and laboratories for treatment, handling and dismantling. The recycling companies are in favour of providing used monitors in order to boost the reuse culture. Their participation is meaningful for the evolution and establishment of the reuse pilot project to increase the amount of used LCD monitors in consumption. Although the authorized recycling companies were not the main targets of the project, MEF and MINAM elaborated strong ties with these partners. MEF's partnership with the companies succeeded to widen their knowledge of project management, new economic niches convincing entrepreneurs about the value of handling WEEE, particularly LCD monitors, to strengthen the reuse initiatives.

The little waste of the formal and informal waste treatments is especially for MINAM a great achievement. The formal treatment process records less waste leaving the system. As a result, less hazardous substances end up in the well-managed and not well-managed landfills. MINAM and MEF succeeded to reduce the waste in the formal recycling area and the potential release of toxic materials to the environment.

“Let’s reuse it! – WEEE and EEE” purpose was to inform those who are involved in the informal recycling sector about the negative effects and to encourage them to shift to the reuse market. People at schools, universities, recycling companies and the informal sector decided to be involved in the opportunities of a reuse culture. The informal sector was a deep concern for MINAM and MEF due to the environmental exposure impacts, uncertain recycling techniques and economic revenues. However, the project of the stakeholders was successful by creating a solid reuse niche, informing the population and reducing the waste of LCD monitors.

3.4.2 Scenario 2 – Relatively High Amount of Waste

In the second case it is assumed that there is a relatively high amount of LCD computer monitor waste generated in the formal recycling process due to the lack of promotion of take-back systems in Lima.

DIGESA, MTC, MINAM, IPES and EMPA cooperate to reinforce the take-back systems of LCD monitors. EMPA initiated the partnership project to adjust the processing cycle of LCD monitors in Lima, taking Switzerland's take-back systems as an example. They have an agreement to work with the producers of the monitors and the five authorized WEEE recycling companies in Lima. The project has been implemented primarily to control the amount of WEEE, particularly LCD monitors, and to secure their appropriate handling. EMPA's objective is to strengthen the formal collection, recycling, handling, dismantling and final disposal, without considering the informal sector. Nevertheless, a relatively high amount of reused LCD monitors can be noticed in the flow from the informal collection to the consumption stock of the MFA.

The Peruvian National Law for the Conduct and Management of WEEE has its basis on the EPR. The purpose is to make the actors involved in WEEE and producers of EEE bear the responsibility of recycling and disposal of their products through a shared system of WEEE management. The shared system is a comprehensive and integrated one which includes the consumers, municipalities and WEEE operators (MINAM, 2012).

Implementation of this EPR based regulation ensured the establishment of facilities and collection points for LCD monitors and other EEE products in Lima. These locations are accessible to consumers for direct disposal of their EEE. From the collection points the EEE are taken to authorized firms for further processing, i.e. collection, handling, dismantling and treatment (RAEE, 2016).

The aim is the strengthening and appropriate application of recycling technologies and the mitigation of potential environmental issues. According to the Peruvian legislation producers, operators and consumers are required to take their EEE, in this case LCD monitors, to registered recycling facilities with EPS-RS (Certified Solid Waste Service Provider) and EC-RS (Commercial Marketing Company for Solid Waste) licenses. These are specific licenses that were introduced for comprehensive and formal management of WEEE, and approved by DIGESA. Authorized WEEE recycling companies possess these certificates. They collect, transport, treat WEEE to be discarded in well-managed sanitary landfills. Furthermore, they

carry out several activities, such as cleaning of public areas, collection and transport, treatment and final disposal of solid waste. They are also responsible for registering their technologies for toxic components. The holder of an EC-RS are operators who collect, transport, separate and treat WEEE with a commercial intention as authorized by law (INDECOPI, 2014).

However, based on the Peruvian WEEE regulatory framework EMPA, IPES, DIGESA, MINAM and MTC further supported the take-back systems. In the Swiss recycling system the producer takes the full responsibility for the implementation and the complete operation of WEEE. The financial baseline of this management system is a product based recycling fee which is introduced for LCD monitors in Lima (Nnorom/Osibanjo, 2008). Buyers of LCD monitors automatically pay a fee for processing the end-of-life of the product. Such fees constitute a solid source for the collection, transport and disposal of WEEE.

DIGESA's participation in the project is to secure adherence to recycling procedures, which are pursued by law, ensure protection of human health and reduce environmental issues as much as possible. DIGESA is also willing to offer workshops about the importance of appropriate and authorized recycling companies. MTC provides its facilities for capacity-building and financial support for the collection points of WEEE. MINAM shares the interests of DIGESA and aims to prevent and control harmful emissions of WEEE to the environment. Therefore, it is highly active in promoting and fostering take-back systems. EMPA and IPES take the role of suppliers, observers and mediators. They give mainly legal and technical guidelines for the enforcement of the take-back systems. However, their contribution is of substantial importance for the implementation and compliance.

The enforcement of the take-back systems leads to a relatively increased quantity of exports in the MFA. The focus is set on handling, dismantling and disposal. All monitors from the formal collected LCD Monitors flow are delivered for further processing. The collection of LCD monitors during the formal operation accounts 70% and 30% during the informal collection in the MFA. The formal reuse flow is zero and the informal process provides 50% of LCD computer monitors for reuse purposes.

Subsequently, the expansion and support of take-back systems in the formal sector indicates fruitful results. The cooperation between DIGESA, MTC, MINAM, IPES and EMPA is an important combination covering the fields of health, environment, economy, communications, politics and law. As a result of interactions and transfer of information with the producers of the monitors and the five authorized recycling companies in Lima, a number of actions were

achieved, i.e. introduction of the product based recycling fees, the enforcement of appropriate collection, handling, dismantling and final disposal technologies and an increased number of collection points. These results can be seen in the MFA.

The implementation of the recycling fees on LCD monitors generated a useful source for the processes of end-of-life monitors. It was a long legal procedure, which was mainly supported by EMPA and IPES. Additionally, EMPA recruited national experts to evaluate and compare the Peruvian and Swiss recycling system. This evaluation was a means for the elaboration of the recycling fees in Lima. The fees were developed by taking into consideration the Peruvian WEEE legislation, EPR and the current economic and financial circumstances. The producers of monitors and consumers of these items agreed on paying a small fee for the purchased LCD monitors to secure appropriate end-of-life strategies by companies with the EPS-RS and EC-RS licenses. This fee enables additional financial provisions for the formal recycling process and supports efforts to formalize the regulations and recycling and dismantling technologies in general. However, its implementation led to a relatively high amount of waste in the formal recycling sector. Since 70% of collected LCD monitors end up for formal processing, the project significantly reinforced the formal sector. The goal of the project to expand the take-back systems, secure and strengthen formal applied technologies for collection, handling, dismantling, treatment and disposal of LCD monitors has been achieved. The formal recycling process decided to use all their collected LCD monitors for dismantling, final disposal and exports. They did not provide their monitors for reuse, hence the formal recycling collection process did not participate in rising the consumption stock.

MTC was in charge of capacity-building of staff at collection points for LCD monitors within Lima. Additional collection points have been established with the support of the producers and operators of EEE. These additional facilities enable MTC, DIGESA, MINAM, IPES and EMPA to have an overview and control of the number of LCD monitors in the capital leading to secure processing and disposal. Therefore, the project reached 70% in the formal collection, handling and disassembly.

DIGESA and MINAM supported the aims of the project by providing workshops about the environmental effects of LCD monitors, if they are not properly treated. They informed the general population about the importance of correct and appropriate treatment of their computer monitors. The transfer and exchange of information is crucial in order to make people aware of potential negative impacts. MTC, DIGESA and MINAM's work was enhancing each other's approaches.

In addition, the relatively high amount of LCD monitor wastes is directly linked to the achievements of the cooperation project. An increased number of collection points, awareness-raising workshops, recycling fees and reinforcement of formal treatment contribute to the high quantity of wastes. The producers of the monitors and the recycling firms ensure appropriate dismantling, treatment and final disposal.

These companies have the expertise in dealing with dangerous components, and apply special attention and precision when dismantling of LCD monitors, particularly the backlights, including fluorescent tubes. If the fluorescent tubes are destroyed, mercury might released. Therefore, different components are carefully separated and those with hazardous substances are delivered to sanitary landfills, which include specialized processes for treatment (RAEE, 2016).

However, the project did not directly interact with the informal collection and recycling sector. Therefore, it is uncertain how the informal sector proceed with the incoming LCD monitors. DIGESA, MINAM, MTC, IPES and EMPA are not able to control the informal waste treatment.

Overall, the aim of the project to enhance the take-back systems by product based recycling fees and to secure and strengthen handling, treatment and disposal by licensed recycling companies has shown an expanded formal waste treatment of LCD monitors. The recycling fees were partly financing the operations costs, contributing to a relatively high amount of LCD monitor wastes in the formal sector. However, the stakeholders of the project missed to incorporate and analyse the informal sector.

3.4.3 Scenario 3 – High Amount of Waste

The third scenario deals with a large amount of LCD monitor wastes in the informal sector. It focuses on the environmental issues caused by informal handling, dismantling, treatment and disposal of the WEEE. The considerable quantity of waste occurs due to a donation of several thousand computer monitors.

In the last 5 years, Peru experienced remarkable economic growth and capital accumulation. The economic situation became a strong and solid pillar and trade ties with USA and European countries were deepened at the international level. Peru had substantial revenues from the electricity, mining and technology sector. With the growing economy, many foreign companies were interested to invest in certain sectors in Lima. Dell and HP were mainly interested in the technology and communication fields. Consequently, the firms offered close trading partnerships for the upcoming years. MEF and MTC were involved in the discussions and decided to work closely with them. Peru signed trade agreements with monitor producers Dell and HP.

MEF and MTC benefit from the relationship, because of the provision of technologically advanced items. These agreements offer them to further develop their economic and communication category. Additionally, HP and Dell suggested working with students to promote their HD monitors, attracting the attention and interest of primarily young people. Their objective is to stabilize their market among young citizens.

However, the large amount of wastes appeared due to a generous donation of Dell and HP. The companies offered to provide several thousand HD monitors to students. This offer was initiated because of an error in the packaging of the products. Dell and HP were not able to further sell the monitors. They had the opportunity to enhance the partnership with MEF and MTC based on this donation. They selected students from university institutions, who work mainly with computers. The majority of engineering and information technology students in Lima received the donated HD monitors for their studies and any other tasks.

The transfer of the HD computer monitors took place within a short period of time. The Dell and HP monitors were delivered at the universities, satisfying many students. Since these students work with sophisticated programmes and analyses, these high resolution were much welcomed. The Dell and HP monitors were intended for the private use of the students. The donation highly reinforced the cooperation with MEF and MTC.

As a consequence, the students had their obsolete LCD and the new HD monitors at home. They were not aware of the EEE end-of-life procedures. Dell and HP's focus was the promotion of their new products among young people and not to inform about the disposal of the used computer monitors. The donation of the new monitors was a good additional income support for students. Therefore, not knowing about formal collection points for EEE, students sold their LCD monitors to not licensed shops and people from the informal sector. Instead of appropriate recycling processing, the monitors are handled under unauthorized circumstances, causing harmful effects to the environment.

In spite of this, there are some people, who collect WEEE and EEE on the streets. They are called "cachineros" in Peru. The term is used for people who collect or buy recyclable goods that can be resold for a profit. They are either on foot or use modified tricycle carts. This type of work takes place in the informal process. It is estimated that 10,000 persons make a living as waste pickers in the streets of Lima. Besides the collection of EEE, they also dismantle and recover inorganic materials, including displays, plastics, ferrous metals and non-ferrous metals. They live for an economy of subsistence and work under severe conditions causing impacts on their health (IPES/WASTE/SKAT, 2006).

In this case, students sold their LCD monitors primarily to "cachineros" who are easily to reach, and earned some money from the sale of the obsolete monitors. They were not aware of the precise recycling methods of the "cachineros". Upon collection, they sell the goods to various disposal areas, which can be found all over the capital. The workers at the disposal areas collect EEE according to their categories. Since there are no regulations, it is hard to assume handled, dismantled and disposed quantities of EEE by these informal collectors (IPES, 2011).

Many informal collectors handle and treat waste without following formal regulations, they simply leave contaminated parts of WEEE on public areas or informal disposals causing release of toxic elements and hazardous components. In addition, they collect the cables of obsolete EEE and burn them to obtain the copper contained in it. The plastics, which cover the cables, release carcinogenic components at high temperatures. The informal collectors do not protect themselves or the environment by sanitary or protectoral mechanisms. During the treatment toxic emissions are released which are harmful to the environment and to human health (RAEE, 2016).

The people in the informal recycling area focus on the recovery of reusable parts and materials from obsolete EEE. It is a source of income for poor communities. However, the

flow of plastics in the system contain PBDE in the casing which causes serious damage to persons during the dismantling process. The LCD monitors include PBDE for the cooling, which prevents extraordinary heating of the item. The plastic from the flow in the informal sector might be evenutally in secondary markets (El Comercio, 2014).

The flow of ferrous substances, such as metals, includes segments that are sold to third parties in the secondary market. Since there is no accurate data about the final destination of the products, they might be purchased by local companies or exported.

Despite the recycling of metals, the disassembly of PCBs are considered to be of high risk for the environment and informal collectors. Their content consists of precious and valuable materials, for instance, copper. The extraction of the materials occurs usually in the surrounding area of rivers. The “cachineros” burn the PCBs next to the river “Chillón” in Lima (El Comercio, 2014). Generally, acid and cyanide are used during this procedure. The emission of hazardous substances and metals happens by acid leaching of PCB nearby rivers. Moreover, the air is emitted by furans, dioxins and PAHs (Polycyclic Aromatic Hydrocarbon) are emitted to air. The handling of PCBs is highly dangerous and toxic for the environment and the people involved. The flow of PCBs is one of the main risks within the informal handling, dismantling, treatment and disposal. Nevertheless, it lacks regulations, capacities, data and technologies to observe, control and prevent the hazardous impacts of the processing of PCBs in Lima. The involved people are often not aware of the exposed toxic chemicals to the environment and to their physical conditions (Williams et al., 2008).

In addition, gold and silver are related to the extraction of PCBs. Gold is contained in PCBs, being of high interest for the informal collectors. However, the quantity of gold is minimal in monitors. The extraction requires advanced recycling technologies and expertise and knowledge about the processing. It also requires personal protection equipment for workers. In general, the recovery of gold involves high operation costs. There are only few companies worldwide who perform the task of gold recovery. They are located in Germany, Belgium, China and Japan. Technologies for the extraction of PCBs and other valuable materials do not exist in Lima (El Comercio, 2014).

Informal flow of backlights and LCD displays are also of concern due to the high magnitude of LCD monitor wastes. The CFL (Compact Fluorescent Lamps) and CCFL in the backlights of the monitors include mercury in gaseous form. According to estimates, CCFLs contain approximately 3 mg mercury per tube. LCD monitors dispose normally two, four, six or eight CCFL tubes, depending on the size of the monitor (Swico Recycling, 2011).

The dismantling of the fluorescent tubes in the monitors has to be carrioud out with great attention, because they are bery fragile and break easily. Since the informal collector does not use the appropriate equipment and technologies for this process, the likelihood that the mercury tubes will break is high. Consequently, there might be a contamination of mercury and emissions released to the recycling facilities (Goosey, 2012).

In particular, mercury exposure carries potential health concerns, affecting the structure of proteins and functions of enzymes. The nervous system is the most vulnerable organ of the human body. Mercury vapours are mainly inhaled by the workers. The lungs take up nearly 80% of these vapours, which are harmful for the blood circulation. Furthermore, mercury damages the throat, pharynx and oesophagus, in case of oral ingestion. The mercury contamination in the oral part of the body causes chemical burns and nausea. The major harm is caused to persons working in the informal sector handling, dismantling and treatment of LCD monitors (Swico Recycling, 2011).

Despite the impacts of the informal waste treatment process, Lima has 8 sanitary landfills, which is a low number considering a population of 8.5 million inhabitants. As a consequence, large amounts of LCD monitor wastes are disposed in informal locations. The well-managed landfills collect around 99% of the leachate generated by the disposed WEEE. Generally, the pollution of heavy metals and substances are small in appropriate disposal facilities. According to statistics, the leaching of hazardous parts of LCD monitors in not well-managed landfills may release harmful emission to the environment, but their proportion is small as well (Williams et al., 2008).

Overall, the partnership between Dell, HP, MEF and MTC might not idientified the side effects of their generous donation of HD monitors to students.

4. Results and Discussion

4.1 Results of MFAs

In the following the results of the three scenarios cases, namely little waste, relatively high amount of waste and high amount of waste, are described in general. The import figures are in all three case studies the same. All the figures of the MFA are in tonnes per year.

4.1.1 Scenario 1

The first case with little waste of LCD monitors occurred because of the promotion and initiatives of reuse activities organized by MEF and MINAM. The calculations are mainly based on using the transfer coefficient.

New and Used LCD Monitors Import Flows

Scenario1 has a total import of 280.963 and export of 39.335 tonnes per year (See detailed information in Appendix III). The exported is very low compared to the import, thus little waste leaves the system. The import flow new LCD monitors accounts 144.027 tonnes and the import flow of used LCD monitors is 136.936 tonnes. The figures are from SUNAT.

Consumption Process

30% of the total import stays in the stock of the consumption process, which are 84.288 tonnes. The calculation of the stock is the following: 280.963 x 0.3, resulting 84.288 tonnes.

Collection Process

While 30% of the imports flows to the stock, 70% is transferred to the collection process illustrated by the flow collected LCD monitors, having 196.674 tonnes. The collection process is divided by the formal and informal collected LCD monitors flow and is applied by the transfer coefficient. It is assumed that 60% of the collected LCD monitors is operated by formal waste treatment activities and the informal waste treatment process treats 40%. As a result, the flow to the formal waste treatment process is 118.004 tonnes and 78.670 tonnes are delivered to the informal treatment. Generally, the transfer coefficient is multiplied by the import → $Y_1 = TC_1 \times X$

Table 1: Scenario 1 Transfer Coefficient Collection Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Collected LCD Monitors	280.963 x 0.7	196.674
Formal Collected LCD Monitors	196.674 x 0.6	118.004
Informal Collected LCD Monitors	196.674 x 0.4	78.670

Formal Waste Treatment Process

The formal waste process delivers a certain amount of LCD monitors for reuse and for formal trade purposes. Consequently, the quantity of collected monitors is divided into two different flows. On the one hand 80% of the monitors are sent to the stock of the consumption by the reuse flow, and on the other hand 20% of LCD monitors are handled, dismantled and treated in the recycling process. For this calculation the transfer coefficient is applied. Thus, the formal reuse flow shows 94.404 tonnes and the formal trade flow 23.601 tonnes.

Table 2: Scenario 1 Transfer Coefficient Formal Waste Treatment Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Formal Reuse	118.004 x 0.8	94.404
Formal Trade	118.004 x 0.2	23.601

Consumption Stock

Due to the large amount of reused LCD monitors, the stock rises annually by 241.628 tonnes.

Formal Export Market Process

The formal export market process receives 23.601 tonnes from the formal waste treatment process, which is further applied by the use of the transfer coefficient. This process consists of 7 flows, which reveal 100% in total. Therefore, the formal export market process is split by a transfer of 39% to the metals export flow, 36.5% to the plastics export flow, 9.5% to the LCD displays flow, 8.5% to the PCB flow, 2.5%to the cables export flow, 1% to the backlight export flow and 3% are other materials.

Table 3: Scenario 1 Transfer Coefficient Formal Export Market Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Metals to iron foundries in Peru	23.601 x 0.39	9.204
Plastics exported to China	23.601 x 0.365	8.614
LCD Displays to landfills	23.601 x 0.095	2.242
PCB exported to Germany, Belgium and China	23.601 x 0.085	2.006
Cables to Peruvian secondary market and exported to China	23.601 x 0.025	0.590
Backlight to landfills	23.601 x 0.01	0.236
Other materials to disposal	23.601 x 0.03	0.708

Informal Waste Treatment Process

The informal waste treatment process provides a quantity of the collected LCD monitors for the reuse flow and another part is being handled, treated and dismantled in the waste treatment process. In particular, 80% of the monitors are transferred by the informal reuse flow to the consumption stock and 20% are handled for export and trade interests. The transfer coefficient is the useful mean for applying this distribution.

Table 4: Scenario 1 Transfer Coefficient Informal Waste Treatment Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Informal Reuse	78.670 x 0.8	62.936
Formal Trade	78.670 x 0.2	15.734

Informal Export Market Process

The informal export market process is divided into the different materials and components of LCD monitors, which are dismantled and handled in the informal waste treatment plant. The process is provided with monitors for informal trade purposes. The transfer coefficient of the informal export market export is divided the following: 39% to the metals, 36.5% to the plastics, 9.5% to the LCD displays, 8.5% to the PCB, 2.5% to the cables, 1% to the backlights

and 3% to other materials. The table indicates the result of the flows by the application of the transfer coefficient.

Table 5: Scenario 1 Transfer Coefficient Informal Export Market Process
Source: Author

Flow	**Transfer Coefficient**	**Tonnes**
Metals to Secondary Market	15.734 x 0.39	6.136
Plastics to Secondary Market	15.734 x 0.365	5.743
LCD Displays to Secondary Market	15.734 x 0.095	1.495
PCB to Secondary Market	15.734 x 0.085	1.337
Cables to Secondary Market	15.734 x 0.025	0.393
Backlight to the Street	15.734 x 0.01	0.157
Other materials to the Street	15.734 x 0.03	0.472

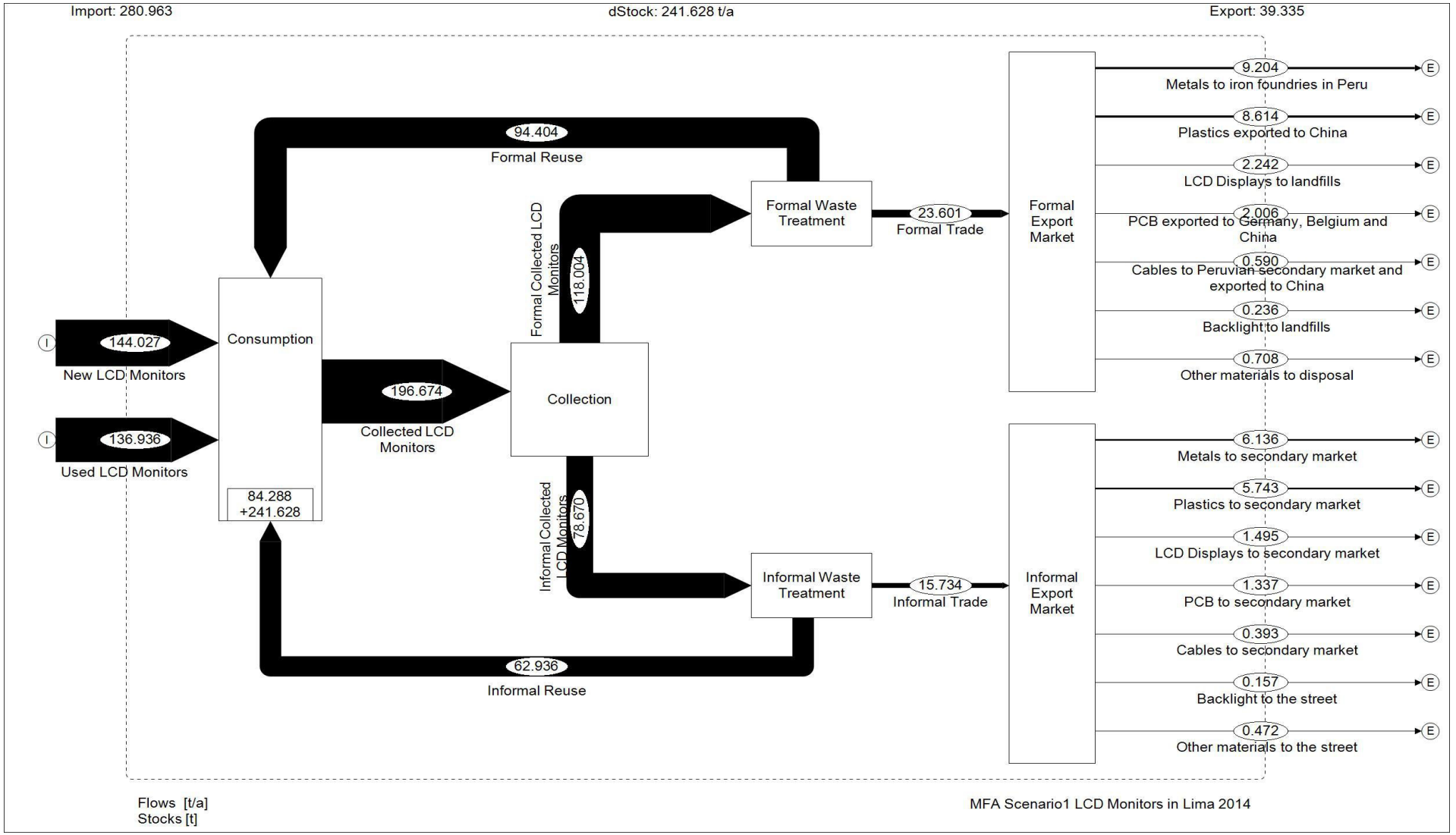

Figure 2: MFA Scenario 1 LCD Monitors in Lima 2014
Source: Author

4.1.2 Scenario 2

The second case with the scenario of relatively high amount of waste of LCD monitors takes place because of the strengthening of take-back systems and the introduction of product based recycling fees. The project is a cooperation between DIGESA, MTC, MINAM, IPES and EMPA. The transfer coefficient is the major mean for the calculations in the system.

New and Used LCD Monitors Import Flows

The total imports of the second case are 280.963 and export 167.173 tonnes per year. The imports stay the same, however the exports have significantly changed. More than half of the imports exists the system. It is a considerably high amount of components from LCD monitors. The import flow of new LCD monitors has 144.027 tonnes and the import flow of used LCD monitors is 136.936 tonnes.

Consumption Process

The consumption process stays with 30% of the total import, which flows directly to the stock. The stock accounts for 84.288 tonnes.

Collection Process

The collection process receives 70% of the imported used and new LCD monitors that are disposed after their end-of-life, thus it has 196.674 tonnes entering by the flow of collected LCD monitors. One part is undertaken by the formal collected LCD monitors flow, while the other part is collected by the informal sector. Particularly, 70% of computer monitors are collected formally and 30% informally.

Table 6: Scenario 2 Transfer Coefficient Collection Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Formal Collected LCD Monitors	196.674 x 0.7	137.672
Informal Collected LCD Monitors	196.674 x 0.3	59.002

Formal Waste Treatment Process

The formal waste treatment process has two flows exiting it. Zero percent are going to the formal reuse flow and 100% are transferred by the formal trade flow to the export market

process. 100% of the collected LCD monitors, which are handled, disassembled and treated in the formal waste treatment process experience the flow to the next process.

Table 7: Scenario 2 Transfer Coefficient Formal Waste Treatment Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Formal Reuse	137.672 x 0	0.000
Formal Trade	137.672 x 1	137.672

Formal Export Market Process

The delivery to the formal export market process consist of the collected and afterwards disassembled and handled LCD monitors, having 137.674 tonnes of monitors for trade activities. This process consists of 7 flows, where the transfer coefficient was used to calculate the various materials of the export flows in the system. As a result, the formal export market process transfers 39% metals, 36.5% plastics, 9.5% LCD displays, 8.5% PC, 2.5% cables, 1% backlight and 3% other materials.

Table 8: Scenario 2 Transfer Coefficient Formal Export Market Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Metals to Iron foundries in Peru	137.672 x 0.39	53.692
Plastics exported to China	137.672 x 0.365	50.250
LCD Displays to landfills	137.672 x 0.095	13.079
PCB exported to Germany, Belgium and China	137.672 x 0.085	11.702
Cables to Peruvian secondary market and exported to China	137.672 x 0.025	3.442
Backlight to landfills	137.672 x 0.01	1.377
Other materials to disposal	137.672 x 0.03	4.130

Informal Waste Treatment Process

The informal waste treatment process is distributed by applying the transfer coefficient. The informal reuse flow receives 50% and the informal trade flow has 50% as well.

Table 9: Scenario 2 Transfer Coefficient Informal Waste Treatment Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Informal Reuse	59.002 x 0.5	29.501
Informal Trade	59.002 x 0.5	29.501

Informal Export Market Process

The informal export market process is based on the same structure as the formal export market, but it has different flow destinations. The transfer coefficient calculates the several components of LCD monitors in the informal sector, considering 39% to the metals, 36.5% to the plastics, 9.5% to the LCD displays, 8.5% to the PCB, 2.5% to the cables, 1% to the backlights and 3% to other materials. The result of using the transfer coefficient can be seen in the table.

Table 10: Scenario 2 Transfer Coefficient Informal Export Market Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Metals to Secondary Market	29.501 x 0.39	11.505
Plastics to the Secondary Market	29.501 x 0.365	10.768
LCD Displays to Secondary Market	29.501 x 0.095	2.803
PCB to Secondary Market	29.501 x 0.085	2.508
Cables to Secondary Market	29.501 x 0.025	0.738
Backlight to the street	29.501 x 0.01	0.295
Other materials to the street	29.501 x 0.03	0.885

Consumption Stock

Since the formal waste treatment process does not transfer computer monitors for reuse, only the informal sector provides used LCD monitors. The stock increases by the amount of monitors of the informal waste treatment process. There is an annual rise of 113.790 tonnes of LCD monitors in use (See detailed information in Appendix IV).

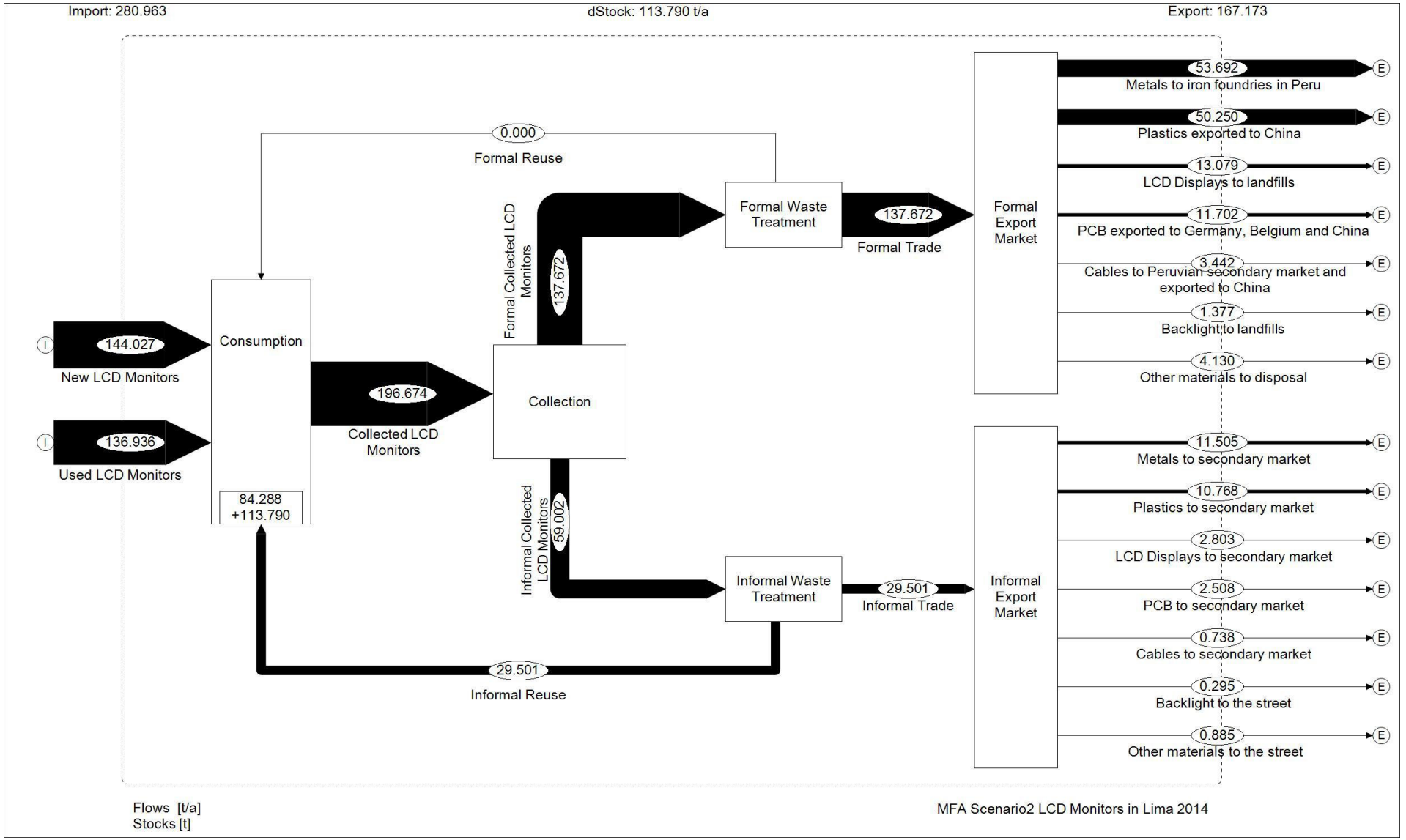

Figure 3: MFA Scenario 2 LCD Monitors in Lima 2014
Source: Author

4.1.3 Scenario 3

Scenario 3 deals with high amount of wastes due to the large magnitude of LCD computer monitors collected, handled, dismantled and treated in the informal waste treatment process. The third case study is about a donation of HD monitors from Dell and HP, who agreed on a partnership with MEF and MTC (See detailed information in Appendix V)

New and Used LCD Monitors Import Flows

As mentioned in the above scenarios, the import flows have the same figures: new LCD monitors 144.027 tonnes and used LCD monitors 136.936 tonnes. However, the export flows increased significantly. Almost all of the imported LCD monitors are transferred to the informal and formal export market, departing the system, particularly 196.674 tonnes of export flows.

Consumption Process

The total amounts of LCD monitors linked to the consumption process are 280.963 tonnes, while 30% is not transferred to the collection process. Thus 84.288 tonnes are accumulated in the stock of the consumption in the system. The total import is multiplied by the percentage 0.3, resulting 84.288.

Collection Process

The collection process assumes 70% of the importing flows of used and new LCD monitors. The quantity of the flow of collected LCD monitors is composed of 196.674 tonnes, calculating the following way: 280.963 x 0.7. However, the collection process has two flows leaving the process (formal and informal collected LCD monitors flow). The formal collected LCD monitors flow assumes only 10% in the third case study and the informal flow has 90% of collected LCD monitors. The larger amount is dismantled and treated by the informal sector. The calculation of the transfer coefficient of both flows is shown in the table.

Table 11: Scenario 3 Transfer Coefficient Collection Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Formal Collected LCD Monitors	196.674 x 0.1	19.667
Informal Collected LCD Monitors	196.674 x 0.9	177.007

Formal Waste Treatment Process

The formal collected LCD computer monitors are treated in this process. The process differentiates between the formal reuse and formal trade flow. Particularly, the reuse flow represents zero percent and the formal trade flow indicates 100%. Thus all the collected monitors end up for further processing. It can be seen how these both flows are calculated in the MFA.

Table 12: Scenario 3 Transfer Coefficient Formal Waste Treatment Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Formal Reuse	19.667 x 0	0.000
Formal Trade	19.667 x 1	19.667

Formal Export Market Process

The formal export market process has the most flows in the system. 7 flows are characterized in the evaluation. The dismantled substances and materials are provided for further economic trade activities or are disposed in sanitary well-managed landfills. The 7 flows are the following: 39% are transferred to metals, 36.5% to plastics, 9.5% to LCD displays, 8.5% to PC, 2.5% to cables, 1% to backlights and 3% to other materials.

Table 13: Scenario 3 Transfer Coefficient Formal Export Market Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Metals to Iron foundries in Peru	19.667 x 0.39	7.670
Plastics exported to China	19.667 x 0.365	7.179
LCD Displays to landfills	19.667 x 0.095	1.868
PCB exported to Germany, Belgium and China	19.667 x 0.085	1.672
Cables to Peruvian secondary market and exported to China	19.667 x 0.025	0.492
Backlight to landfills	19.667 x 0.01	0.197
Other materials to disposal	19.667 x 0.03	0.590

Informal Waste Treatment Process

The informal waste treatment process has the flow informal reuse and informal trade. The formal and informal sectors do not deliver any LCD monitors to the reuse flow. As a consequence, the reuse flows account for 0%. Nevertheless, 100% of the monitors, which are disassembled, are sent in order have an economic benefit of the products. The accurate numbers of the flows are described in the table. In addition, the stock does not increase by a provision through the reuse flow.

Table 14: Scenario 3 Transfer Coefficient Informal Waste Treatment Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Informal Reuse	177.007 x 0	0.000
Informal Trade	177.007 x 1	177.007

Informal Export Market Process

The last process in the system has the large amount of treated LCD monitors and generates high quantity of wastes. The considered flows of the informal export market process account 39% of the metals, 36.5% of the plastics, 9.5% of the LCD displays, 8.5% of the PCB, 2.5% of the cables, 1% of the backlights and 3% of other materials. The table indicates the calculation way and the result of the 7 flows.

Table 15: Scenario 3 Transfer Coefficient Informal Export Market Process
Source: Author

Flow	Transfer Coefficient	Tonnes
Metals to Secondary Market	177.007 x 0.39	69.033
Plastics to the Secondary Market	177.007 x 0.365	64.607
LCD Displays to Secondary Market	177.007 x 0.095	16.816
PCB to Secondary Market	177.007 x 0.085	15.046
Cables to Secondary Market	177.007 x 0.025	4.425
Backlight to the street	177.007 x 0.01	1.770
Other materials to the street	177.007 x 0.03	5.310

Consumption Stock

The informal and formal waste treatment processes do not provide monitors for reuse. Subsequently, the stock in the consumption process does not experience remarkable changes. It increases annually by 84.289 tonnes.

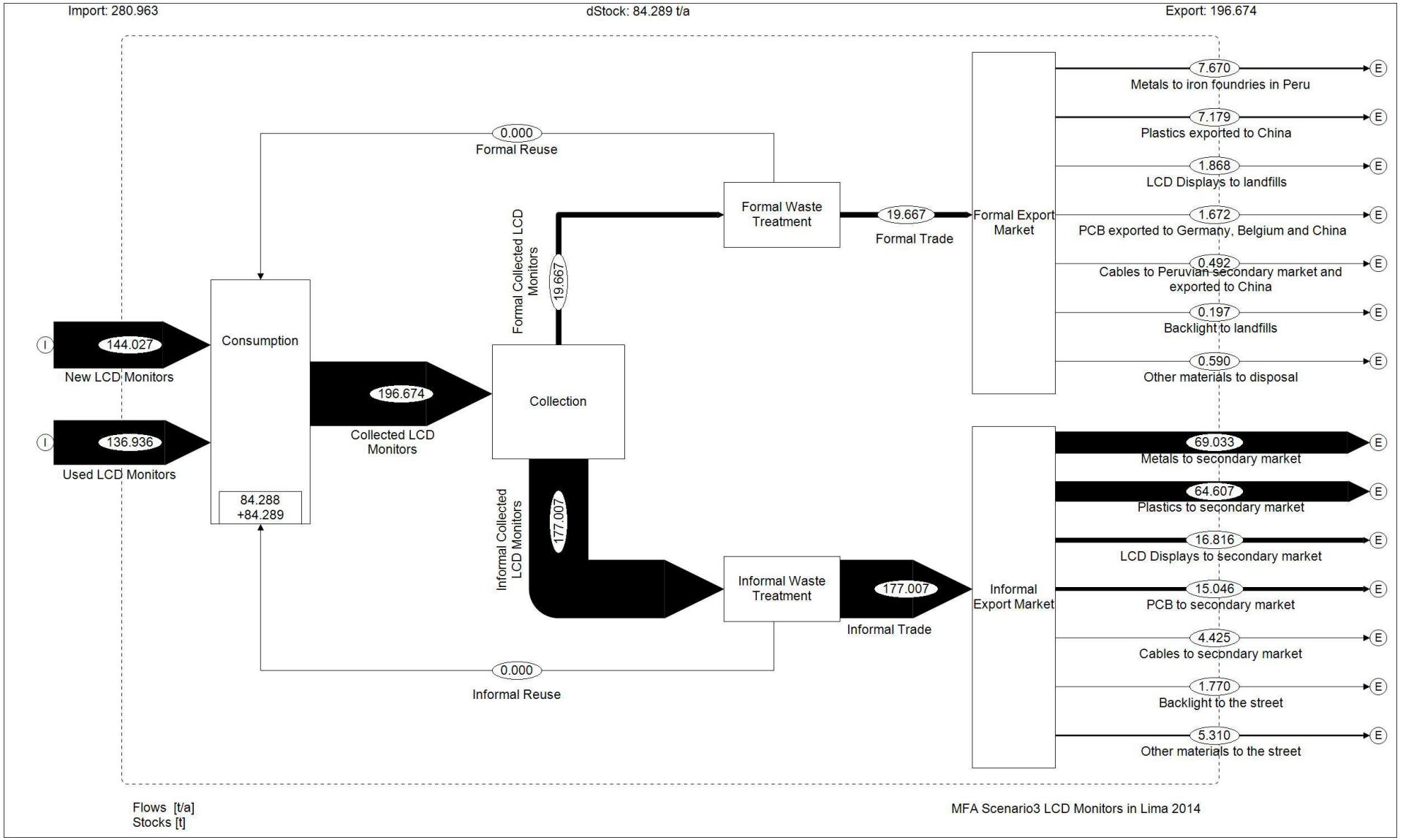

Figure 4: MFA Scenario 3 LCD Monitors in Lima 2014
Source: Author

4.2 Discussion of MFAs

4.2.1 Little Waste

The MFA shows the situation of Scenario 1, where the cycle of the LCD monitors after 15 years after the project "Let's reuse it! – WEEE and EEE" has been implemented. The enhancement of the formal and informal reuse flows are the central aim of the system. It shows that an alternative to disposal and export is feasible and profitable for businesses.

The number of imports of new and used LCD monitors stays the same. The stock of the consumption process, reuse flows and export flows have the most significant changes in the MFA. In general, the MFA has a decreased amount of waste leaving the system.

The collection process does not have deviations. It receives LCD monitors from different sources, which can be the public and private sector, and/or individuals. The collection part flows into two processes, the formal and informal collection of LCD monitors. The reuse flow reaches a higher number of LCD monitors, while the flows to the formal and informal waste treatment significantly decrease. The solid reuse niche, which flows to the consumption stock, has grown in the MFA, having a plus of 241.628 tonnes per year. The consumption stock increases because of the large number of reused LCD monitors in the system.

The little amount of waste and exports means that less harmful substances are released to the environment. A smaller quantity of metals is delivered to iron foundries in Peru. The amount of dismantled plastics from the LCD monitors, which is exported to China, has decreased. In addition, less LCD monitors are disposed in landfills in Lima by the formal and informal sector. The LCD monitor has different layers and backlights and the backlights include mercury content. If this type of display is disposed in not well-managed landfills, it might cause hazardous exposure to the environment. Since there is a reduced amount of LCD displays and backlights, the probability of hazardous impacts on the environment is less likely to happen. Backlights and mercury are disposed to a significant lower quantity in the landfills in Lima and the surrounding region. A higher amount of PCBs are processed and managed by the authorized recycling companies and exported to China, Germany and Belgium. The declined extraction and disassembly of PCBs, mercury and rare substances, such as indium and gold, have significantly reduced negative effects on the environment. The extraction of mercury and PCBs is highly toxic for those who are working on these parts and there is high concern regarding their final disposal. It is uncertain how mercury is treated and disposed in the informal sector. It might pose serious danger to humans, the surrounding area, including

plants and animals. At the same time, the lower amount of LCD monitors handled in the informal waste treatment process leads to a decreased potential of hazardous emissions caused by the informal sector. Furthermore, fewer cables from the monitors are treated and exported to secondary market. Due to its copper content it has environmentally concerning exposures.

Overall, the MFA has more imports flowing into the system than exporting flows out of the system. The imports overweight the export flows due to a reduction of LCD monitor wastes in the formal and informal process. The biggest part of monitors is transferred to the consumption stock because of the increased reuse activities.

However, the MFA proves that society's thinking of WEEE disposal can be changed to develop a reuse culture. The exchange of economic, technical and environmental information and expertise is the key mechanism. It is necessary to inform and develop an alternative to disassembly hence promoting the reuse culture among informal recycling participants and groups. The reuse culture reduces exposure to hazardous substances for human and the environment. As a result, it also mitigates potential harmful effects of mercury in not well-managed landfills.

Furthermore, it shows that a change of mind-set from constant disposal of products to reuse opportunities was initiated, proving that it is possible to change the disposal attitude of a society. However, the informal sector has to be a part of it. The contribution and inclusion of the informal waste treatment process is crucial to reduce LCD monitor wastes and to implement several reuse initiatives. In addition, the reuse culture offers new opportunities, for both, the public and private sector.

4.2.2 Relatively High Amount of Waste

The case study of relatively high amount of waste can mainly be regulated by the formal waste treatment process, if further recycling initiatives are introduced. Take-back systems combined with the introduction of product based recycling fees are key contributor for the amount of exports in this scenario. The MFA illustrates the achievement of the enhanced formalization of recycling operations. However, the Basel and Stockholm Convention have to be discussed and considered in the case of relatively high amount of waste.

As a matter of fact, the imports to the consumption process do not change. However, the stock of the consumption has slight changes due to the incoming used LCD monitors from the informal reuse flow to the consumption stock. The reuse flows are dominated by the informal sector. 50% of the computer monitors are linked to the consumption stock. Consequently, the consumptions stock increases annually through the imports of the informal waste treatment process.

The high number of wastes generated mainly by the formal waste treatment process, shows that the formal sector has been expanded, settled and commercialized. In detail, more components from LCD monitors are dismantled and treated by authorized recycling companies, which ensure secure and appropriate disposal and export of the materials from the monitors. In particular, more metals are delivered to local iron foundries and more plastics are exported to China. LCD displays and backlights are disposed in well-managed sanitary landfills, while PCBs are sent to Germany, Belgium and China for specialized operations. Cables are sold to Peruvian secondary markets or exported to China to avoid releases of copper. These countries have special refineries for further treatment and partial recovery of valuable used metals. Since the dismantled components of LCD monitors are appropriately treated and disposed in the formal sector, there is no high risk of harmful releases of the substances. A mitigation of potential negative environmental effects can be seen in the MFA. As a result, the collected amount of LCD monitors being treated in the formal processing increased compared to the informal collection process.

However, in scenario 2 the informal sector has neither been incorporated nor analysed. 30% of the collected LCD monitors are treated by the informal waste treatment process. There is no facility, which is able to control or evaluate all these items. Since the formal waste treatment is dominant, the informal sector has been neglected. Despite this fact, the informal recycling operations are still of public and environmental concern. The waste from the informal export market process is not controlled and regulated by any regulations or recycling

technology. As a consequence, it is difficult to assess the hazardous exposure generated during the dismantling and disposal phase. There is no estimate available about the environmental negative impacts from the informal sector. Since the informal recyclers do not work with authorized licenses and appropriate technologies, the environmental issues caused by the different components from the LCD monitors is unknown.

Therefore, it has to be analysed, if any violations of the Basel Convention occur. In general, Peru is not strict in the definition of products for reuse (Kahhat/Williams, 2009). The authorized recycling companies operate according to the guidelines and standards provided by the Peruvian WEEE legislation. The National Regulation on the Administration and Management of WEEE has been designed in accordance to the standards of the Basel and Stockholm Convention. The Peruvian recycling companies (San Antonio Recycling, COIPSA, Peru Green Recycling and Comimtel) act with the EPS-RS and EC-RS certificates, which at the same time obliges them to pursue the content of the Convention. The licenses should ensure that there is no violation of the Stockholm Convention. As LCD displays and backlights are disposed to landfills in the region of Lima, it might contradict the Convention. Since there are only 8 sanitary final disposals, hazardous releases might occur. However, usually the exposure of these substances are low, even in not well-managed landfills (Williams et al., 2008).

In addition, the informal sector is not committed to the national legislation, Basel and Stockholm Convention. It is not known, if the informal collection flow contains LCD monitors from trade exchanges. It would be illegal, as trade of WEEE violates international law, particularly according to the Basel Convention. As mentioned in chapter 2.3.1, trade of WEEE requires prior notification of the trading partners. However, the reuse flow from the informal collection to the consumption process accounts to 50%. The high percentage is a concern and might include some trade agreements between the Peruvian informal sector and other parties. Imported LCD monitors that are intended for reuse purposes are excluded from any controls. Therefore, it is hard to estimate and analyze, if the informal sector is dealing with these types of monitors and if it is violating the international law. Furthermore, it is difficult to control and/or regulate the quantity of LCD monitors sold and imported to secondary markets.

The second case study indicates that the formalization of the collection, handling and dismantling of LCD monitors is feasible by financial and economic support, particularly, implementation of recycling fees and expanding take-back systems.

4.2.3 High Amount of Waste

Scenario 3 with high amount of LCD monitor waste clearly reveals the problems of the Peruvian WEEE management. The issues of lack of financial support, limited economic capacity, lack of commitment to complex regulations and release of hazardous substances from EEEs are addressed in this case study. The formal waste treatment of LCD monitors is approximately 15-20%, hence a large quantity of monitors are handled and treated by the informal sector.

The MFA shows that the number of LCD monitors was accumulated primarily in the informal sector. The formal waste treatment process received 10%, while the informal field had 90% of the collected LCD monitors. The majority of waste has its origin in the informal waste treatment process, where the components of the products are not properly treated and dismantled under severely dangerous conditions. Furthermore, the reuse flow of the formal and informal collection process is zero. Consequently, the consumption stock is not connected to the formal and informal waste treatment activities. In addition, it does not experience significant changes and rises within the system.

In this case study it is assumed that the workers handle, disassemble and treat LCD monitors according to their own methods. The high amount of LCD monitor wastes in the informal waste treatment process, leaving the system in the MFA, is highly concerning. The export flows of the informal export market overweight export flows from the formal waste treatment process, which were performed under authorized mechanisms. Since informal recyclers are not committed to any WEEE regulations, their techniques of collection, handling, dismantling and treatment are not in accordance with the Peruvian WEEE regulation, nor the Stockholm and Basel Conventions. It is difficult for the Peruvian authorities to involve people of the informal recycling field due to lack of financial capacities and financial support. Since their work is not registered, the Ministries are not able to assess the number of persons involved in the informal waste treatment process. Without the commitment to national and international legislation, the LCD monitors collected, disassembled and treated in the informal sector cannot be controlled. As a consequence, the majority of waste is treated under unauthorized methods.

It can be observed that the informal sector has a remarkably high proportion in the system which can be attributed to the little financial capacities to formalize the processing, treatment and disposal of EEE. It is a problem to provide facilities for formal waste treatment methods. Since informal recycling workers do not perform in accordance to the given national and

international legal frameworks, violations of the Basel and Stockholm Conventions might occur. The informal as well the formal waste treatment process might not pursue standards to avoid additional expenditures. Especially, the informal sector has the likelihood to violate the Basel Convention by selling LCD monitors abroad. At the same time, informal workers would violate the law by receiving monitors, which were imported without prior notification. However, the formal sector is also able to contradict the international law through their export activities.

In addition, the content and guidelines of the Stockholm Convention should be considered. The informal sector covers a large part of the collected LCD monitors in this MFA case, the control and reduction of POPs should be observed and analysed. The dismantling of plastics, LCD displays, backlights and PCBs release PBDEs and various POPs, if not the appropriate technology is applied. As mentioned in 3.4.3, many informal recyclers burn cables and extract the valuable substances next to rivers, contaminating the water, soil and air. In addition, these extracting methods do damage to their health. It can more likely be said that the informal sector violates the Stockholm Convention. However, the protection and mitigation of chemical pollution is not secured in the informal recycling process. There are no analyses of the amount of potential exposure of POPs. It is known that within the dismantling of PCBs POPs are emitted to the atmosphere and environment, but it is cannot be regulated yet. The elimination of released POPs in the informal handling, treatment and disposal can only be controlled and mitigated by formalizing this sector. However, it cannot be estimated to which extent informal operators violate the Stockholm Convention.

The dangerous and harmful part of the informal sector is rather the procedures of handling, dismantling and treatment than the disposal. The non-existence of regulations and appropriate technologies, including protectional equipment, risks the environment, but mainly the health of the participating persons. Nevertheless, the chemical emissions to the environment are not considered to be concerning. It is necessary to involve the informal sector in formalizing their recycling techniques, but it requires financial capacities and support, and commitment to complex recycling regulations.

The case scenario and MFA show that the magnitude of the informal sector is large and demands the implemenation and involvement of recycling regulations, prevention technologies and information exchange of expertise.

4.3 Answers to Research Questions

The following research questions (See chapter 1.4) are answered by the work:

1. How far does the legal framework of Peru include the regulations of the Basel and Stockholm Convention?

   The Peruvian National Regulation on the Administration and Management of WEEE was elaborated in respect to the content and standards of the Basel and Stockholm Convention. Only authorized recycling companies are obliged to perform in accordance to the Conventions, EPR and specified regulations. However, the informal waste treatment sector is not included in the legal framework of Peru.

2. To which extent do they or do not overlap in the main processes of recycling (collection, dismantling, treatment systems and final disposal)?

   The Peruvian WEEE framework is the first legislation, which is based on EPR. It has its origin in the e-waste project organized by EMPA. In 2007, EMPA started an e-waste project in Peru to reduce poverty and enhance the bilateral relation. Previously, the problem was that there was no legal regulation for the WEEE recycling operations. In the following years, the project was expanded, including IPES, Cleaner Production Centers and MINAM. A WEEE regulation was elaborated with the participation of IPES, EMPA, MINAM, DIGESA, and the private and public sector. As a result, in 2012 the national WEEE legislation entered into force. The regulation includes standards for the collection, dismantling, treatment and final disposal for the 10 WEEE categories, but only category 3 and 4 were mandatory. However, it is not clearly stated, if the national legal framework overlaps or not in the recycling methods and technologies.

3. Which measures should be taken by Peruvian authorities to improve the recycling life cycle of LCD monitors?

   On the one hand, Peruvian authorities should implement further mechanisms, such as the product based recycling fee and awareness-raising campaigns. It would provide wider financial capacity to support the waste treatment and collection of WEEE. At the same time, it would enforce the formalization of WEEE procedures.

   On the other hand, it would be advisable to incorporate the informal sector in the WEEE management. Their participation is of high interest for the parties. The involvement of the informal sector is necessary to be able to further develop and

expand the formal waste treatment of WEEE. If the formal and informal sectors are highly supported by financial capacities, less hazardous substances would be disposed in landfills, avoiding harmful exposure to the environment and human health.

4. Which effects will the proposed measures have in comparison to today's situation?
   The proposed measures will on the one hand support the national legislation, and on the other hand tackle the problem of lacking financial support and capacities, and reduce the release of hazardous substances from EEEs. The Peruvian WEEE legal framework states that the management of WEEE is a shared responsibility. By the implementation of the recycling fees consumers would contribute to the formalization of WEEE collection and treatment.

5. Conclusion and Recommendations

The aim of the work was to analyze the national WEEE legislation and the international Basel and Stockholm Conventions by the MFA, considering the problems in the case study Peru. Based on the three MFA scenarios the issues of WEEE management were evaluated and discussed.

The evaluation of the MFAs clearly shows that strengthening the formalization of waste treatment of WEEE is required. Peru introduced its first WEEE legal framework in 2012 and several projects took place. Previously, there were no legal standards for the collection, handling, dismantling and disposal of WEEE. In the last 4 years, the parties involved achieved to create a formal baseline for WEEE operations with the aim to reach collection targets of 16%. Currently, 4 recycling companies perform the collection and handling of WEEE. It has to be considered that Peru as a developing country succeeded within 9 years (previously working with WEEE projects) to implement a formal legislation, which was elaborated in cooperation with IPES, EMPA, DIGESA, MINAM and public and private actors. Therefore, the Peruvian legal framework includes interests and guidelines for the mentioned parties. However, the National Regulation on the Administration and Management of WEEE does not provide detailed information about the distribution of the responsibility of the handling, dismantling and disposal methods, nor its implementation. In addition, the financial sources are not explained in the legislation. Nevertheless, it stresses that the WEEE management is a common and shared responsibility.

Furthermore, the analyses of the scenarios reveal that the informal sector has to be addressed. The informal waste treatment process is primarly causing harmful impacts on the people involved. The problem is the release of hazardous substances during the dismantling and treatment process. The proportion of toxic emissions to the environment, which are released in the well-managed and not-well-managed landfills, is very small. Therefore, there is no high risk of harmful pollution to the environment rather the persons involved in the dismantling phase are exposed to the chemical substances.

The combination of the inclusion of the informal waste treatment sector and the enhancement of WEEE formalization are necessary to tackle the issues of financial support, capacities and lack of commitment to complex WEEE regulations. There is clear need for promotions of the Peruvian WEEE recycling system. Based on this combination the following recommendations are suggested:

The recommendations are focused on the exchange of information, awareness-raising initiatives, the inclusion of all parties and new financial and economic sources.

- *Awareness-raising campaigns*: The provision and exchange of knowledge about the importance of appropriate WEEE processing after their end-of-life is crucial. There should be training programs and workshops about the components and life cycle of EEE products. It is advisable that the awareness-raising campaigns target young people. Thus, the exchange of information workshops should be held at schools, universities, public and private and informal sector. In addition, the population has to be informed where, why and how to dispose their obsolete EEEs. The consumers have to know the effects, if their EEE is not treated and disposed properly. Awareness-raising promotions and initiatives are the first step to make consumers bear the responsibility.

- *Lottery donations:* After the training programs of information and knowledge exchange, the population has to be attracted to dispose their EEE at the collection points for appropriate and formal treatment. The establishment of an incentive for the population is the key mean. An incentive to encourage people to hand in their EEE is the donation of lottery tickets. These tickets would arouse interest, especially among the young population. At the same time, the formal waste collection and treatment of WEEE would be accumulated.

- *Inclusion of the informal sector:* An integrated WEEE system is of high interest for the ministries and the private sector. Since the proportion of WEEE handled, dismantled, treated and disposed by informal recyclers is significantly high, their involvement in the formal WEEE management is useful. Many young people work in this sector and have a wide knowledge and expertise of disassembly, reuse and recovery of WEEE products. There is high potential to include their expertise. However, this recommendation requires additional financial support, which can be implemented by the following 2 recommendations.

- *Reuse Culture:* The reuse culture can be initiated and strengthened by the introduction of reuse factories, led by authorized recycling operators. There are several small and large reuse companies at the international level, for example, the Austrian company "Trash Design". The reuse factories offer new economic and financial niches and provide working possibilities for the people involved in the informal sector. This type

of work requires advanced knowledge of dismantling and treatment, which is also given in the informal collection and waste treatment process. Generally, reuse factories sell notepads made out of PCBs, vase made by glass of monitors and necklaces out of colourful cables. The reuse culture is an interesting niche to invest, to reduce waste and to encourage the interest of young informal recyclers.

- *Recycling fees:* The recycling fees according to the example of Switzerland, is applicable to the Peruvian society. The product based recycling fees are an additional financial source to prevent the problem of lack of financial support and economic capacities. The consumers are actively involved by paying a certain amount for the processing phase of their purchased EEE. In addition, they also take responsibility and support the payments for the collection, transport and handling of WEEE. The recycling fees establish a shared and common responsibility among the manufacturers, consumers, private and public sector and the authorized recycling companies. This additional financial source promotes the formal waste treatment of WEEE.

Overall, the WEEE management of Peru has improvements regarding the legislations and it is one of the few Latin American countries with an established WEEE system. In the last years, the country experienced the implementation of formal standards and guidelines to create a formal sector of WEEE. This achievement is not negligible, however some projects and initiatives can still be introduced to further inform and expand the WEEE topic. On the one hand it is important to directly address the informal sector with the proposed initiatives and on the other hand to create new financial and economic niches for the accumulation of the WEEE management.

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Appendices

Appendix I: Research Field Trip to Peru, Lima

I conducted research for my Master Thesis ("Material Flow Analysis and Application of LCD Monitors in Peru. A Case Study of WEEE) for two weeks (February 2016) in Lima, Peru. My host professor was Mr. Ramzy Kahhat from the Pontificia Universidad Cátolica of Peru. He supported me by providing documents related to my thesis and sharing contact persons. The Peruvian university offered me an office for the period of my research.

Since my thesis is focused on the recycling of waste of electrical and electronic equipment (WEEE), during my stay I met and interviewed persons who are involved in the academic, economic, political and legal procedures of WEEE in Peru. The hosting professor and I discussed in detail the mechanism, problem and regulation of WEEE. He works more than ten years in the area of waste of electrical and electronic equipment, and has investigated various case studies of Latin American countries. Additionally, he recommended me to take a look at the informal sector of recycling in Lima, which I did. It was very interesting to see what kind of people and for which purposes they work in this field. Mostly, young people work in the informal part of recycling, having a mechanical background from lower-graded institutions which are not classified for a qualified profession in the formal sector. However, there are also many elderly people who are mostly not aware of the exposure of WEEE. These persons work without any health protection devices, which in turn have effects on their health (lungs, asthma, bronchial area, organs). Nevertheless, the informal sector is seen as an income source for many families.

Moreover, I met an engineer of the NGO called IPES, who explained me their role in the legislation of WEEE. Its function is rather being an observer and adviser regarding awareness-raising projects for especially young people. IPES took part in the formulation of the Peruvian legislation of WEEE. I had as well an interview with an expert from the ASPAGER (Asociación Peruana de Actores para la Gestión de Residuos). She described in detail the Association's role in interacting between the public and private sector for sustainable and appropriate means of WEEE. She also stressed that ASPAGER sets its sights to elaborate the extended producer responsibility (EPR). ASPAGER works as well on awareness-raising projects

I also met the directors of two different recycling companies (COIPSA and San Antonio Recycling). The director of COIPSA had more critical views about the legal and political procedures of WEEE in Peru, which was interesting to hear. He has always been very active

in the field of recycling and thus, he knew about the changes and interventions in the recycling mechanism. He also showed me the different parts of his company and explained how every machines works, where it goes and how the laboratories work. The director of San Antonio Recycling informed of its bilateral relations to the Ministry of Environment and other Ministries. She was very convinced about the Peruvian legal improvements of recycling. She also explained the recycling procedure of WEEE in detail and provided me with the useful data for my MFA. Additionally, I had an interview with an expert from the private sector of recycling (RLG Reverse Logistics Group Americas). He described its interaction with other companies. Basically, they offer hospitals, schools etc. recycling possibilities. They are less involved in the legal framework of WEEE.

In addition, I conducted interviews with Daniel Ott (RLG Reverse Logistics Group Americas), Mathias Schluep (World Resources Forum), Joyce Vallejos (Peru Green Recycling), Heinz Boeni (EMPA) and Oscar Espinoza. These interviews were essential for the content of the three scenario cases.

Furthermore, I had a meeting with an expert from the Ministry of the Environment. She gave me a brief overview of the steps and development of the regulatory framework of WEEE in Peru. Technically, there are two regulations which will be amended in the next years, however many parts of the legislation are not yet implemented by the recycling enterprises.

Overall, the research trip was extremely fruitful and essential for the understanding of the Peruvian recycling mechanism. Besides that I conducted useful and accurate information about the quality, quantity, impacts, effects and framework of WEEE in Peru. I will use the collected information for my analysis of the regulatory frameworks and MFA scenarios.

Appendix II: MFA Process List without figures

	Process	Flow	Flow name	Source process	Destination Process	Mass flow [t/ a]	Mass flow (calculated) [t/ a]
Process name: Collection							
Input							
	P2	F3	Collected LCD Monit	P1,Consumption	P2,Collection		
Output							
	P2	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		
	P2	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		
Process name: Consumption							
Input							
	P1	F1	New LCD Monitors		P1,Consumption		
	P1	F2	Used LCD Monitors		P1,Consumption		
	P1	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		
	P1	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		
Output							
	P1	F3	Collected LCD Monit	P1,Consumption	P2,Collection		
Process name: Formal Export Market							
Input							
	P5	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		
Output							
	P5	F9	Metals to iron foundri	P5,Formal Export Market			
	P5	F10	Plastics exported to (	P5,Formal Export Market			
	P5	F11	LCD Displays to land	P5,Formal Export Market			
	P5	F12	PCB exported to Ger	P5,Formal Export Market			
	P5	F13	Cables to Peruvian s	P5,Formal Export Market			
	P5	F14	Backlight to landfills	P5,Formal Export Market			
	P5	F15	Other materials to dis	P5,Formal Export Market			
Process name: Formal Waste Treatment							
Input							
	P3	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		
Output							
	P3	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		
	P3	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		
Process name: Informal Export Market							
Input							
	P6	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		
Output							
	P6	F17	Metals to secondary	P6,Informal Export Market			
	P6	F18	Plastics to secondary	P6,Informal Export Market			
	P6	F19	LCD Displays to sec	P6,Informal Export Market			
	P6	F20	PCB to secondary ma	P6,Informal Export Market			
	P6	F21	Cables to secondary	P6,Informal Export Market			
	P6	F22	Backlight to the stree	P6,Informal Export Market			
	P6	F23	Other materials to the	P6,Informal Export Market			
Process name: Informal Waste Treatment							
Input							
	P4	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		
Output							
	P4	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		
	P4	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		

Appendix III: MFA Process List Scenario 1

	Process	Flow	Flow name	Source process	Destination Process	Mass flow [t/ a]	Mass flow (calculated) [t/ a]
Process name: Collection							
Input							
	P2	F3	Collected LCD Monit	P1,Consumption	P2,Collection	196.674	196.674
Output							
	P2	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		118.004
	P2	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		78.670
Process name: Consumption							
Input							
	P1	F1	New LCD Monitors		P1,Consumption	144.027	144.027
	P1	F2	Used LCD Monitors		P1,Consumption	136.936	136.936
	P1	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		94.404
	P1	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		62.936
Output							
	P1	F3	Collected LCD Monit	P1,Consumption	P2,Collection	196.674	196.674
Process name: Formal Export Market							
Input							
	P5	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		23.601
Output							
	P5	F9	Metals to iron foundri	P5,Formal Export Market			9.204
	P5	F10	Plastics exported to (	P5,Formal Export Market			8.614
	P5	F11	LCD Displays to land	P5,Formal Export Market			2.242
	P5	F12	PCB exported to Ger	P5,Formal Export Market			2.006
	P5	F13	Cables to Peruvian s	P5,Formal Export Market			0.590
	P5	F14	Backlight to landfills	P5,Formal Export Market			0.236
	P5	F15	Other materials to dis	P5,Formal Export Market			0.708
Process name: Formal Waste Treatment							
Input							
	P3	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		118.004
Output							
	P3	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		94.404
	P3	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		23.601
Process name: Informal Export Market							
Input							
	P6	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		15.734
Output							
	P6	F17	Metals to secondary	P6,Informal Export Market			6.136
	P6	F18	Plastics to secondary	P6,Informal Export Market			5.743
	P6	F19	LCD Displays to secc	P6,Informal Export Market			1.495
	P6	F20	PCB to secondary ma	P6,Informal Export Market			1.337
	P6	F21	Cables to secondary	P6,Informal Export Market			0.393
	P6	F22	Backlight to the stree	P6,Informal Export Market			0.157
	P6	F23	Other materials to the	P6,Informal Export Market			0.472
Process name: Informal Waste Treatment							
Input							
	P4	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		78.670
Output							
	P4	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		62.936
	P4	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		15.734

Appendix IV: MFA Process List Scenario 2

	Process	Flow	Flow name	Source process	Destination Process	Mass flow [t/ a]	Mass flow (calculated) [t/ a]
Process name: Collection							
Input							
	P2	F3	Collected LCD Monit	P1,Consumption	P2,Collection	196.674	196.674
Output							
	P2	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		137.672
	P2	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		59.002
Process name: Consumption							
Input							
	P1	F1	New LCD Monitors		P1,Consumption	144.027	144.027
	P1	F2	Used LCD Monitors		P1,Consumption	136.936	136.936
	P1	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		0.000
	P1	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		29.501
Output							
	P1	F3	Collected LCD Monit	P1,Consumption	P2,Collection	196.674	196.674
Process name: Formal Export Market							
Input							
	P5	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		137.672
Output							
	P5	F9	Metals to iron foundri	P5,Formal Export Market			53.692
	P5	F10	Plastics exported to (	P5,Formal Export Market			50.250
	P5	F11	LCD Displays to land	P5,Formal Export Market			13.079
	P5	F12	PCB exported to Ger	P5,Formal Export Market			11.702
	P5	F13	Cables to Peruvian s	P5,Formal Export Market			3.442
	P5	F14	Backlight to landfills	P5,Formal Export Market			1.377
	P5	F15	Other materials to dis	P5,Formal Export Market			4.130
Process name: Formal Waste Treatment							
Input							
	P3	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		137.672
Output							
	P3	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		0.000
	P3	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		137.672
Process name: Informal Export Market							
Input							
	P6	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		29.501
Output							
	P6	F17	Metals to secondary	P6,Informal Export Market			11.505
	P6	F18	Plastics to secondary	P6,Informal Export Market			10.768
	P6	F19	LCD Displays to secc	P6,Informal Export Market			2.803
	P6	F20	PCB to secondary ma	P6,Informal Export Market			2.508
	P6	F21	Cables to secondary	P6,Informal Export Market			0.738
	P6	F22	Backlight to the stree	P6,Informal Export Market			0.295
	P6	F23	Other materials to the	P6,Informal Export Market			0.885
Process name: Informal Waste Treatment							
Input							
	P4	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		59.002
Output							
	P4	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		29.501
	P4	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		29.501

Appendix V: MFA Process List Scenario 3

Process	Flow	Flow name	Source process	Destination Process	Mass flow [t/ a]	Mass flow (calculated) [t/ a]
Process name: Collection						
Input						
P2	F3	Collected LCD Monit	P1,Consumption	P2,Collection	196.674	196.674
Output						
P2	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		19.667
P2	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		177.007
Process name: Consumption						
Input						
P1	F1	New LCD Monitors		P1,Consumption	144.027	144.027
P1	F2	Used LCD Monitors		P1,Consumption	136.936	136.936
P1	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		0.000
P1	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		0.000
Output						
P1	F3	Collected LCD Monit	P1,Consumption	P2,Collection	196.674	196.674
Process name: Formal Export Market						
Input						
P5	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		19.667
Output						
P5	F9	Metals to iron foundri	P5,Formal Export Market			7.670
P5	F10	Plastics exported to (	P5,Formal Export Market			7.179
P5	F11	LCD Displays to land	P5,Formal Export Market			1.868
P5	F12	PCB exported to Ger	P5,Formal Export Market			1.672
P5	F13	Cables to Peruvian s	P5,Formal Export Market			0.492
P5	F14	Backlight to landfills	P5,Formal Export Market			0.197
P5	F15	Other materials to dis	P5,Formal Export Market			0.590
Process name: Formal Waste Treatment						
Input						
P3	F4	Formal Collection	P2,Collection	P3,Formal Waste Treatment		19.667
Output						
P3	F6	Formal Reuse	P3,Formal Waste Treatme	P1,Consumption		0.000
P3	F8	Formal Trade	P3,Formal Waste Treatme	P5,Formal Export Market		19.667
Process name: Informal Export Market						
Input						
P6	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		177.007
Output						
P6	F17	Metals to secondary	P6,Informal Export Market			69.033
P6	F18	Plastics to secondary	P6,Informal Export Market			64.607
P6	F19	LCD Displays to secc	P6,Informal Export Market			16.816
P6	F20	PCB to secondary ma	P6,Informal Export Market			15.046
P6	F21	Cables to secondary	P6,Informal Export Market			4.425
P6	F22	Backlight to the stree	P6,Informal Export Market			1.770
P6	F23	Other materials to the	P6,Informal Export Market			5.310
Process name: Informal Waste Treatment						
Input						
P4	F5	Informal Collection	P2,Collection	P4,Informal Waste Treatment		177.007
Output						
P4	F7	Informal Reuse	P4,Informal Waste Treatn	P1,Consumption		0.000
P4	F16	Informal Trade	P4,Informal Waste Treatn	P6,Informal Export Market		177.007