WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE) MANAGEMENT SYSTEMS IN THE DEVELOPED AND THE DEVELOPING COUNTRIES: A COMPARATIVE STRUCTURAL STUDY

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Abstract

The disposal, treatment, and recovery of Waste Electrical and Electronic Equipment (WEEE) are becoming a global environmental issue. These issues drive the developed and the developing countries to set up and improve the management systems for the waste. Previous authors have produced a sufficient number of study on WEEE management systems of the developed countries together with their success stories and of the developing countries with their existing problems, but only provide limited ones on how to compare the situations and the systems of these two regions. Hence, it is imperative to develop a comparative framework to distinguish the structures and the relationships within a particular WEEE management system of the developed and developing countries. This study proposes such framework which integrates a qualitative with quantitative approaches and incorporates the system thinking perspective. In particular, it comprises a series of research stages. Initially, a qualitative framework is developed to extract the characteristics of WEEE management systems in the developing countries from the scientific literature and then to compare them with the ones from the developed systems. Secondly, a System Dynamics approach is applied to assess the dynamical behaviors within the systems of the two regions. Thirdly, enhanced quantitative analysis, consist of Factorial Design with Analysis of Variance and then Policy Analysis, are conducted to further understand the determinants and interactions among the factors in the systems and to assess the impact of the selected policies on the systems' behaviors. This study figures out the list of the determinants, the structural relationships, and the dynamics within the systems, characterizing and connecting the WEEE-specific problems in the developed and the developing countries. This study concludes the main findings and the policy recommendations for the future development and collaboration within and between the two regions.

Keywords: WEEE, Management Systems, Comparison, Developed and Developing Countries, Systems Dynamics

Zusammenfassung

Die Entsorgung von Elektro- und Elektronik-Altgeräten stellen sowohl für Industrie- als auch für Entwicklungsländer ein weitreichendes Problem dar. Industrie- und Entwicklungsländer haben in der Vergangenheit verschiedene Vorgehensweisen und Systeme entwickelt um diese Problematik zu lösen. Die Systeme der Industrieländer können hierbei bessere Ergebnisse aufweisen als die Systeme der Entwicklungsländer, weshalb es Ziel dieser Arbeit ist die Vorgehensweisen miteinander zu vergleichen und aufzuzeigen, welche Faktoren für den Erfolg wichtig sind. Die in dieser Arbeit durchgeführte Studie beinhaltet drei Stufen. In der ersten Stufe werden die Charakteristika der Verfahren und Systeme zur Verwertung von Elektro- und Elektronik-Altgeräten in den Entwicklungsländern dargestellt und mit Verfahren der Industrieländer verglichen. In der zweiten Stufe werden Ansätze der Systemdynamik verwendet um das Systemverhalten der beiden Regionen zu analysieren. Anschließend wird in der dritten Stufe eine verbesserte quantitative Analyse durchgeführt, um herauszufinden, welche Faktoren die Verfahren am meisten beeinflussen. Diese Analyse besteht zum einen aus einem vollständigen Versuchsplan mit einer Varianzanalyse und zum anderen einer Policy-Analyse. Neben dem Aufzeigen und dem Vergleich der einzelnen Erfolgsfaktoren bei der Verwertung von Elektro- und Elektronik-Altgeräten werden darüber hinaus Handlungsempfehlungen für Entwicklungsländer aufgezeigt, damit diese erfolgreichere Systeme aufbauen können.

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"For indeed, with hardship [will be] ease. Indeed, with hardship [will be] ease. So when you have finished [your duties], then stand up [for worship]. And to your Lord direct [your] longing (Quran 94:5-8)"

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List of Abbreviations and Acronyms

AD	Automatic dispenser
ANOVA	Analysis of Variance
ARF	Advance Recycling Fee
Bo2W	Best-of-2-Worlds
BPH	Bromophenols
CC	Compliance Cost
CE	Consumer equipment and photovoltaic panels
CLSC	Closed-loop Supply Chain
CPR	Collective Producer Responsibility
CWIT	Countering WEEE Illegal Trade
DfR	Design for Recovery
DoE	Design of Experiments
DSD	Duales Systems Deutschland
EAR	Foundation of "Stiftung Elektro-Altgeräte Register" (Germany)
EEE	Electronic and Electric Equipment
EET	Electrical and Electronic tools
EFFACE	European Union Action to Fight Environmental Crime
ElektroG	Legal Act Governing the Sale, Return and Environmentally Sound Disposal of Electrical and Electronic Equipment (Germany)
EPR	Extended Producers Responsibility
EU	The European Union
GA	Genetic Algorithm
IOA	Input Output Analysis
INOBAT	The Stakeholder Organisation for Battery Disposal (Switzerland)
IPR	Individual Producer Responsibility
IT	IT and telecommunications equipment
LE	Lightning equipment
LHA	Large household appliances
MAPE	Mean Absolute Percentage Error
MeO-PBDE	Methoxylated polybrominated diphenyl ethers
MILP	Mixed-Integer Linear Programming

MCI	Monitoring and control instrument
MD	Medical devices
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OfN	Old for New Rabat Program
OH-PBDE	Hydroxylated polybrominated diphenyl ethers
OH-PCB	Hydroxylated PCB congeners
ORDEE	Ordinance on "The Return, the Taking Back and the Disposal of Electrical and Electronic Equipment" (Switzerland)
SHA	Small household appliances
PBDE	Polybrominated diphenyl ethers
PC	Personal Computer
PCB	Polychlorinated biphenyls
PRO	Producer Responsibility Organization
PVC	polyvinyl chloride
RCC	Reimbursed Compliance Cost
RF	Recycling Fee
RoHS	Restriction of the Use of Certain Hazardous Substances in EEE
SD	Systems Dynamics
SENS	Stiftung Entsorgung Schweiz
SLRS	Swiss Light Recycling Foundation
SRF	Shared Recycling Fee
STeP	Solving the e-waste problem
SWICO	Swiss Association for Information Communication and Organizational Technology
TLSE	Toys, leisure, and sports equipment
TV	Television
UEEE	Used Electronic and Electric Equipment
UNEP	United Nations Environmental Program
UNU	United Nation University
VF	Visible Fee
WEEE	Waste Electrical and Electronic Equipment

Chapter 1 Introduction

1.1 Background

Waste Electrical and Electronic Equipment (WEEE) and its treatment are nowadays becoming a global concern. These issues emerge because of the interrelationships between the nature of WEEE substances and components, on the one hand, and the sustainability aspects that are related to them on the other. On the micro level, WEEE contains not only potential valuable materials such as ferrous metals, non-ferrous metals, glass, plastics, and other materials; but also hazardous substances including arsenic, cadmium, mercury, lead, and polyvinyl chloride (PVC). Hence, WEEE possesses both latent economic opportunities and environmental threats. On the macro level, WEEE treatments and recoveries affect the three sustainability pillars: economic, environmental, and social. Previous authors pay much attention to the economics of WEEE recovery activities, such as direct reuse, refurbishment, recycling, and complete closed-loop supply chains (for example Georgiadis and Besiou, 2009a; Geyer and Doctori Blass, 2009; Shinkuma and Managi, 2010; Toyasaki et al., 2011; Walther et al., 2009). Similarly, this condition also appears in the environmental aspects of WEEE issues, in which several approaches have already been developed, e.g. Life Cycle Assessment, Material Flow Analysis, Multi-Criteria Analysis, and System Dynamics (Georgiadis and Besiou, 2009b; Kiddee et al., 2013; B. Lu et al., 2015; Menikpura et al., 2014; Wäger et al., 2011). Social issues of WEEE recovery operations have started to gain more authors' interest, though the number of papers in such issues is still limited (Georgiadis and Besiou, 2009a; Manhart, 2007; Pérez-Belis et al., 2014).

The magnitude of the WEEE issues raises significantly because of one important factor: the alarming size of the generation of WEEE. The recent report from United Nation University (UNU) records that 41.8 million tons of WEEE were produced across the globe in 2014; most of them were generated in Asia (Baldé et al., 2014). This UNU report figures out that only 10 to 40 percent of the generated WEEE was treated properly according to the regulation. It also provides a projection for the future generation, i.e. the amount of global WEEE is estimated to reach 49.8 million tons by 2018.

To handle the WEEE problems, many countries have implemented, started to implement, or started to develop regulatory approaches based on the concept of Extended Producers Responsibility (EPR). Lindhqvist (2000) defines EPR as *"a policy principle to* *promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the entire life cycle of the product, and especially to the take-back, recycling and final disposal of the product."*

The most prominent example of this approach is the European Union (EU) Directive on WEEE. The EU initiated this directive in 2003, aiming to limit the generation of WEEE and to reduce the number of WEEE disposal by promoting reuse, recycle and other treatment activities(The European Union, 2003). In 2012, the WEEE Directive has been revised to increase the efficiency of administrative costs, to advance the effectiveness of the compliance scheme, and to reduce the impact of treatment activities on the environment. The EU Directive has influenced and improved the WEEE management across the member states. These improvements include raising the awareness of the society on the WEEE issues, increasing the involvement of the consumers and the manufacturers across the member states, limiting the environmental impact through diverting the waste from the final disposal and driving higher economic impacts within the WEEE businesses. This directive has also been recommended as the model to develop the systems in developing countries (I. C. Nnorom and Osibanjo, 2008).

Nevertheless, the recast of the 2003 EU Directive by Huisman et al. (2007)revealed a problematic phenomenon: the plethora of implementation phases opted by the EU member states, including 27 different variations of the legislation and more than 150 different compliance schemes (Deepali Sinha Khetriwal et al., 2011). This phenomenon also implies that there are some deviations between the intended goals and the means of the directive with the reality of practices in the member states (Huisman, 2013; Lifset and Lindhqvist, 2008; Mayers et al., 2011). Accordingly, this setting poses problems to stakeholders; operationally, tactically, and strategically. Atasu and Van Wassenhove (2012) analyze these variations within the EU states, Japan, and the United States; recording the existing differences in the collection methods, waste management models, financial obligations, cost allocation heuristics, etc.

The aforementioned variations, together with another fact that there is a gap between the theoretically optimal policies in the literature and the ones chosen by the member states (Atasu and Wassenhove, 2012), conclude one thing: there is no one-size-fits-all EPR model that can be universally implemented in every country (Atasu et al., 2013; Khetriwal et al., 2009). Hence, this condition raises one issue: how should a country, together with its unique characteristics – especially a developing country – adapt and/or adopt the EPR model from several developed countries which arguably are successful in tackling their WEEE problems.

It is vital to deal with this issue, in light of increasing WEEE problems in the developing countries. In this region, WEEE generation rate increases rapidly as supported by the results of several estimations. Yang et al. (2008) forecast the growth rate of Chinese obsolete personal computers (PCs), Televisions (TVs), refrigerators, washing machines, and air conditioners at the average level of 24.69%, 8.2%, 4.1 %, 13.05%, and 40.01% per year, respectively. Dwivedy & Mittal (2010) estimate the average growth of WEEE generation in India by 7% annually. In a study with a broader scope, Yu et al. (2010b) present relatively large figures of 400 – 700 million units obsolete PCs in the developing countries by the year 2030, as compared with 200 to 400 million units in the developed ones. Considering this situation, it is expected that there will be more developing countries introducing WEEE-specific and EPR-based legislation (Sthiannopkao and Wong, 2013). However, the speed of initiation remains slow (Ongondo et al., 2011).

Note should be taken specifically to the issue of the informal sector. In most of the developing countries, informal activities appear in all parts of the reverse supply chain, i.e. in the collection, refurbishment, treatment, recycling, and secondary markets. The informal sector poses challenges to the nation-wide WEEE management systems, because their improper treatment and recycling methods harm the environment and the workers (Sthiannopkao and Wong, 2013; UNEP, 2009) and their complex networks and process efficiency contribute to the failure of some formal initiatives (Chi et al., 2011; Raghupathy et al., 2011). Though several developing countries, such as China and India, have started to impose their regulatory approaches, still, many difficulties arise in the implementation phase, e.g. fierce competition with the informal sector to get obsolete products from households, large numbers of orphan products, lack of recycling infrastructures, etc. (Chi et al., 2011; Kojima et al., 2009; Manomaivibool, 2009; Yu et al., 2010a). Remarkably, the regulations generally deny the roles of the informal sectors in the systems (Besiou et al., 2012).

One can argue that the WEEE-specific problems rising in the developing countries stem from the weakness of their national directive (e.g. ambiguities and incompleteness in the regulation text), from their poorly performing governmental agencies (e.g. weak law enforcement) or even from the poor operations of the informal sectors in these countries. But it seems that the root causes lie in another area: the unique endogenous and exogenous factors – and their interrelationships – within the systems (Khetriwal et al., 2009). The former factor represents any factor within the management systems' boundary which is fundamental for the changes of system behaviors. Whereas the latter factor captures any variable, typically put outside the boundary of the systems but actually is essential in triggering the emergence of such behaviors. These interrelationships, altogether, produce unique dynamic behaviors that further will affect the sustainability of the WEEE management systems in the region.

1.2 Problem Formulation

In recent scientific publications concerning WEEE issues, comparative and review analysis between the developed and developing countries or within one particular region have been conducted to identify the characteristics of waste systems in a particular country and to take the key lesson learned from more advanced systems. These research streams were initiated by studies that compare the recycling systems in Switzerland and India (Sinha-Khetriwal et al., 2005; Widmer et al., 2005). In their work, Widmer et al. (2005) attempt to characterize the WEEE management system within a country by comparing the systems with selected countries – including also Switzerland and India – using five key parameters, i.e. the legal regulation, system coverage, system financing, producer responsibility, and rate of return target. This work reveals remarkable differences, even between countries with comparable economic indicators. In the same year, Sinha-Khetriwal et al. (2005) describe in depth the WEEE systems in Switzerland and India and then compare them to understand the existing differences. Using e-waste per capita, employment potential, occupational hazard, and toxic emission as the criterion, these authors characterize both Swiss and Indian systems and their implication.

Comparative analysis of the systems also has been conducted among specific countries with similar characteristics, e.g. within a region or with similar problems. Chung and Murakami-Suzuki (2008) compare the WEEE systems in Japan, Taiwan, and South Korea based on the background of the legislation enactment, the responsibility imposed on manufacturers, and the impact of the EPR-based approaches to general WEEE flows. They figure out a possibility to adapt positive aspects of WEEE systems from one country to another especially after considering the economic and cultural factors within the country. Similarly, Lee and Na (2010)assess the WEEE systems in the aforementioned three East Asian countries together with China and identify the future challenges in this region. From another region, Torretta et al. (2013)deliver a comparative work between Romania and Italy because both countries failed to fulfill the target of the EU Directive in 2008. The authors then suggest different aspects of consideration for other transient economies which have big differences between the urban and rural areas. From the Nordic region, Ylä-Mella et al. (2014)evaluate the WEEE directive, its implementation, and the developed infrastructure in Finland, Sweden, and Norway. Using the resource efficiencies and best practices as the comparative indicators, the authors reveal the success stories of WEEE management systems in these countries and suggest them as the consideration for other countries.

There exists also a cluster study that tries to take lessons learned from a particular well-developed WEEE system and then use it to propose a development roadmap for a developing country. Wath et al. (2010) provide an assessment of WEEE management systems from the developed and developing countries with a special focus on Swiss and Indian systems. By their approach, these authors then propose a comprehensive roadmap for the development of the WEEE management system in India. Similarly, Silveira and Chang (2010) assess deeply the available cell phone recycling programs in the United States and the current recycling situation in Brazil. Herewith, these authors propose a mobile phone recycling system for Brazil with a deposit / refund / advance recycling fee.

Apart from those proposing the new roadmap, the comparison between the developed and developing systems has been carried out in a more generic way. Salhofer et al. (2015) attempt to compare the WEEE management systems in Europe and China. These authors consider three aspects as the comparative framework, consisting of the collection mechanism, waste treatment capability, and systems setup. Based on this framework, several notable outcomes are concluded. It is noteworthy to mention a rather novel work from Wang et al.(2012). They propose a 'Best-of-2-Worlds' philosophy (Bo2W), to solve the existing problems in the developing countries because of the limited infrastructure and access to technology. This work integrates the advantages of the existing manual dismantling pre-processes for the waste in the developing countries and the high-tech end-processes (such as metal refinery and toxic removal) in the developed countries. The pilot projects show promising results in the term of eco-efficiency with some acknowledged limitations.

Another type of study deals particularly with the difficulties existing within developing countries. Osibanjo & Nnorom (2007) and Nnorom & Osibanjo (2008) present the reason behind these difficulties, including the long absence of WEEE-specific legislation, lack of infrastructure, and different disposal behaviors from the consumers. Kojima et al. (2009) assess the difficulties in implementing the EPR-based approach in the developing regions using cases from Thailand and China. They point out two specific issues, i.e. the identification of producers and subsidies for the collectors and recyclers.

Remarkably, the previous references have provided significant works in a global / regional review of the WEEE issues and approaches. Ongondo et al. (2011) provide a comprehensive review of WEEE global trends based on the composition and generation of WEEE and the various approaches to tackle the WEEE issues. This work includes specific examples from Europe, Asia, Africa, South America, North America, and Australia. Likewise, Sthiannopkao and Wong (2013) explain the initiatives, policies, and strategies to deal with

WEEE in the developed and developing countries and provide a comparison between them. In the term of WEEE trans-boundary movement, Li et al. (2013) review the WEEE facilities and regulations in the source countries (i.e. developed countries) and destination countries (i.e. developing countries). These authors point out some of the existing differences and promote EPR-approach and uniform standards for processing WEEE in an environmentally sound manner as the solution.

Many of these works still rely, solely, on qualitative and empirical analyses. It is still difficult to answer the notion raised by Khetriwal et al. (2009), "*…..why EPR policies are more suited to particular waste streams and why some countries are able to adopt and implement EPR legislation more effectively.*". Indeed, there exist different contexts between the developed and developing countries that provide different social, economical, cultural, and political landscapes in solving waste issues (Marshall and Farahbakhsh, 2013). Furthermore, the context within a particular country is structured by different forms of interrelationships and is filled by multiple actors, increasing the complexity of the problems. To date, there is no comparative framework analysis which incorporates system thinking and quantitative analysis to characterize the unique WEEE issues within the developed and developing countries, to identify the drivers of these issues, to assess their relationships, and to analyze their impacts to the economic, social, and environmental factors. Such approach has started to gain prominence in the more generic solid waste management literature (Marshall and Farahbakhsh, 2013; Pires et al., 2011; Seadon, 2010); but little can be found in the WEEE-specific sources. As the waste issue could not be seen as an isolated entity anymore, it is imperative to answer this research need before even trying to adapt the WEEE-specific approaches and to transfer strategies from developed to developing countries.

1.3 Research Goal

The issues outlined in the previous sub-sections serve as the platform for this thesis. The main goal of this research is to construct a systematic and integrative framework for comparing WEEE management systems for both of the developed and developing countries. This framework should be able to extract the endogenous and exogenous factors within the systems, to analyze their interrelationships, and to assess the impact of these factors to the dynamic behavior of WEEE management systems.

To achieve this aim, the following questions are addressed in this study:

1. What are the WEEE issues existing within the developed and developing countries?

2. What are the determinants of the WEEE issues the within developed and developing countries?
3. How is the dynamics of WEEE management systems within the developed and developing countries?
4. Are the answers to the previous questions mutually exclusive between both of the countries' categories?
5. Which policy options are suitable to tackle the WEEE issues for both categories?

1.4 Generic Methodology

This research consists of the following works which are interrelated among each other. In the initial stage, the topics and the issues within WEEE contexts are highlighted. This effort also provides the literature review on the quantitative approaches for solving the WEEE-specific problems. These approaches include WEEE generation estimates, the methods to optimize the systems, and the use of the System Dynamics (SD) approach.

The second stage deals with the qualitative comparison of WEEE management systems in the developed and the developing countries. This stage proceeds with two major steps, i.e. conceptualizing the characteristics of the WEEE management systems in the developing countries and comparing the conceptualized characteristics with the one from the developed countries. The former step begins with the assessment of the problems and issues appeared in three selected countries: China, India, and Nigeria. The emerged issues then are compared to find the mutuality and the main causes for them are examined. Afterwards, the causal relationships within the developing systems are conceptualized using a causal map. The comparative perspective, the latter step is conducted through assessing the general condition of the systems in the developed countries and then comparing such conditions with the ones examined in the developing countries.

In the third stage, this research follows the steps from System Dynamics (SD) analysis as the beginning of the quantitative analysis. There are two quantitative models that further will be developed: (1) the system dynamics model of WEEE management systems from a developed country, and (2) the system dynamics model of WEEE management systems from a developing country. The SD steps begin by determining model boundaries and developing causal-loop diagrams based on the constructed conceptual models. Then, the study develops stock-flow diagrams as the representation of the mathematical formulations behind the models.

To ensure the robustness of the models, a set of model testing procedures is conducted based on Sterman (2000). Lastly, this research incorporates base case and sensitivity analysis to test the behavior of the SD models in respond to the selected conditions of the secondary market. The results from this analysis are analyzed in a comparative perspective between the both systems.

In the fourth stage, the selected numerical analysis aims to extract the significant determinants within the two models. Firstly, Factorial Design from Design of Experiment (DoE) is used to determine the factors and the levels that will be further analyzed. Then, an extensive number of experiments are performed through simulation. To achieve the aim in this stage, the simulation results are further analyzed using Analysis of Variance (ANOVA). Afterwards, the results taken from ANOVA are also analyzed qualitatively based on the characteristics of the WEEE management systems in the two regions.

In the same stage as well, this study incorporates policy analysis to assess which policy options are suitable for a particular system. One policy, the selection of funding schemes, is chosen for a developed country and a developing country models. Then, this work focuses on the developing systems by assessing the impact of the regulatory factors and the integration of the informal sector on the behavior of the systems in the model of developing country.

1.5 Manuscript Organization

This thesis is organized as follows. Chapter 2 provides literature reviews regarding WEEE, EPR concept, WEEE regulation, the practical implementation of EPR-based approaches, and the quantitative approaches on WEEE issues. Chapter 3 deals specifically with the qualitative analyses of the work. Chapter 4 explains deeply about the SD methodology for the boundaries under study, including the model formulation, the model testing, the base case and scenario analysis. Chapter 5 discusses the numerical analysis using ANOVA and the policy analyses and their results. Chapter 6 summarizes the important findings from this study.

Chapter 2 Literature Review

Chapter 2 highlights the topics and the literature review within WEEE contexts. It captures the definition, classification, and substances of WEEE. Subsequently, this chapter reviews the concepts dealing with WEEE management. The chapter proceeds with the explanation of WEEE management systems in the selected developed and developing countries. Also, the literature review on quantitative approaches to WEEE issues appears here. Finally, the last part of the chapter explains the System Dynamics (SD) methodology and provides a critical review of SD analysis for WEEE issues.

2.1 Waste Electrical and Electronic Equipment (WEEE)

The EU WEEE Directive 2012/19/EU defines "electrical and electronic equipment" as "equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1000 volts for alternating current and 1500 volts for direct current". The directive continues with the definition of WEEE as "electrical or electronic equipment which is waste" within the meaning of the previous definition. Khetriwal et al. (2009) noted that Widmer et al. (2005) have included several definitions of WEEE and used the term of "WEEE" synonymously with another term, i.e. "e-waste".

2.1.1 Classification of WEEE

The EU WEEE Directive 2002/96/EC categorizes WEEE into ten different groups as listed in Table 1. In the proposal for EU WEEE Directive recast (2008), the WEEE categories were suggested to adopt the same classification as has been used in the Restriction of the Use of Certain Hazardous Substances in EEE (RoHS) Directive (The European Union, 2003). This proposal aims to simplify collection and administrative processes taken by private parties. Afterwards, the EU enacted the WEEE Directive 2012, which keeps the ten categories of the previous WEEE Directive only in the transitional period from 13 August 2012 to 14 August 2018. After this period, the WEEE shall be grouped as mentioned in Annex III and IV of the 2012 EU Directive. Interestingly, the 2012 EU directive shows a progress to include product category with a long life cycle, i.e. photovoltaic panels (Besiou and Van Wassenhove, 2015a) . Table 2 shows the categories after the transitional period.

Table 1. The Category of EU WEEE Directive 2002

No	WEEE Category	Example of Indicative List within Category
1	Large household appliances (LHA)	Refrigerators, freezers, washing machines
2	Small household appliances (SHA)	Vacuum cleaners, toasters, irons
3	IT and telecommunications equipment (IT)	Personal computers, laptops, printers
4	Consumer equipment and photovoltaic panels (CE)	Radio sets, TV sets, video cameras
5	Lightning equipment (LE)	Lamps
6	Electrical and electronic tools (EET)	Drills, saws, sewing machines
7	Toys, leisure, and sports equipment (TLSE)	Video games, electric trains, coin slot machines
8	Medical devices (MD)	Radiotherapy and cardiology equipment
9	Monitoring and control instrument (MCI)	Thermostats, smoke detectors, heating regulators
10	Automatic dispensers (AD)	Drink dispensers, solid product dispensers

The member states of EU have transposed the categorization of WEEE variously. For instance, Germany clusters the ten groups of WEEE in EU 2002 Directive into five groups of WEEE under the legal Act Governing the Sale, Return and Environmentally Sound Disposal of Electrical and Electronic Equipment (ElektroG). Table 3 indicates one example of different categorization between the EU and its member states' legislations (Walther et al., 2009).

2.1.2 Contents and Substances of WEEE

WEEE covers five major types of materials: ferrous metals, non-ferrous metals, glass, plastics, and other materials (Ongondo et al., 2011; Widmer et al., 2005). Table 4 lists the material compositions (rounded) of the large household appliance (LHA), small household appliance (SHA), and ICT-consumer electronics (Empa, 2016). The "Solving the e-waste Problem (Step)" report from the United Nations Environmental Program (UNEP, 2009) records several elements which are potentially recoverable in mobile phones, laptops, and PCs, e.g. copper, silver, gold, and palladium. At the same time, there are several commonly reported hazardous substances in WEEE.

Table 2. The Category of EU WEEE Directive 2012 after the Transitional Period

No	WEEE Category	Notes	Example of Indicative List within Category
1	Temperature exchange equipment	-	Refrigerators, Freezers, Air Conditioners
2	Screens and monitors	equipment containing screens having a surface greater than 100 cm^2	Screens, Televisions, Laptops
3	Lamps	-	Straight fluorescent lamps, Compact fluorescent lamps, LED
4	Large Equipment	any external dimension more than 50 cm	Washing Machines, Clothes Dryers, Dishwashing machines
5	Small Equipment	no external dimension more than 50 cm	Vacuum Cleaners, Microwaves, Toasters
6	Small IT and telecommunication equipment	no external dimension more than 50 cm	Mobile Phones, GPSs, Telephones

Table 3. The Comparison of WEEE Category between EU WEEE Directive 2002 and ElektroG

No	WEEE Category	ElektroG Collection Group
1	Large household appliances (LHA)	Collection Group 1
2	Small household appliances (SHA)	Collection Group 5, except Refrigerator/Freezer that come into Collection Group 2
3	IT and telecommunications equipment (IT)	Collection Group 3
4	Consumer equipment and photovoltaic panels (CE)	Collection Group 3
5	Lightning equipment (LE)	Collection Group 4
6	Electrical and electronic tools (EET)	Collection Group 5
7	Toys, leisure, and sports equipment (TLSE)	Collection Group 5
8	Medical devices (MD)	Collection Group 5
9	Monitoring and control instrument (MCI)	Collection Group 5
10	Automatic dispensers (AD)	Collection Group 1

Table 4. Material Composition of the Overall Weight of the Three WEEE Categories (rounded, adapted from Empa, 2013)

Material	Composition in Large Household Appliances (%)	Composition in Small Household Appliances (%)	Composition in ICT and Consumer Electronics (%)
Ferrous metal	43	29	36
Aluminium	14	9.3	5
Copper	12	17	4
Lead	1,6	0.57	0.29
Cadmium	0.0014	0.0068	0.018
Mercury	0.000038	0.000018	0.00007
Gold	0.00000067	0.00000061	0.00024
Silver	0.0000077	0.000007	0.0012
Palladium	0.0000003	0.00000024	0.00006
Indium	0	0	0.0005
Brominated plastics	0.29	0,75	18
Plastics	19	37	12
Lead glass	0	0	19
Glass	0,017	0,16	0,3
Other	10	6,9	5,7
Total	100	100	100

The StEP report (UNEP, 2009) distinguishes three types of emission in WEEE:

- Primary emission: Existing hazardous materials inside electronic and electrical product, e.g. lead, mercury, arsenic, polychlorinated biphenyls, and fluorinated cooling fluids.
- Secondary emission: Hazardous reaction released because of inappropriate WEEE treatments, e.g. dioxins and furans formed by incineration.
- Tertiary emission: Hazardous substances used as a reagent during improper recycling activities, e.g. cyanide, mercury.

2.2 WEEE Management Systems: Concept

This section explains the concept of Extended Producer Responsibility. It also describes WEEE treatment, recoveries, and reverse logistics. Lastly, this part of the thesis examines the available funding mechanisms for WEEE.

2.2.1 Extended Producer Responsibility (EPR)

Current world's WEEE management systems are highly influenced by Extended Producer Responsibility (EPR). EPR has been viewed not only as a principle but also as an environmental approach and strategy (Manomaivibool, 2009). Through EPR-based legislation, producers are not only responsible for the upstream phases, but also now responsible financially and physically for the downstream phases of their own products, i.e. collection, environment sound treatments, and recoveries of WEEE.

Previous authors (Cahill et al., 2011; Khetriwal et al., 2009; Lifset et al., 2013) notes several interrelated objectives of EPR, including:

- Reducing primary resource usage,
- Promoting Design for Recovery (DfR) through incentives,
- Preventing waste through reuse, recycle and other recovery activities,
- Shifting the financial burden of waste management from local authorities to producers, and
- Closing the loop of material flow.

To achieve its goal, EPR provides administrative, economic, and informative policy instruments, e.g. product standards, collection and recycling target, material and product taxes, products labeling, advanced recycling fees, and environmentally sound treatments. (Bohr, 2007; Lindqvist, 2000).

EPR gained prominence when EU introduced WEEE EU Directive 2002. Respectively, a few member states of EU, including Sweden, Belgium, and the Netherlands, have implemented EPR-based approaches before the Directive came into force (Bohr, 2007). Soon, other member states transposed the directive into national laws and implemented the EPR-based programs. Several alternatives exist in how member states embed the EPR into their national laws and how they developed the policy instruments. These varieties include the definition of "Producer", the scope of the legislation, the organizational form, funding mechanism, etc. (Huisman et al., 2007; Sander et al., 2007).

2.2.2 EPR: Individual Producer Responsibility (IPR) and Collective Producer Responsibility (CPR)

Producers may fulfill their end-of-life responsibilities in one of these two approaches of EPR: Collective Producer Responsibilities (CPR) and Individual Producer Responsibilities (IPR). IPR reflects the original idea of EPR: to make producers think their business in complete/comprehensive economic cycles, thus promote feedback incentive to the design phase (Bohr, 2007). To achieve this incentive, producers should be able to access the waste from their brand in the downstream wastes. This access might encourage the producers to minimize their end-of-life cost, through Design for Recovery (DfR) (Atasu and Subramanian, 2012). According to Rotter et al. (2011), IPR can be implemented in one of three ways: (1) individual collection with individual treatment, (2) collective collection with brand sorting and individual treatment, and (3) collective collection without sorting, but with the distinction of recycling costs. In practice, the operations of IPR concept face real-world challenges, e.g. expensive and inefficient brand sorting for “mix waste” in municipality waste collection (Huisman, 2013) and complex statistical procedures to distinguish producers’ recycling costs under collective collection (Rotter et al., 2011).

Under CPR, the producers lost connection with their “own-waste”, since the waste is treated collectively in mixed collection stream. The producers pay the waste collectively and share their operational cost based on their recent years’ market share. The CPR-based program can be implemented in a monopoly by the state or competitively by multiple private systems (Atasu and Wassenhove, 2012). In the latter case, producers may join or establish a sharing responsibility group, i.e. Producer Responsibility Organization (PRO). PROs, on behalf of the producers, are responsible for managing the physical activities of WEEE collections and treatments. Since PROs usually do not have their collection and processing system, they outsource the waste processing to the third parties, e.g. logistics providers, sorting plants, and recycling plants (Mayers and Butler, 2013). The logic behind using CPR is that it is simpler to create appropriate economics of scale (Bohr, 2007). However, as noted by Atasu and Subramanian (2012), CPR also have been criticized because, to a certain degree, this approach allows the existence of unfair sharing among producers and weakens the feedback incentive to promote DfR.

Nevertheless, Sander et al. (2007) mention the possibility to implement individual financial responsibility within four collectively organized compliance schemes. These alternative design schemes are:

- System Design 1. This type of systems is categorized by permitting only one national compliance scheme/producer responsibility organization (PRO) dealing with WEEE management services. The producers are obliged to use this single scheme. In this system, individual producers’ collections are not recognized/counted to comply with the regulation.
- System Design 2. This type of systems is similar to the type 1 as also only allowing one national compliance scheme to existing. However, additionally, individual producers’

collections are recognized by the systems and may be counted in the fulfillment of producers' responsibilities.

- System Design 3. This type of systems allows multiple compliance schemes or PROs to exist to prevent monopoly in the national market. However, the system recognizes no individual collection efforts by the producers.
- System Design 4. Multiple national schemes are operating in this type of systems. At the same time, the individual producers' operations are also recognized and can be counted as compliance with the regulation.

2.2.3 WEEE Treatments and Recoveries

To ensure the total life-cycle environmental improvements, WEEE needs to be treated according to the standards for treatment, recycling and recovery of materials. Figure 1 depicts a graphical representation of activities existing in WEEE end-of-life treatments and recovery.

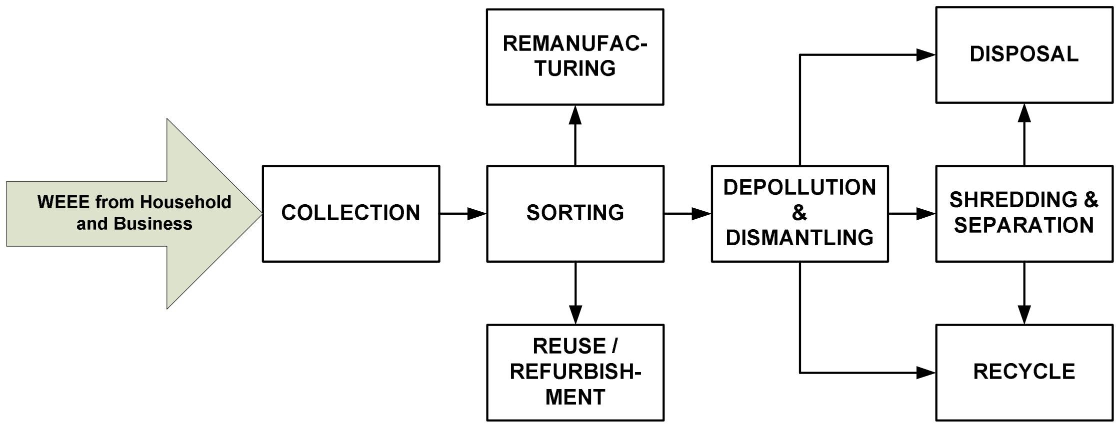

Figure 1. End-of-life Treatments and Recovery of WEEE

Collection refers to any activities that make the disposal of EEE being available in any shared places where the next treatments await (Fleischmann, 2000). This activity includes two main phases: the placement of a discarded product in a particular location and the transportation (Lambert et al., 2011). In general, the placement of WEEE appears in two types: pick-up and drop-off collection (Bohr, 2007). Pick-up is favored by the consumers since the municipality will directly take the waste from desirable places based on consumers' perspective. Drop-off, on the contrary, demands the consumers to bring their discarded products to a collection point. According to van Rossem (2008), several specific collection options appear in the implementation of EPR programs. The options include municipality collection sites, curbside collection/mobile, retail collection sites, retail pick-up when delivering new products, PROoperated collection depots, direct return to the producer or recycler via courier service, and special collection options.

Sorting activities distinguish WEEE based on a certain type of classification or procedure, e.g. a category of WEEE based on the legislation or procedure to determine whether a particular EEE is still reusable or not. The classification splits the products into several flows based on the assessments of the participating actors. If allowed by regulation, the municipality may sort and separate the discarded product for direct reuse and refurbishment (Walther et al., 2009), avoiding the EEE to become WEEE. Informal scavengers also seek opportunity by collecting and sorting the products that are still reusable and recyclable.

Subsequently, some activities await WEEE, i.e. reuse, remanufacturing, refurbishment, recycling, and disposal (Fleischmann, 2000; Kumar and Putnam, 2008). After the visual assessment, cleaning, and minor maintenance, some WEEE may be reused directly by selling it into the secondary market. Apart from the reusable ones, some portions of WEEE could either come to the refurbishment process to restore its working order or to the remanufacturing to make it as new condition (Herold, 2007). The remaining products or components of WEEE can be recycled to recover the valuable materials. Finally, some parts are still left and cannot be recovered. These parts will be disposed of in the form of landfilling or incineration.

The rest of WEEE which cannot be reused and refurbished enters the dismantling and depollution processes. As noted by van Rossem (2008) from Boks (2002), these processes are required because of two main reasons: (1) to recover the valuable components and to remove parts that have high purity of material and (2) to remove hazardous substances existing in the WEEE, so that the systems can comply with the regulation. Then, shredding and separation may take place to separate further the existing material. Initially, WEEE is shredded into smaller pieces using coarse shredders or smaller-size shredders (Bohr, 2007). The shredded material, then, is separated using several kinds of technologies, e.g. overband magnets, eddy current separation, rotating trommel screens, air tables, and optical screening (van Rossem, 2008).

2.2.4 WEEE Reverse Logistics

Based on the total life cycle perspective, the flow of materials is designed to close the material loop. The flow of products comes originally from the producers of raw material and should end again into these producers. There are several possible reverse logistics channels of WEEE as provided in Figure 2 (Fleischmann, 2000; Khetriwal et al., 2009; Rotter et al., 2011; Walther et al., 2009).

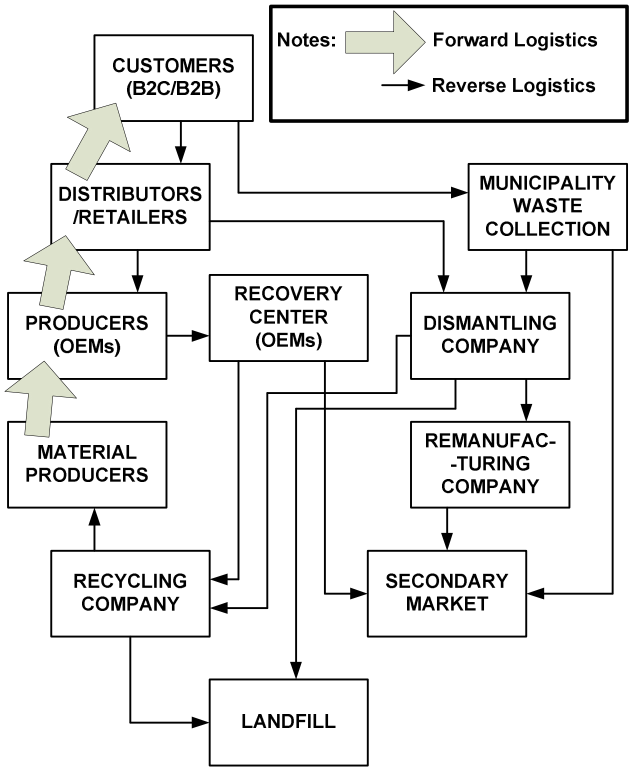

Figure 2. WEEE Reverse Logistics together with its Forward Logistics (Fleischmann, 2000; Khetriwal et al., 2009; Rotter et al., 2011; Walther et al., 2009)

2.2.5 Funding Mechanism of the Systems

Under the EPR approach, producers take the responsibility to finance the take-back activities, the treatments, and the recycling in the end-of-life of the products. Several possible funding mechanisms may be opted, depending on the requirements of the national/regional regulation. According to Magalini and Huisman (2007), there are four types of schemes to finance the WEEE management systems in EU:

- Compliance Cost (CC). In this case, producers are responsible financially for WEEE management systems in all type of WEEE, i.e. Historical WEEE (discarded product from EEE put on EU market before August 13th, 2005) and New WEEE (discarded product from EEE put on EU market starting at August 13th, 2005).
- The combination of Compliance Cost (CC) and Visible Fee (VF). In this type of scheme, producers also are fully responsible for financing WEEE management systems of Historical and New WEEE. However, when allowed by National Regulation, producers can use VF to shift the management cost of Historical WEEE to the customers. Producers reimburse their WEEE management cost by putting VF at the time of purchase.

- Reimbursed Compliance Cost (RCC). Under RCC, producers bear the responsibility to finance the management systems for both Historical and New WEEE. Furthermore, producers can pass their management cost to the customers by using VF on both Historical and New WEEE.
- Recycling Fee (RF). In this scheme, instead of producers, customers are responsible for financing the management cost for all type of WEEE. Customers pay the cost in point of sales when they buy the EEE. There is no financial contribution from the producers. Magalini and Huisman (2007) noted that there are two types of RF: (1) Advance Recycling Fee (ARF) and (2) Shared Recycling Fee (SRF). On the one hand, ARF is estimated to finance future recycling cost of the recent sold EEE. On the other hand, SRF is shared to finance the recycling cost that currently appears in the waste stream. Only Visible Fee in the form of SRF is allowed strictly by EU WEEE Directive with the respect of Historical WEEE (Magalini and Huisman, 2007). Otherwise, producers must bear the financial responsibility based on EPR approach.

Outside the EU region, there are some regions/countries that implement ARF as means to finance the WEEE management systems, including Switzerland, Taiwan and several states in the United States of America (Atasu and Wassenhove, 2012; Khetriwal et al., 2009; Wath et al., 2010).

There are some other possible financial mechanisms to support WEEE management systems, including disposal fee, deposit-refund systems, and government subsidy (Atasu and Wassenhove, 2012; Chi et al., 2014; Wath et al., 2010). Disposal fee charges consumers to pay the recycling cost when they discard the end-of-life products such as it appears in the Japanese systems. In the case of deposit-refund systems, the customers pay an additional fee at the point of sales that can be refunded when they carry back the WEEE to the licensed collectors. Lastly, the government may subsidize the certified collectors and recyclers who participate in take-back programs, such as in the Chinese “Old-for-New” program.

2.3 WEEE Management Systems in Selected Developed Countries

This section assesses the WEEE management systems in two developed countries. It includes the review of the Swiss and German systems. These two systems are selected because the unique characteristics they possess. The Swiss system represents a single compliance system using ARF in a country which has a relatively small and landlocked area, while the German’s denotes a system which allows multiple competing compliance systems without

ARF in a country which has a relatively large and non-landlocked area (Atasu and Wassenhove, 2012).

2.3.1 WEEE Management Systems in Switzerland

Switzerland has been recognized as the pioneer in developing a formal WEEE management system and in regulating this system by EPR-based approach (Khetriwal et al., 2009; Wath et al., 2010). The efforts initiated prior to the enactment of Swiss national regulation, by the establishment of two major PROs: The Swiss Association for Information Communication and Organizational Technology (SWICO) Recycling and Stiftung Entsorgung Schweiz (SENS). SWICO Recycling was founded in 1993 by the producers association of copiers and IT equipment (Ongondo et al., 2011). Being originally only dealt with the discarded office electronics and IT equipment, SWICO currently manages the waste from the various categories of products e.g. the computer equipment, consumer electronics, safety technologies, measurement and medical equipment, and dental equipment. In 2012, the annual collection rate of SWICO achieved 61,000 tons of waste taken from collection points, retailers, companies, and manufacturers (SWICO, 2013).

SENS was founded in 1990. It originally only treated freezers and refrigerators (Ongondo et al., 2011). The category of products covered by today's SENS systems includes small and large household appliances; refrigerating equipment; building, gardening and hobby equipment; toys; and lamps, light bulbs, and tubes. This non-profit organization is currently able to process more than 74,700 tons of waste annually (SENS, 2012). Beside SWICO and SENS, there also exist two other smaller PROs. They are the Swiss Light Recycling Foundation (SLRS) that only processes lighting equipment and the Stakeholder Organisation for Battery Disposal (INOBAT) that handles battery (Khetriwal et al., 2009; Ongondo et al., 2011).

In 1998, Switzerland introduced its WEEE management systems' legal basis, the Ordinance on The Return, the Taking Back and the Disposal of Electrical and Electronic Equipment (ORDEE). This regulation deals with the entire aspects of end of life management for WEEE, i.e. take-back responsibilities, the obligation of traders and manufacturers, obligation and requirement of waste disposal, and requirement of WEEE trans-boundary movement (Khetriwal et al., 2009). Through ORDEE, the customers bear the responsibility to bring back their discarded products into selected collection points or retailers. Retailers are obliged to accept the discarded products, irrespective whether the products were bought there or not and whether the customers replace the discarded product by buying a new EEE or not. The discarded products, then, are sent to the waste treatments and processing plant to decontaminate the hazardous components and recover the valuable material. Afterwards, the remaining parts flow to the recycling plant for further processing.

The daily operations of Switzerland's systems are financed by Advance Recycling Fee (ARF). ARF reflects the gap between the total cost of the WEEE management systems and total value recovered from the waste (Wath et al., 2010). It finances the whole process in the system, i.e. collection, transportation, dismantling, decontamination, and recycling of WEEE (Khetriwal, 2009). According to Khetriwal et al. (2009), the mechanism of Swiss ARF are:

1. The producers pay ARF to PROs when they sell or import new electronic products.
2. The producers pass down the ARF to the distributors and retailers.
3. The distributors and retailers invoice the customers at the points of sale.
4. The PROs distribute ARF to the selected companies which handle the WEEE.

This situation implies, instead of producers, the customers bear the final responsibility to finance the whole systems.

Recently, total Swiss' systems handle about 135,570 tons of WEEE annually, equal to 16.87 kg per capita in 2013 (SWICO, 2015). This high number has exceeded the EU's collection target and supports the notion that the Swiss model is among the most proficient systems in the world (Huisman, 2012; Wäger et al., 2011). Figure 3 represents the Switzerland's WEEE management system completed with its material and financial flow (Khetriwal et al., 2009; Wäger et al., 2011; Wath et al., 2010).

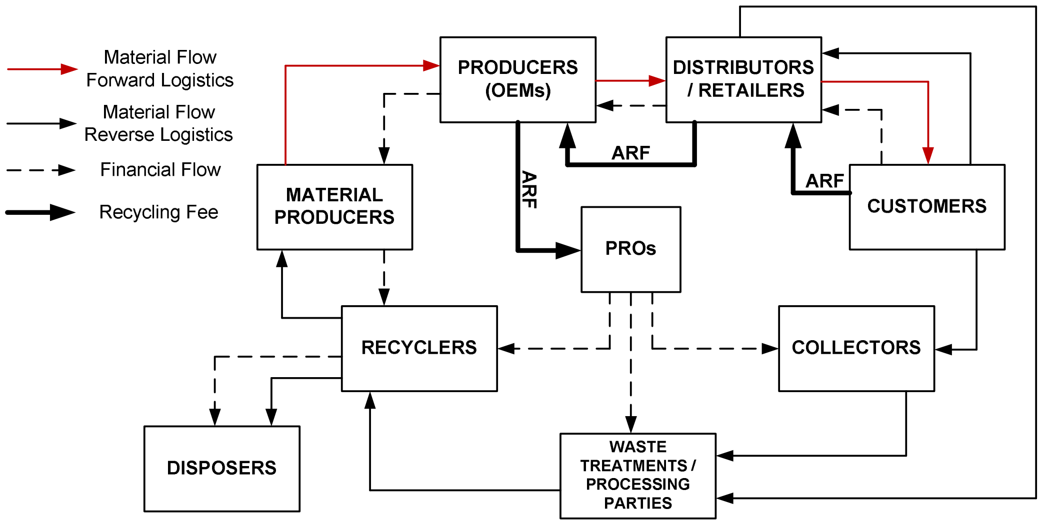

Figure 3. WEEE Management Systems in Switzerland
(Khetriwal et al., 2009; Wäger et al., 2011; Wath et al., 2010)

2.3.2 WEEE Management Systems in Germany

Germany pioneered the development of EPR-based systems and regulation in dealing with solid waste by the introduction of the Duales System Deutschland (DSD) in 1990 and the Ordinance on the Avoidance of Packaging Waste in 1991. Through these regulations, the producers bear the responsibility to recover, recycle and dispose of packaging material which they put on the market. However, Germany finally introduced its own specific EPR-based regulation only after the presence of EU WEEE Directive 2002. Germany established “the legal Act Governing the Sale, Return and Environmentally Sound Disposal of Electrical and Electronic Equipment” (ElektroG) in 2005. ElektoG obligates producers to deal with WEEE management systems, physically and financially (ElektroG, 2005). Producers may also choose whether to set their individual take-back systems or join collective systems to fulfill their responsibilities. ElektroG established Foundation of “Stiftung Elektro-Altgeräte Register” (EAR) as a neutral national clearing house and registration body (Sander et al., 2007). EAR is responsible for managing the pick-up process as well as the collection, recycling, and recovery target (Walther et al., 2009).

Under ElektroG, the WEEE from households is collected by municipalities. Customers are free of charges when they return their discarded products. In the municipalities, WEEE is sorted into five categories of products and put into special containers of 30 m^3 for general equipment and $3m^3$ for lighting equipment. If at least one container from any category is filled completely, the municipalities request a pick-up order to the producers via EAR. Based on a proprietary algorithm, EAR then chooses a specific producer who is responsible for pick-up and to perform environmental sound treatment to the discarded products (Walther et al., 2009).

The financial mechanisms in the German system are categorized based on the period of products’ time of sale: historical and new. For the Historical WEEE, the German system obligates all of the producers to bear the financial responsibilities together based on the current EEE market share when the waste management cost arises. In the case of New WEEE, the producers may opt whether they want to use market share or return share option. Return share option is calculated based on producers’ share of the actual collection rates in municipality waste collection. Until recently, there is no producer who chooses to use return share option for New WEEE (Rotter et al., 2011). Return share option requires producers to conduct brand samples or brand counting which are complex to be implemented.

In October 2015, Germany amended ElektroG to adapt the changes occurred in EU WEEE Directive 2012. The new regulation, named as “ElektroG 2”, incorporates some improvements, including:

- Broadening the scope of WEEE category under the law which now includes night storage heaters, photovoltaic modules, and luminaires in private households.
- Improving the collection target from previously 4 kg WEEE from private household per capita per year to 45% and 65% of the average input of EEE in the three preceding years at the beginning of 2016 and 2019, subsequently.
- Obligating large distributors, resellers, and retailers (including online) to take back WEEE from the customers.

The German systems recently collect 727,998 tons of WEEE – equal to 9.027 kg per capita (Eurostat, 2016). Figure 4 shows the graphical representation of WEEE Management Systems in Germany (Bohr, 2007; Rotter et al., 2011; Walther et al., 2009).

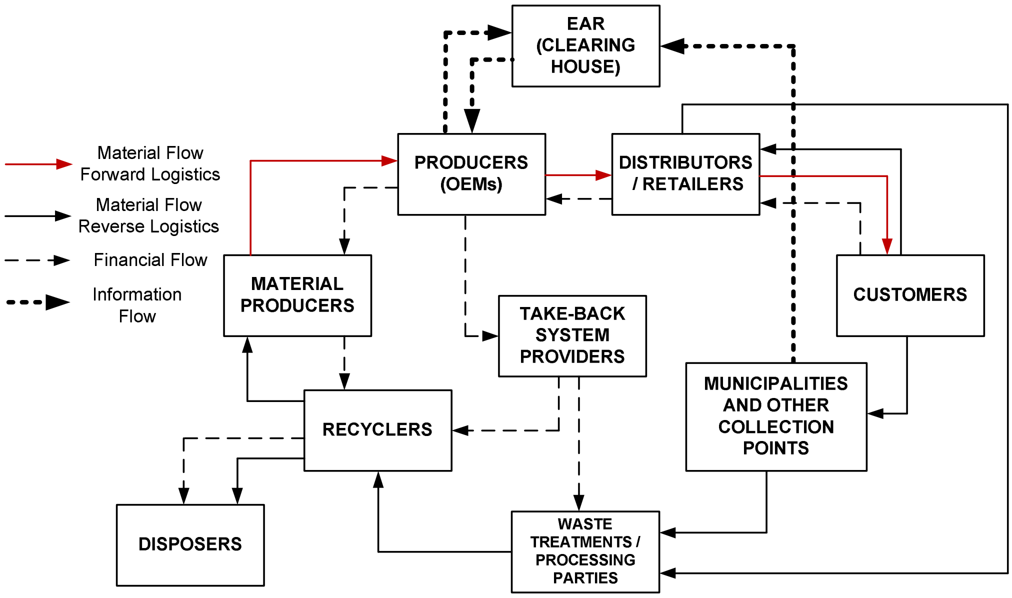

Figure 4. WEEE Management Systems in Germany
(Bohr, 2007; Rotter et al., 2011; Walther et al., 2009)

2.4 WEEE Management Systems in Selected Developing Countries

This section assesses the WEEE management systems in two developing countries. It consists of the Chinese, Indian, and Nigerian management systems.

2.4.1 WEEE Management Systems in China

The quantity of WEEE is increasing at a rapid rate in China. This phenomenon happens because of at least three things (Kojima et al., 2009; Ongondo et al., 2011):

- China is the world’s largest manufacturer of electronic products,
- China is the world’s largest importer of WEEE,

- The electronic market in China is still growing and far from being saturated.

According to Zeng et al. (2013), the development of WEEE management systems in China, historically, can be categorized into four phases:

(1) Informal manual dismantling phase (the 1980s – 2000) in which the absence of regulation provided spaces for the informal sector to flourish, by taking advantages from the incoming illegal transboundary movement of WEEE,

(2) Co-existing phase (2001 – 2008) in which Chinese government initiated pilot projects to establish WEEE recycling system and drafted several regulations. Hence, the formal sector started to co-exist with the informal sector.

(3) Development phase (2009 – 2020) in which the "Home Appliance Old for New Rebate Program" took places from 2009 to 2011 – and achieved respectable collection results – and the government enacted Chinese WEEE regulation in 2011.

(4) Mature Phase (expected from 2020 onwards) in which the expected large scale of WEEE recycling system will have already been well-established.

China established two important regulations which are similar with the EU's: (1) The Ordinance on Management of Prevention and Control of Pollution from Electronic Information Products in 2007 (MIIT, 2006) and (2) Regulation on Management of the Recycling and Disposal of Waste Electrical and Electronic Equipment in 2011 (Yu et al., 2010a). The former regulation is the counterpart of the EU RoHS Directive that deals with the restriction to use several hazardous substances in the electronic products and pollution reduction in the life cycles of the products. The latter regulation corresponds with the EU WEEE Directive and obligates the collection of WEEE from multiple channels to the licensed recycling parties (Zhou and Xu, 2012).

China also enacted "Administrative measures for levy and use of treatment fund for waste electronic and electric products" in 2012 (Zhang et al., 2015). This regulation requires the producers to be involved in financing the WEEE management systems through product tax for producers or importers. The tax includes 13 RMB, 12 RMB, 7 RMB, 7 RMB and 10 RMB, for each television, refrigerator, washing machine, air conditioner, and personal computer, respectively (Zhang et al., 2015). This fund is collected through the local taxation and customs bureaus for each sold and imported electronic product (Zeng et al., 2013). Then, the fund is distributed through local administration to the licensed companies that dismantle and recycle WEEE. These companies can take 85 RMB, 80 RMB, 35 RMB, 35 RMB and 85 RMB for treating each unit of products above. To ensure the sufficiency of the fund, the Chinese government subsidies the systems (Yu et al., 2010a). The amount of subsidy reaches approx. 540 million dollars based on 39,87 million units of treated WEEE in 2013 (Li et al., 2015).

Chinese consumers are expected to bring the discarded products to the retailers, after-sales service providers, or licensed recyclers. The existing approach aims to direct the WEEE into the formal systems; thus ensuring the environmental sound treatment to the WEEE and maintaining the feasibility of financial mechanism in the formal systems. OfN program is a clear example demonstrating this effort. It attempts specifically to stimulate Chinese consumers to buy new home appliances and, at the same time, to dispose of the waste in the formal collection. It was launched in nine regions and implemented from June 1st, 2009 until December 31st, 2011 (Wang et al., 2013b). This pilot project has produced at least two notable results, (1) the increasing sales rate of EEE in China up to 92.48 million units by December 2011 and (2) the high number of collected WEEE in the formal channels, i.e. 83.73 million units at the end of November 2011 (Zeng et al., 2013).

However, outside the OfN program, the formal collection faces scarcity of input because of fierce competition with the informal sector. WEEE from Chinese households flows majorly into the informal channels and actors, e.g. informal traders, informal refurbishments, device separators, manual recycling shops, and leaching facilities. (Chi et al., 2011). Figure 5 captures the WEEE management systems in China, considering the existence of the informal sector in the reverse stream (Chi et al., 2011; Kojima et al., 2009; Yu et al., 2010a; Zhou and Xu, 2012).

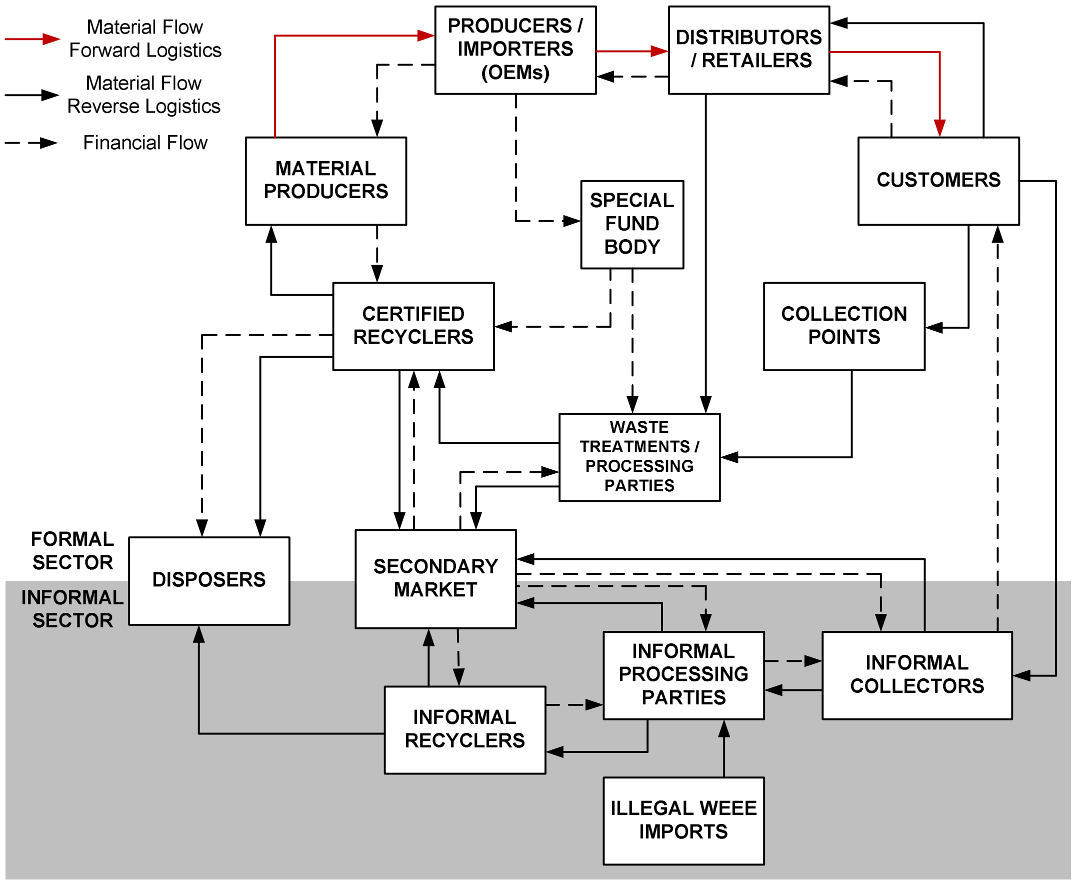

Figure 5. WEEE Management Systems in China
(Chi et al., 2011; Kojima et al., 2009; Yu et al., 2010a; Zhou and Xu, 2012)

2.4.2 WEEE Management Systems in India

India has established itself as one the largest global WEEE producers with 1.7 million tons of generation in 2014 alone (Baldé et al., 2014). Initially, India started to consider WEEE as hazardous waste, albeit limited, in “the hazardous wastes (management and handling) amendment rules, 2003”. Afterwards, “Guidelines for environmentally sound management of e-waste” appeared in 2008, already mentioning the EPR concept (Garlapati, 2016). Not until 2011 India finally enacted a specific regulation addressing the WEEE issues, by introducing “E-Waste (Management and Handling) Rules” (MoEF, 2011). This approach applies distinct responsibilities to producers, consumers, bulk consumers, recyclers, collection centers, and dismantlers of WEEE. Remarkably, it also provides a door for the informal sector to become a member of formal WEEE management, as collection centers or dismantlers, through formalization (CERAG, 2013).

Just recently, India introduced the stringent and more practical ‘E-Waste Management Rules, 2016’ which replaces the previous directive (MoEF, 2016a, 2016b). Some notable improvements in this new regulations are as follows:

- The applicability of the WEEE rule is extended to the manufacturer, dealer, refurbisher and Producer Responsibility Organization (PRO).
- The rule covers also components, consumables, spares and parts of EEE.
- Producers exclusively bear responsibility developing the collection mechanism, either via setting up collection points/centers or initiating a buy-back program.
- Producers may set up PRO, e-waste exchange, e-retailer, or Deposit Refund Scheme as additional channels.
- The rule specifically mentions the collection target, i.e. weight shall be 30% of the quantity of generated waste as showed in EPR Plan during the first two years of implementation of rules followed by 40% during third and fourth years, 50% during fifth and sixth years and 70% during seventh year onwards.

Nevertheless, one should consider the significant appearance of the informal recycling sector. It is estimated that 1% of the Indian population is involved in the informal waste sector (Chikarmane et al., 2008). These informal workers are recognized as *Kabadiwalas* (waste collectors/dealers), *Thailawalas* (collectors), small *Kabaris* (small scrap collectors), and big *Kabaris* (large scrap collectors) (Pandey and Govind, 2014; Wath et al., 2010). Figure 6 exhibits the WEEE management systems in India, considering the existence of the informal sector and the changes induced by the 2016 amended WEEE rule (Manomaivibool, 2009; MoEF, 2016a, 2016b; Wath et al., 2011).

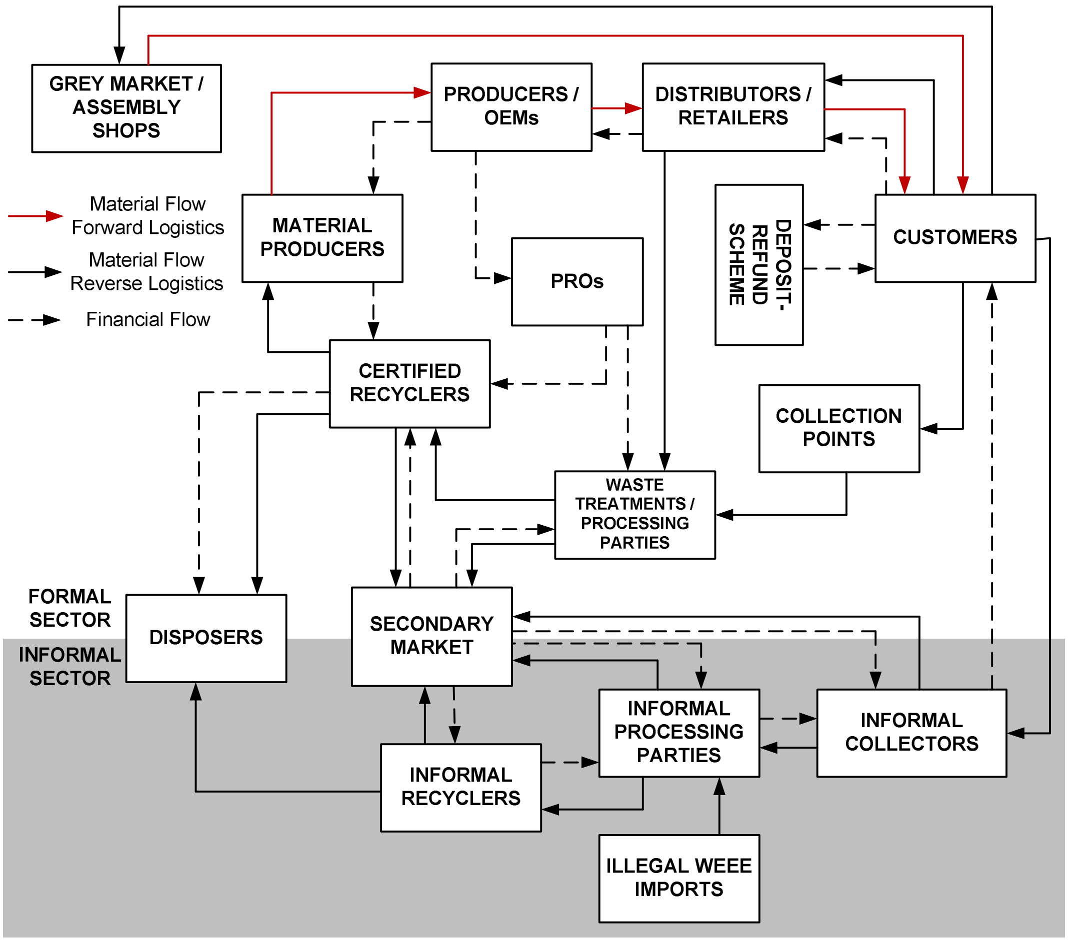

Figure 6. WEEE Management Systems in India
(Manomaivibool, 2009; MoEF, 2016a, 2016b; Wath et al., 2011)

2.4.3 WEEE Management Systems in Nigeria

Nigeria had been used as the destination of illegal WEEE dumping since the end of the 1980s. Recently, it is one the highest generator of WEEE in Africa based on an absolute waste quantity (Baldé et al., 2014). Not until 2011 did finally Nigeria enact the National Environmental (Electrical Electronic Sector) Regulations SI No 23 of 2011. The regulation is designed based on total life-cycle perspective and to cover all aspect of WEEE. Nevertheless, it is difficult to assess the current state of implementation for the regulation. One of most recent study finds out that, as of 2012, there was no attempt to organize the collection activity, indicated by the absence of collection center (Peluola, 2016). Figure 7, adapted from the latest mapping of Ogungbuyi et al. (2012) and the latest update of the proposed registration systems (Amachree, 2013), depicts the current state of the systems in Nigeria.

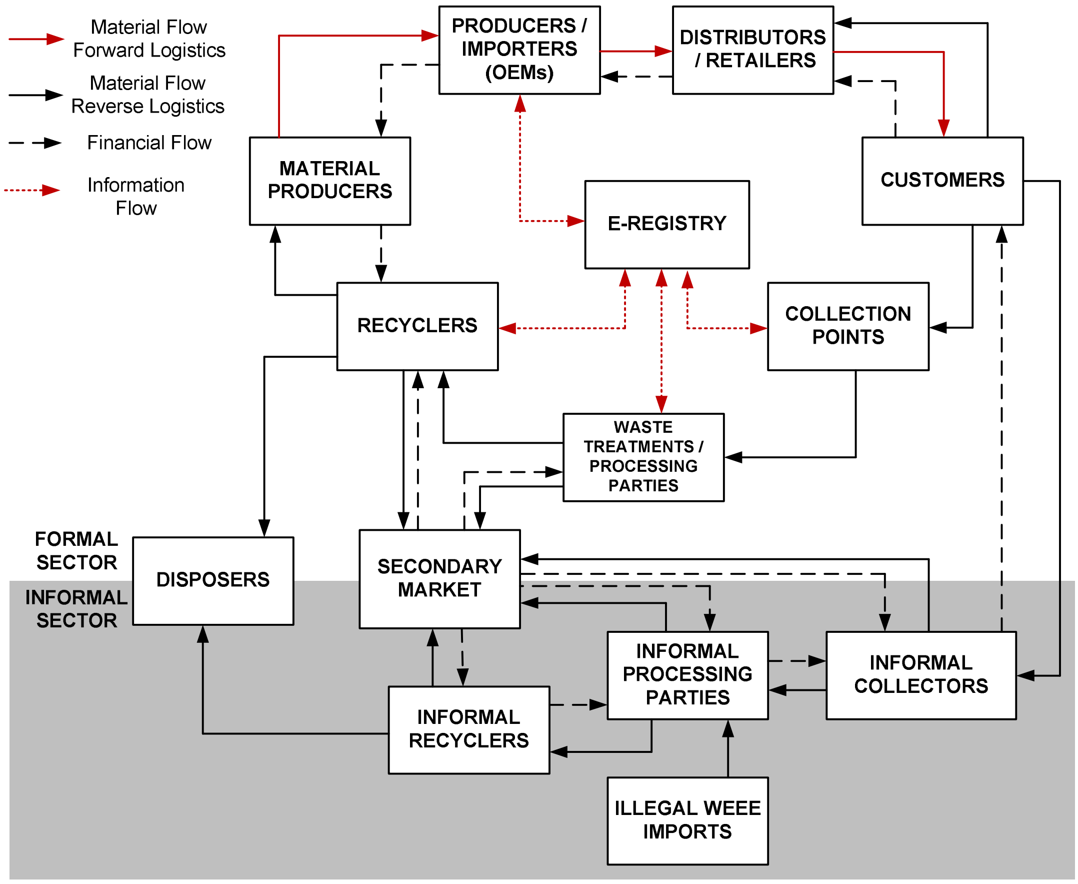

Figure 7. WEEE Management Systems in Nigeria
(Amachree, 2013; Ogungbuyi et al., 2012)

2.5 Literature Review on Quantitative Approaches to WEEE-related Issues

This section reviews the existing quantitative works dealing with the WEEE-related issues. It aims to shed some light about the growing trend of the approaches used. The first sub-section examines the recent approaches to estimate the future waste generation. The second sub-section discusses approaches to optimize parts or overall reverse supply chain of WEEE systems. Lastly, the third sub-section assesses the utilization of System Dynamics in WEEE management systems.

2.5.1 Literature Review on WEEE Estimate Methods

This section reviews the previous approaches to estimate the future trend of WEEE generation. By no means it claims to be exhaustive as previous work has provided such review (Wang et al., 2013a). In general, WEEE generation estimates aim to project the future obsolete trend of EEE from a particular society. This estimation is important to understand the potential value of the precious and scarce metals and the potential threat of the hazardous substances within the future generation. Also, by having a robust projection result, the policy makers in WEEE management systems may determine the required capacity of the collection and recycling infrastructures to handle the future waste.

According to Wang et al. (2013a), WEEE generation approaches have been classified into four groups: disposal related analysis, time series analysis (projection model), factor models, and Input-Output-Analysis (IOA). They further reviewed IOA, the most frequent approaches used by authors, based on the use of its three main pillars, i.e. sales of EEE, the number of EEE stock in society, and lifespan of the product. Their classification comprises as:

- Time Step Model, which uses discrete data of sales and continuous data of stock.
- Market Supply Model (Distribution Delay) which makes use of continuous sales data and lifespan age distribution.
- Market Supply Model (Simple Delay) which creates a projection based on continuous sales data and average lifespan.
- Stock and Lifespan Model which requires the continuous data of EEE stock and lifespan age distribution.
- Leaching model which involves the continuous stock data and average life span, and
- By considering the limitation of the methods above, Wang et al. (2013) propose an advanced sales-stock-lifespan that uses all of the three variables of IOA.

This study refers to their work for further detail of the calculation process for each method.

In the similar period, Sinha (2012) offer an adapted projection method based on the prominent Bass Model. This method – Reverse Diffusion method – utilize three parameters which are estimated using existing historical collection data. The first parameter, *p*, represents a proportion of customers who disposes of their EEE based on technical reasons. The second parameter, q, exhibits a fraction of customers who decide to dispose of their product based on discretionary disposal. Finally, m means the maximum total number of EEE products in society. *p, q,* and *m* are parallel to the innovation coefficient, imitation coefficient, and market population parameter in the Bass Model, respectively. The calculation method of Reverse Diffusion method is as follows.

$$d(t) = m * r(t) \quad (1)$$

$$r(t) = \frac{(p+q)^2}{p} \times \frac{e^{-(p+q)t}}{(1+\frac{q}{p}\times e^{-(p+q)t})^2} \quad (2)$$

where *d(t)* is the absolute disposal rate at the time *t* and *r(t)* is the disposal density function, also at the time *t.*

One should note that since Reverse Diffusion method requires disposal data to estimate its parameters, every country not having filed respective historical data and/or not having yet established at least one respective system might face difficulties to apply this approach.

Previous studies have employed waste generation/estimation methods in country-specific cases. Polák and Drápalová (2012) use a distribution delay model to estimate the future mobile phones waste in the Czech Republic. Their study finds a relatively long average lifespan of the mobile phone (7.99 years) and the estimation of generated waste from 2010 – 2020 (26.3 million units) in Czech. Kim et al. (2013) apply the population balance model (PBM) to project the future waste of eight waste items in South Korea. They survey 1000 households to generate the domestic service lifespan distribution, using Weibull distribution. Using the shipment volume and the household stock data, these authors predict the future generation of WEEE from 2000 until 2020. Their work further determines the collection rate of Korean systems from 2003 to 2009 by comparing the predicted value with waste historical data.

Subsequently, Rahmani et al. (2014) attempt to estimate the past and future generation rate of obsolete computers and mobile phones in Iran. These authors combine the time-series multiple life span model with the simplified logistic function model to produce the future generation trend. Using the import data from 1999 to 2011, the number of active mobile subscribers, and 1000 interviewed users, their work reveals that the Iranian waste mobile phone and computer generation will reach their maximum number by 2035 (90 million units) and 2040 (50 million units), respectively. Zeng et al. (2015) provide an effort to project the e-waste trend in China using material flow analysis and lifespan model of the Weibull distribution. Their findings show the potential rapid increasing rate of Chinese WEEE generation with 15.5 million tons of WEEE by 2020 and 28.4 million tons by 2030.

Beside of the country-specific projection, previous works have also addressed the waste generation on the regional and on the global level. In one of the pioneer works, Yu et al. (2010b) forecast the global penetration of waste personal computers (PCs) using the logistic model and material flow analysis. Using historical sales and computer stock data, their model predicts that the number of obsolete PCs in developing countries will exceed its developed region counterparts by two times higher in 2030. In another work, Petridis et al. (2015) propose a procedure to forecast waste computer generations in Western Europe, Eastern Europe, Asia/Pacific, Japan-Australia-New Zealand, and Middle/South America; using the sales data from 1985 to 2012. Their procedure consists of a distribution fitting process for the product lifespan, obsolete amount calculation, and waste forecasting. Using six types of distribution as the basis for the fitting process; these authors find the Weibull distribution to be the best fitting distribution for all of the regions, except Asia/Pacific region which suits better with the normal distribution. Afterwards, this work compares the waste trend projection with in-sample estimation using forecasting techniques. The comparison reveals the Autoregressive Moving Average model as the most accurate forecasting technique in their study.

There also exists a cluster of research dealing with the waste estimation in the hierarchy of material composition and metal level. Duan et al. (2015) use a Sales Obsolescence Model to estimate the trend of composition and metal generation in Chinese waste streams, considering uncertainty in input and output of the model. Their work utilizes various data, including sales-production data of large household appliances, monitors, computers, mobile phones and TV from 1990 to 2012, market shares from released statistical data, and unit weight from previous works. As results, their model predicts the increasing rate of certain composite and metals in the waste stream, i.e. ferrous as the major material composite, copper from the precious metals, and Bismuth from the rare metals. In another work, Peeters et al. (2015) present a distribution delay forecasting method to project the growth of plastic housing waste from flat panel display (FPD) TVs, FPD monitors, cathode ray tube (CRT) TVs, and CRT monitors in Belgium. Using Belgium sales data from 1995 – 2013 and extrapolation from the Netherlands data for the lifespan distribution, their model estimates the shifting dominance of the plastic types in the waste stream. This shift happened because of the evolution of the monitor type and the material selection from the Original Equipment Manufacturers (OEMs). Hence, they note that there will be a high loss of plastic material when recycling companies rely only on the current density-based separation technologies rather than the novel disassembly/dismantling based treatments and plastic separation based on the optical identification. Table 5, adapted from Petridis et al. (2015), summarizes the literature review of quantitative approaches dealing with WEEE estimates.

Table 5. List of Reviewed Articles on WEEE Estimate Approaches

No.	Authors (Year)	Evaluation Method	Methodology	Applied Case	Type of Estimated Waste	Type of Estimated Component or Material of Waste (if any)	Findings
1	Yu et al. (2010b)	Time series and input-output analysis	Logistic model, MFA	Global Region	PCs	n/a	Developing countries will generate WEEE two times higher than developed ones by 2030
2	Polák and Drápalová (2012)	Time series	Distribution delay model	Czech Republic	Mobile phones	n/a	Calculation for the lifespan which is unique to the Czech Republic and estimation of waste phones by 2030
3	Wang et al. (2013)	Input-output analysis	Multivariate Input-Output Analysis	Netherland	Washing machines, laptop computers, CRT TVs, and Flat TVs	n/a	An enhanced WEEE estimate technique
4	Sinha (2013)	Time series	Reverse diffusion method	Switzerland	CRT Monitors, CRT TVs, LCD Monitors	n/a	A proposed estimate technique based on Bass diffusion model
5	Kim et al. (2013)	Factor analysis	Survey, population balance model	South Korea	Air conditioners, microwave ovens, mobile phones, TVs, refrigerators, kimchi refrigerators, vacuum cleaners, and washing machines	n/a	Prediction of future WEEE generation from 2000 until 2020 in South Korea
6	Rahmani et al. (2014)	Time series	Time series multiple life span model, simplified logistic function	Iran	Computers, mobile phones	n/a	Estimation of WEEE generation in Iran until the year of 2040 and 2035 for computers and mobile phone subsequently
7	Zeng et al. (2015)	Input-output analysis	Material flow analysis, life span model of Weibull distribution	China	14 categories under Chinese WEEE Regulation	n/a	China will generate 15.5 and 28.4 million tons WEEE by 2020 and 2030
8	Petridis et al. (2015)	Time series and input-output analysis	Distribution fitting procedure for the lifespan, obsolete generation calculation, and waste forecasting	Global Region	PCs	n/a	Weibull distribution fit the situation in all regions, except in Asia/Pacific region which suits with a Normal distribution.
9	Duan et al. (2015)	Time series and input-output analysis	Sales obsolescence model	China	TVs (CRT and flat panel), mobile phones, computers (laptops and desktops), monitors (CRT and flat panel), and LHAs (including refrigerators, air conditioners, and washing machines)	PCBs, CRT glass panel, CRT glass funnel, other glass, Li-Battery (component); Cu, Pb, Ba, Sr, Zn, Sn. Co, Au, Ag, In, Ta, Pd, Bi, Ga (Metal)	Estimation of WEEE generation in the hierarchy of products, components, and metal by 2025
10	Peeters et al. (2015)	Input-output analysis	A distribution delay forecasting method	Belgium	Flat panel display (FPD) TVs, FPD monitors, cathode ray tube (CRT) TVs, & CRT monitor	Plastics	Estimation of the evolution of waste of plastic housings from electronic displays in Belgium by 2025

2.5.2 Literature Review on Approaches to Optimize the Reverse Logistics of WEEE Systems

This section aims to review the previous works dealing with methods to optimize reverse logistics of WEEE recycling systems. The research stream is essential in the design and planning phase of new recycling systems or in assessing the existing ones. In general, the approaches may consist of mathematical programming, heuristic methods, and a stylized economic model.

Initially, Walther and Spengler (2005) conduct a study assessing the impact of EU WEEE Directive 2003 to the practice of reverse logistics in Germany. They propose a linear activity-based model to optimize the allocation of discarded products, disassembly activities, and disassembly fractions to actors of the treatment systems. Their model predicts the impacts of network structure, specialization to certain products, allocation of disassembly contract to network members, utilization of transportation vehicles, selective treatment of waste, and fulfillment of recovery target; to the economics of reverse logistics, e.g. cost structures and annual marginal income.

Multi-objective linear programming method has taken place in the attempt to optimize WEEE reverse logistics. Quariguasi Frota Neto et al. (2009) conduct a study to solve the problems dealing with the balanced solution and the trade-offs between environmental and business concerns in logistics networks. They design an algorithm for the multi-objective linear problem with three objectives: minimizing cost, cumulative energy demand, and landfilled waste. Dealing with the challenge to fulfill WEEE-directive requirements through existing recycling infrastructures, their model provides not one preferred solution, but a spectrum of efficient solutions that can show the trade-off between the goals considered. In a remarkable study which incorporates the informal sector, Li and Tee (2012) employ a multi-objective linear programming model to explore the integration of the sector with its formal counterpart. Using two objective functions – minimizing producers' cost and maximizing informal sector's profit – their work provides certain options to successfully integrate the informal sector into the system.

Subsequently, mixed-integer linear programming (MILP) seems to appeal the most preferred method by the authors dealing with these issues. Grunow and Gobbi (2009) attempt to design a network of reverse logistics in Denmark. They use an approach based on MILP considering the aspects of *efficiency* and *fairness*. Using the actual Danish WEEE-systems as the comparative indicator, their model produces relatively good results in terms of computing time and low deviations from the actual waste volumes. Also using MILP, Achillas et al. (2010) present a decision support tool for policy-makers to optimize the reverse logistics network.

Their model aims to minimize the total cost including transportation costs, fixed costs, variable costs for WEEE management, and fixed costs of using/renting the required containers. By employing a real-world case study for the Region of Central Macedonia (Greece), their model produces robust solutions which minimize total cost and computing time. MILP approach also appears in the works of Gomes et al. (2011) and Kilic et al. (2015). By minimizing the total cost of logistics, both studies are able to determine the optimum locations for recycling infrastructures in their case study from Portugal (the former) and Turkey (the latter), respectively. In another MILP using Turkish study, Aras et al. (2015) formulate a multi-period capacitated facility location-allocation model. It aims at designing the optimal locations and the capacities of recycling facilities which will handle the returned products. Their model produces two notable results: (1) the projection the number of Obsolete IT-based WEEE from 2013 to 2018, and (2) the optimum design of recycling facility locations, i.e. in Ankara, Istanbul_E, and Izmir. Capraz et al. (2015) apply MILP to propose efficient and profit-oriented decision tools, considering best operation planning strategies (i.e., recycling methods and types and quantities of WEEE to be processed) in the perspective of the WEEE recyclers. The proposed model is compared with the current operational approach for a particular WEEE recycling facility. Their work reveals the increase of profitability when a certain combination of disassembly and bulk recycling is considered for certain groups of WEEE.

Previous studies have also utilized Genetic Algorithm (GA) as a means to solve problems in WEEE reverse logistics. For example, Zhi et al. (2010) and Elbadrawy et al. (2015) apply GA to design a reverse logistics network model for WEEE in China and Egypt, respectively. Though limited in the presentation of their specific case study, their works have produced initial promising results. Another example appears in the innovative work from Król et al. (2016). This work combines GA, to optimize the route length and number of vehicles used in the logistics' network, with fuzzy logic to evaluate the residents' satisfaction with the take-back services provided by the collection companies. Using a case study from a city in Poland, their proposed method is able to design a flexible optimized collection schedule within an individual work day and with only minimum required computing time.

Some authors propose an integrated approach to solving the problems. Yao et al. (2013) try to assess the current WEEE problems in China using such approach. Their work includes a quadratic optimizing model solved by an exact algorithm, vehicle routing planning with a modified ant colony algorithm, and determining the minimum trips of the vehicles and proper shipping arrangements. By applying their model to a case study of WEEE collection in Shanghai, their study concludes the best collection network consisted of 191 collection sites from downtown and suburban areas of the city, and 11 intermediate recycling facilities. Gamberini et al. (2010) attempt to generate waste management strategy based on a frequent collection service, considering the technical design and environmental impact analysis. Their methodology consists of data collection techniques, vehicle routing methods and heuristic procedures for creating different system scenarios, simulation modeling for obtaining solutions satisfying technical performance measures, life cycle analysis methodology for assessing the environmental impact of such solutions, and multi-criteria decision methods for selecting the best choices. Considering four parameters (route set, typology of the vehicle, the number of vehicles, and the number of weekly working days), their method reveals the best solutions for each of the proposed scenario. Also, an exceptional work appears in the literature dealing with uncertainty issues in WEEE systems. This work, from Ayvaz et al. (2015), attempts to propose a generic Reverse Logistics Network Design model under the uncertainty of return quantity, sorting ratio (quality), and transportation cost. Particularly, this study proposes a generic multi-echelon, multi-product and capacity constrained two-stage stochastic programming model to consider uncertainties faced by third party WEEE recyclers. Using a real-world case study from a WEEE recycler in Turkey, their model produces the optimal solutions which are in line with the actual required capacity in Turkey.

There also appears a stream of literature dealing with the social welfare issues using stylized economic models. This stream is particularly lead by the works of Atasu et al. (Atasu et al., 2013, 2009; Atasu and Subramanian, 2012). Initially, Atasu et al. (2009) attempt to assess the economic and environmental impact of EU WEEE Directive. These authors develop a model to maximize the total welfare of systems, determined by a sum of maximizing manufacturer profit, maximizing consumer surplus, maximizing environmental benefit and minimizing additional cost and take-back subsidy. Their work produces several important outcomes such as a finding that the weight based legislation may not necessarily be economically and ecologically efficient. In another work, Atasu and Subramanian (2012) investigate the impact of selecting IPR and CPR for the operational implementation on the Design for Recovery (DfR) of the manufacturer and on consumer surplus. Their model figures out four notable results: (1) the producers receive less incentive for DfR under CPR, (2) the selecting CPR may motivate manufacturers to be a free-rider in the systems, (3) the identity of free riders under CPR depends on the mechanism to calculate recovery cost, and (4) consumer surplus may become higher under CPR. Lastly, Atasu et al. (2013) attempt to compare the impact of selecting manufacturer-operated systems and state-operated systems on a different type of stakeholder, i.e. social welfare, manufacturers, consumers, and the environment. Their model includes maximizing manufacturers' profit, maximizing consumer surplus, maximizing landfill aversion, and a specific variable that depends on the policy selection. These authors figure out several important results, e.g. a variety of the stakeholders' preference on the implemented policies and the potential positive correspondence between preference of manufacturers and the environmental goals.

Table 6 summarizes the literature review of quantitative approaches dealing with the optimization methods on WEEE reverse logistics.

2.6 System Dynamics (SD): The Methodology and Previous Studies on WEEE Issues

This section attempts to describe System Dynamics which will be used in the subsequent chapter as the quantitative approach. It comprises the general explanation of SD methodology and the review on SD works in the WEEE-related issues.

2.6.1 Generic SD Methodology

This sub-section provides a critical review of SD analysis for assessing issues in WEEE management systems. It attempts to gather previous works, as many as possible, concerning this issue. It is to be mentioned that part of this section has appeared in Ardi and Leisten (2016).

The SD methodology, initially developed by Jay Forrester (1961), aims to understand the interconnection among elements of the system under consideration to achieve a particular goal/set of goals (Meadows, 2008). SD models consist of stocks and flows, feedback loops, and nonlinearities formed by interactions among physical and information structures and the decision-making process (Sterman, 2000). Altogether, it might reproduce a typical dynamic behavior over a particular period (Vlachos et al., 2007).

In general, SD modeling processes involve model conceptualization, model formulation, model testing, and implementation (Martinez-Moyano and Richardson, 2013). This process incorporates two main tools: causal-loop diagram and stock-flow diagram. Initially, the causal-loop diagram visualizes the relationships among variables and the feedback structure within the system. It contains causal links, shown by the arrows, representing causal influence from one variable to another variable. As explained by Sterman (2000), the positive sign (+) means "if the cause increases (decreases), the effect increases (decreases) above (below) what it would otherwise have been". On the other hand, the negative sign (−) means the opposite direction from the previous definition.

Table 6. List of Reviewed Articles on WEEE Reverse Logistics Optimization Approaches

No.	Authors (Year)	Research Objectives	Country Case	Method	Goal of Methods	Findings
1	Walther et al. (2005)	To predict the effect of WEEE-directive on German reverse logistics	Germany	A linear, activity-based model is presented, optimizing the allocation of discarded products, disassembly activities and disassembly fractions to actors of the treatment system	To maximize annual marginal income of the network as sum of acceptance and sales revenues minus sales, transportation, sorting and disassembly costs	The effects of the WEEE directive to German systems are predicted, e.g. the dominance of disassembly cost; transportation costs are lower in decentralized systems
2	Grunow and Gobbi (2009)	To propose a WEEE network modeling aiming at efficiency and fairness	Denmark	An approach based on mixed-integer linear programming (MILP)	To minimize collection points assigned to the collective schemes	The municipalities have to interact with a significantly lower number of collective schemes
3	Neto et al. (2009)	To explore Pareto-optimal solutions for business and the environment that allows decision makers to assess their preferred solution	Germany	An algorithm for multi-objective linear problem	To maximize marginal revenue of a reverse logistic network and minimize two environmental impacts, i.e.,.. cumulative energy demands and land-filled waste	The results show that there is very little room for trade-off between the two environmental indicators, and the profit of the reverse supply chain
4	Atasu et al. (2009)	To assess the impact of WEEE directive on the efficiency of the systems	n/a	A stylized economic model	To maximize social welfare of the systems	The weight based legislation may not be economically and ecologically efficient for the systems
5	Achillas et al. (2010)	To propose a decision support tool for policy-makers to optimize reverse logistics network	Greece	A Mixed Integer Linear Programming mathematical model considering existing infrastructures	To minimize total cost including transportation costs, fixed costs, variable costs for WEEE management and fixed costs of using/renting the required containers	The case study demonstrates the applicability of the proposed model
6	Gamberini et al. (2010)	To firstly generate and finally compare different feasible WEEE-system configurations to identify the best-performing one	Italy	An integrated method consisting: data collection techniques, vehicle routing methods and heuristic procedures for creating different system scenarios, simulation modeling for obtaining solutions satisfying technical performance measures, LCA methodology for assessing the environmental impact of such solutions, multi-criteria decision methods for selecting the best choice	To maximize vehicle and working-time utilization and to minimize environmental impact	The best solutions for seven scenarios are presented

Table 6. List of Reviewed Articles on WEEE Reverse Logistics Optimization (continued)

No.	Authors (Year)	Research Objectives	Country Case	Method	Goal of Methods	Findings
7	Zhi et al. (2010)	To apply Genetic Algorithm to design WEEE network	China	A genetic algorithm model to get the optimal set of collection centers, disassembly centers, returning centers and the optimal path of shipment.	To minimize the total of costs of reverse logistics, shipping cost and fixed operating expenses of the disassembly centers, and return centers	The best solutions for seven scenarios are presented
8	Gomes et al. (2011)	To design and plan a nationwide recovery network for WEEE	Portugal	A generic mixed-integer linear programming model	To minimize the network cost subject to a set of constraints	The initial experiments show relatively effective results
9	Li and Tee (2012)	To model the integration of formal and informal e-waste systems	n/a	Multi-objective linear programming model	To minimize the producers' cost and maximize the informal sector's profit in WEEE systems	Certain options to integrate informal sector in the system are selected: e.g. higher waste mandate leads to higher requirement of integration process
10	Atasu and Subramanian (2012)	To compare the impact of selecting CPR and IPR on DfR and consumer surplus	n/a	A stylized economic model	To maximize manufacturer profit under selected scheme	CRP scheme may dismotivate the producers to improve DfR and motivate them to be a free-rider
11.	Atasu et al. (2013)	To compare the impact of selecting manufacturer based operation and state-based operation on stakeholders	n/a	A stylized economic model	To maximize the social welfare and to assess the impact of such goal to stakeholders	A variety of stakeholders' preference on the assessed policies
12	Yao et al. (2013)	To design WEEE collection and the transportation network in Shanghai using an integrated solution approach	China	A quadratic optimizing model solved by exact algorithm; vehicle routing planning with a modified ant colony algorithm; and defining of minimum transportation cycles and proper shipping arrangements	To minimize the number of transit sites; to minimize overall costs that consist of fixed cost, operating cost, and transportation cost;	The study reveals the required location of sites and vehicle routes in Shanghai
13	Kilic et al. (2015)	To design a reverse logistic model for WEEE systems	Turkey	A mixed integer linear programming model considering ten scenarios with different collection rates, costs, storage sites, and facilities	To minimize the total cost of reverse logistics	The optimum locations and flows are determined for each of ten scenarios

Table 6. List of Reviewed Articles on WEEE Reverse Logistics Optimization (continued)

No.	Authors (Year)	Research Objectives	Country Case	Method	Goal of Methods	Findings
14	Ayvaz et al. (2015)	To determine optimal locations for collecting, sorting and recycling centers	Turkey	Sample average approximation (SAA), for Stochastic Programming (SP) problems	To maximize profit of third-party recycling companies considering uncertainties in reverse logistics network design	The best solution is in line with the actual requirement of WEEE recycling capacity in Turkey
15	Capraz et al. (2015)	To propose an efficient and profit-oriented decisions tool under the best operation planning strategies (i.e., recycling methods and types and quantities of WEEE to be processed)	a particular WEEE recycling facility (country's name is not mentioned)	A mixed integer linear programming model	To maximize bid price offer during bidding for e-waste recycler	Profitability is increased when a combination of disassembly and bulk recycling is considered for certain types of WEEE
16	Aras et al. (2015)	To determine the locations and capacities of recycling facilities that will handle the returned products	Turkey	A multi-period capacitated facility location-allocation model that is formulated as a mixed-integer linear program	To minimize total cost that includes operating cost, transportation cost, the cost of capacity expansion and reduction in the facilities, the cost of labor, and cost of landfill	The number of Turkish discarded IT-based products for 2013-2018 is estimated and the optimized recycling facility locations are determined, i.e. in Ankara, Istanbul_E and Izmir
17	Elbadrawy et al. (2015)	To propose a reverse logistics network model for e-waste products	Egypt	A genetic algorithm model	To minimize the total cost considering the collection cost, installation cost of sorting, repairing & recycling facilities, processing capacity, and transportation cost	The model is presented
18	Krol et al. (2016)	To propose an innovative program based on a multi-criteria collection model that is able to optimize the number of vehicles, route length, and resident satisfaction	Poland	A genetic algorithm for optimization of the route length and number of vehicles and fuzzy logic for representation of the household residents' satisfaction on the take-back service provided	To reduce collection cost by minimizing route length, the number of vehicles and the number of collection staff	The presented method can design an agile optimized collection scheduling in an individual work day with only minimum required computing time

Furthermore, the stock-flow diagram depicts the mathematical formulation of the model. Figure 8 depicts the incorporated notations in SD modeling with its functions and figure 9, redrawn from Sterman (2000), represents the basic stock and flow diagram.

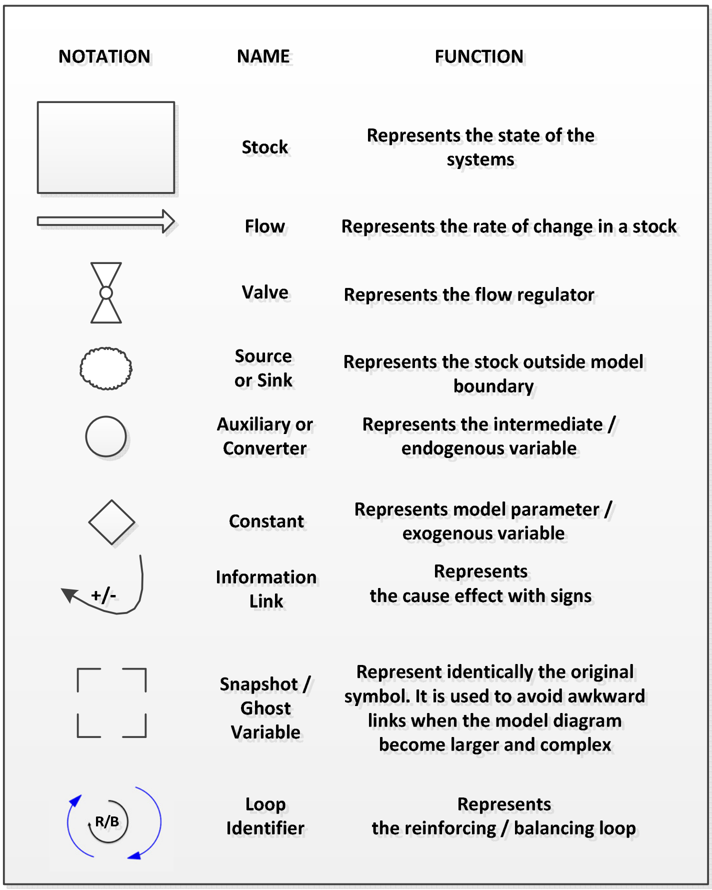

Figure 8. Notations in the System Dynamics Modeling

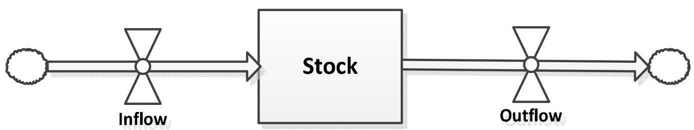

Figure 9. Basic Stock and Flow Diagram

The following equations refer to the stock-flow in fig. 8. First, the integral equation of the accumulated stock is:

$$Stock(t) = \int_{t_0}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t_0) \quad (3)$$

Second, the differential equation of net change in stock is:

$$\frac{d(Stock)}{dt} = Inflow(t) - Outflow(t) \quad (4)$$

SD is suitable to model real-world problems, identified by uncertainty, dynamics, time delays, and conflicting goals of multiple stakeholders (Besiou and Van Wassenhove, 2015b; Van Wassenhove and Besiou, 2013). These authors study the preceding characteristics in several real-world problems, including also WEEE reverse logistics, and conclude that it would not be adequate to solve the real-world problems with the mentioned characteristics, by relying only on optimization methods.

2.6.2 Literature Review on SD Approaches in WEEE Issues

The increasing attention to utilizing SD models in WEEE-related issues perhaps may be attributed to the works of Georgiadis and Besiou (Georgiadis and Besiou, 2009a, 2009b, 2008a, 2008b). These authors set the foundation in assessing the impact of selected important parameters, especially the legislative factors, on the sustainability of WEEE closed-loop supply chain (CLSC). Initially, these authors employ SD to assess the impact of environmental regulation on the environmental indicator of sustainability (Georgiadis and Besiou, 2008b). Using the natural resources and landfill conservation as the main indicators, they apply the proposed model into a real-world WEEE CLSC in Greece. They explain the apparent influences of the collection percentage, recycling percentage, and recyclability on the sustainability of the WEEE systems.

In the same year, Georgiadis and Besiou (2008a) utilize SD methodology to examine the effect of legislation and green image factor to the preservation of natural resources and landfill availability. They enhance their SD model with three sensitivity analyses, using Analysis of Variance (ANOVA) as the measure. ANOVA of their study reveals the impact of selected factors, e.g. legislation, market behavior, and technological innovation, on environmental sustainability. Extending their previous work, Georgiadis and Besiou (2009a) measure the effect of nine types of parameters, coming not only from the environmental aspect but also from the economic pillar of the sustainability. These parameters include legislative measures, quality, firm-related operations, costumers' willingness issues, environmental threats, and financial parameters. Using exhaustive experiments and ANOVA, their model specifies the magnitude of the selected factors, influencing the sustainability of WEEE CLSC. Similarly, Geogiadis and Besiou (2009b) analyze the effect of ten parameters derived from legislative measures, CLSC operations, and green design, on the sustainability. Their work suggests that the combination of certain influential factors might increase the total of supply chain profit while still be able to preserve the availability of natural resources and landfill.

Four subsequent works appear in the literature, attempting to conceptualize the reverse systems of WEEE. Xu (2010) constructs an SD model to assess the feasibility of a third party take-back systems for waste mobile phone. Her model incorporates several stakeholders, including take-back systems providers, OEMs, collection centers, and recyclers. Considering the stakeholders' revenue and hazardous contents in EEE as the main indicators, this work figures out the feasibility of third-party take-back systems in dealing with the future trend of waste. Gnoni and Lanzilotto (2012) attempt to examine the sustainability performance of mobile phone's reverse logistics. Using several indicators from three sustainability pillars, this work reveals that the collection level of obsolete mobile phones might affect the environmental, economic, and social sustainability of the systems. Rasjidin (2013) provide an effort to model WEEE reverse logistics in the computer industry with financial and environmental criteria as the performance index. Using total profit and environmental performance index, his model produces twofold results: (1) the significant impact of six influential factors namely part type, return quality, market attractiveness, custom duty percentage, shipping cost, and re-processor location attractiveness; on the economic sustainability of the recovery systems, and (2) the effect of five significant factors, i.e. part type, return quality, re-processor location, collection percentage, and recycling percentage; on the environmental sustainability of the CLSC. Lastly, Rutebuka et al. (2015) propose a conceptualized System Dynamics framework to estimate the generation of waste mobile phone, using Rwanda as the case study.

Only a few works attempt to integrate the existence of the informal sector to the analysis. Besiou et al. (2012) aim to assess the impact of the integration of scavenging on the sustainability of WEEE CLSC. Particularly, their work attempt to conceptualize such integration under three scenarios: (1) informal scavenging exists, but it is ignored by the regulation, (b) informal scavenging ceases to exist, and (c) informal scavenging is integrated by the regulation with the official collection. This SD work reveals the benefits of the incorporation of the informal sector into the overall WEEE management systems, considering sustainability aspects. In an excerpt of this thesis, Ardi and Leisten (2016) attempt to evaluate the roles of the informal sector in the WEEE systems using SD model. This work incorporates the interaction between formal and informal collections and considers more recovery channels of the informal sector, including scavenging, refurbishment, recycling, and secondary market. Using collection rate, cash availability, and the number of informal workers; this SD model reveals the dominance of the informal sector in the WEEE recycling systems, influencing the potential failure of its formal counterpart. Also, further sensitivity analysis in this work confirms the importance of the second-hand market for the informal activities.

Table 7 summarizes the literature review on the previous works using SD approach in WEEE issues. It appears that the utilization of SD model remains limited in assessing the WEEE management systems. Also, one should note the limitation to incorporate more stakeholders in the model boundaries. The limited inclusion of the informal sector provides a clear example for this drawback, despite the fact this particular sector dominates the recycling systems in many developing countries. Lastly, the following categories of WEEE are presented mostly for the case studies in this research stream: PC, refrigerator, and mobile phone.

Table 7. List of Reviewed Articles on SD-based Analysis in Assessing WEEE Management Systems

No	Authors (Year)	Research Objective	Applied Country Case	Type of WEEE	Key Performance Indicators	Stakeholders and Recovery Networks	Findings
1	Georgiadis and Besiou (2008b)	To assess the impact of environmental regulation on environmental sustainability	Greece	Refrigerators	Availability of natural resources, landfill availability	WEEE closed-loop supply chain: collection, recycling, disposal	The impact of the collection percentage, recycling percentage, and recyclability on sustainability are revealed
2	Georgiadis and Besiou (2008a)	To assess the impact of imposed collection & recycling percentages and technological innovations on sustainability	Greece	Refrigerators	Availability of natural resources landfills availability	WEEE closed-loop supply chain: collection, recycling, disposal	The effect of redesign time, market behavior, and legislation to the indicators are revealed
3	Georgiadis and Besiou (2009a)	To develop a holistic approach to understanding the WEEE CLSCs interactions with the environment	Greece	Refrigerators	Availability of natural resources, landfill availability, and the profitability of CLSC	WEEE closed-loop supply chain: collection, recycling, disposal	The impacts of 9 types of parameter to the indicators are revealed
4	Georgiadis and Besiou (2009b)	To assess the impact of different legislative measures, CLSC activities and DfE practices on the environmental and economic sustainability	Greece	Refrigerators	Availability of natural resources, landfill availability, and the profitability of CLSC	WEEE closed-loop supply chain: collection, recycling, disposal	The impacts of legislative measures, CLSC activities and DfE practices to the sustainability are revealed
5	Xu et al. (2010)	To present an SD model of the third party take-back systems	China	Mobile Phones	Revenue of stakeholders, hazardous contents in EEE	Take-back providers, OEMs, collection centers, recyclers	Prediction that market-oriented third party take-back system will be feasible in the future
6	Gnoni and Lanzilotto (2012)	To develop an SD model for evaluating sustainability performance of mobile phone reverse logistics	n/a	Mobile Phones	Use of natural resources, waste quantity disposed of, saved CO2 emission, profit, accessibility of new users from secondary markets	Collection, refurbishing, recycling, secondary market	The fraction of collected mobile phones is correlated with the achievement of sustainability indicators

Table 7. List of Reviewed Articles on SD-based Analysis in Assessing WEEE Management Systems (continued)

No	Authors (Year)	Research Objective	Applied Country Case	Type of WEEE	Key Performance Indicators	Stakeholders and Recovery Networks	Findings
7	Besiou et al. (2012)	To assess the impact of scavenging on the operations of the formal recovery system, under three regulatory measures	Greece	Refrigerators	Availability of natural resources, sum of disposal & pollution, total supply chain profit, unemployed scavenger	Formal: collection, recycling, disposal; informal: collection, disposal	The integration of the informal sector to the WEEE systems is fruitful for the sustainability
8	Rasjidin (2013)	To model WEEE reverse logistics in computer industry	Not specifically mentioned	PCs	Total profit, environmental sustainability index	Reusable returns, repairable returns, recyclable returns, supplier's exchangeable returns	The proposed SD model is suitable for managing reverse logistics system considering economics and environmental sector
9	Ardi and Leisten (2016)	To assess the role informal sector in WEEE management systems	India	PCs	Annual collection rate, availability of cash, the number of informal workers	Formal: collection, refurbishing, recycling, disposal; informal: collection, refurbishing, recycling, disposal, secondary market	The informal sector dominates the systems; the secondary market influences the rise and fall of the informal sector
10.	Rutebuka et al. (2015)	To develop a comprehensive dynamics logistic model for waste mobile phone	Rwanda	Mobile Phones	Generated waste	n/a	The study presents the future waste in Rwanda and its impacts

Chapter 3 Comparative Analysis of WEEE Management Systems in the Developed and the Developing Countries: A Qualitative Approach

This chapter provides an approach to analyze the existing differences of the endogenous and the exogenous factors within the developed and the developing countries, influencing the behavior of the systems. Particularly, it has fourfold objectives:

- To examine the problems and challenges of the WEEE management systems in the developing countries.
- To extract the characteristics of WEEE management systems in the developing countries from the scientific literature.
- To assess the landscapes in which a typical behavior of the systems within a specific country appears.
- To compare, distinguish, and contrast between the emerged characteristics and the landscapes in the developed and developing countries.

To accomplish the preceding objectives, this study proceeds with a sequence of steps. The procedure consists of several major steps, consisting of:

1. Assessing the problems in the selected developing countries,
2. Examining the similarity of the problems within the developing region,
3. Analyzing the causal relationship existing within the developing region, and determining the most important defining factors within the systems
4. Comparing the systems in developing countries with the generic condition of the developed countries.

Notice here that this study prioritizes the assessment of the developing countries as compared to the developed ones. As a further note, this comparative effort by no means tries to state that the appeared differences in the variables within the two systems are completely isolated from each other as if such differences are black-and-white matters. One the other hand, this study certainly does not attempt to imply that the conditions of the countries within a similar region, e.g. between China and India, are completely the same (Marshall and Farahbakhsh, 2013).

3.1 Framework to Compare WEEE Management Systems

First, this study chooses three developing countries to be assessed. After the selection took place, this study assesses the issues and problems within each country, including the trend of WEEE generation from the domestic users, the illegal import rate entering the country, the rise of the informal sector and its crude situations, the status of WEEE-related regulation, the consumers' awareness and support to the formal systems, and take-back initiatives / pilot projects.

The second step attempts to highlight the appeared situations from the comparison among the developing countries, then, to compare such situations to extract the similarities among them. These similarities will be further discussed in a more generic manner by categorizing the problems into several classes and assessing the stakeholders involved with a specific problem. Subsequently, the third step tries to determine several plausible causes, influencing the emergence of the discussed problems. These causes will be considered as the determinants of WEEE management systems in the developing countries. To complete the presence of the previous determinants, this step also incorporates several important factors in the systems that have not been discussed before. Then, the relationships among the determinants will be conceptualized using a causal map.

Finally, the generic condition of the developed countries will be presented and then compared to the emerged characteristics from the developing ones. Through this comparative perspective, the fourth step may reveal the differences and similarities between these two types of regions.

3.2 Assessing Issues, Challenges, and Problems of WEEE Management Systems in the Selected Developing Countries

This study selects China, India, and Nigeria as the base to extract the characteristics of the developing systems. These particular countries are selected because of the magnitude of their population and the level of generated WEEE. According to the CIA World Factbook in 2015; China, India, and Nigeria are the first, the second, and the seventh most populated country in the world, respectively. Subsequently, these countries are among the top countries with the highest WEEE generation in absolute quantities within their respective continents in 2014: China with 6 million tons of generated WEEE, India with 1.7 million tons, and Nigeria with 220,000 tons (Baldé et al., 2014).

3.2.1 Assessing Issues, Challenges, and Problems of WEEE Management Systems in China

It is imperative to discuss the challenges and problems in Chinese WEEE systems by starting with the causes of informal sector's domination. Historically, it was triggered by the increasing flow of illegal trans-boundary movements to China, evading the early development of WEEE-specific regulation management in the developed regions and benefitting from the absence of Chinese regulation and weak law enforcement in customs (Chi et al., 2011; Zeng et al., 2013). This flux appeared steadily since the early 1990s, despite the enactment of Basel Convention in 1992. The entrance gates for the imported waste include Guiyu, Longtang, Dali on the Pearl River Delta (Guangdong Province), Taizhou on the Yangtze River Delta, Hebei Province, Hunan Province, and Jiangxi Province (EFFACE, 2015). Though its significance is rampant, it is still difficult to measure the size of the import rate to China because of the data scarcity (Wang et al., 2013b). However, previous studies have provided rough estimates. Puckett et al. (2002) record sources that in the early 2000s, 50 – 80% of generated WEEE in the US was exported abroad to countries like China. Yu et al. (2010a) mention the Basel Action Network claim that around 14 – 35 million tons of WEEE are dumped in China. Zhou and Xu (2012) also place a relatively similar number of approx. 28 million tons coming to China in 2010. Interestingly, Cao et al. (2016) disagree with this higher number – claiming it was untrue and exaggerated – and follow the moderate estimate of at least two million tons of WEEE entered China in 2010.

The initial flux of WEEE had enough amount to trigger the emergence of small-scale informal recyclers, especially in the coastal regions. The informal sector started to take benefit by extracting valuable elements from the waste and producing second-hand components and refurbished products (Wang et al., 2013b). These early existences were then scaled up by increasing domestic consumption of electronic products, further increasing the demand for second-hand components / products (Chi et al., 2011). Soon, another factor complicates the situation: the increasing state of WEEE domestic generation. Wen et al. (2006) mentioned that since 2003 (until their paper has been published) China has generated over 29 million units of WEEE annually, including discarded TVs, refrigerators, washing machines, computers, and mobile phones. The recent UNU Global E-Waste Monitor records that China generates ca. 6 million tons of WEEE in 2014, the highest absolute quantity among Asians countries (Baldé et al., 2014). It is also estimated the total quantity of generated WEEE in China will reach 11,7 million tons in 2020 and 20 million tons in 2040 (Li et al., 2015).

The increasing amount of WEEE, coming both from overseas and domestic generation, influences the rise of the informal sector in China (Chi et al., 2011). As recorded by Duan and

Eugster (2007), informal WEEE sector employs around 790,000 Chinese workers. This huge number represents the ways of migrant workers and urban poor seeking a living opportunity; though the wage level remains low (Manhart, 2007; Orlins and Guan, 2015). Unfortunately, these social groups are marginalized in the society with limited education, skills, and formal job access. These conditions, more broadly, capture the socioeconomic gap between the urban and the rural areas in China (Orlins and Guan, 2015).

Even worse is how the informal workers operate their recycling activities. They handle, dismantle, burn, and extract the valuable material from WEEE without any proper protection (Orlins and Guan, 2015). Previous works have provided a significant number of assessments to reveal the harmful nature of informal operations in China: (1) their manual dismantling and crude recycling methods of the waste (Chi et al., 2011; C. Lu et al., 2015; Yang et al., 2008), (2) the impact on humans' health (Chan et al., 2007; Song and Li, 2015; Xu et al., 2014), and (3) the pollution released to the environment (Leung et al., 2007; Shen et al., 2009; Wu et al., 2008).

To deal with these issues, the Chinese government have enacted 24 WEEE-related rules, regulations, policies and guidance (Step-Initiative, 2016a). This study refers to Zeng et al. (2013) for the further explanation of the evolution of WEEE-specific legislations in the last decade. Despite their significant progress, Chinese regulations still face critics from some authors. Zhang et al. (2015) note five issues concerning the current Chinese approaches, i.e. (1) no significant recognition of the existence of the informal sector, (2) no single regulatory body that is responsible to execute and evaluate the program, (3) no recycling target, (4) no specific legislation that clearly describes the responsibility of different stakeholders, and (5) too many laws came into force in the last decade. Zhou and Xu (2012) express similar views with the fourth and the fifth of the aforementioned issues; adding also the absence of national specific guidelines to implement the regulation as their main concerns. Salhofer et al. (2015) address the absence of the mandated roles for the municipalities and the retailers in the systems and the presence of overlapping tasks between the six regulatory bodies.

The rise of the informal sector and the incompleteness of the regulation affect the shortcomings of the initial projects. Kojima et al. (2009) provide two cases of the formal initiatives, i.e. a cell phone collection program from Nanjing Jinze Metallic Material Co. Ltd. and a dismantling company Hangzhou Dadi, which are forced to cease because of input shortage. Another case appeared in the effort of UNEP to establish several WEEE recycling companies with an advanced technology in Suzhou, Jiangsu Province, in 2006 (Yu et al., 2010a). This project also faced a lack of adequate resources to operate as intended after six months. The critically acclaimed “Old-for-New Rebate Program” still also faced some problems. This program relied heavily on government subsidies and when the program ceased to exist, there were signs of decline in the collection rate at the authorized recyclers (Wang et al., 2013b). Some others problems with respect to the formal actors also have been discussed by authors, including the absence of pre-infrastructures for waste management (Chi et al., 2011), high-cost technology with low utilization rate (Zhou and Xu, 2012), lack of recycling facilities in rural areas (Cao et al., 2016), and reliance of government subsidy (Chi et al., 2014; Wang et al., 2013b).

Lack of support from the consumers also increases the complexity of the issues. For instance, one study records that only 8.8% of customers decided to dispose of the waste mobile phones via the formal channels, while 12.8% via the informal sector and 47.1% decide to store them at home (Yin et al. 2014). Likewise, another study in Beijing figures out that only 12.6% of the respondents were willing to dispose at the recovery spots, whereas 58.59% and 11.36% of them would like to sell the obsolete products to the secondary market and the peddlers, respectively (Wang et al., 2011). Consumers prefer to dispose their WEEE to the informal collectors for taking a small but sufficient amount of money (Orlins and Guan, 2015). They are also convenient with the offer of the door-to-door collection; something that has not been yet fully offered by the formal ones. Only when this incentive is present, the collection rate might raise up significantly. This notion is evident when one compares the achievement of collection rate between pre, during, and post implementation of The “Old for New Program” (Wang et al., 2013b).

3.2.2 Assessing Issues, Challenges, and Problems of WEEE Management Systems in India

India started to face the WEEE problems in the early 1990s after the first period of its market liberation (Wath et al., 2010). This market condition affected the growth of the EEE industry, escalated further by the presence of IT revolution (Wath et al., 2011). Figure 10 provides an instance of such development, represented by the sales rate of PC (desktop only) in the last two decades (MAIT, 2013).

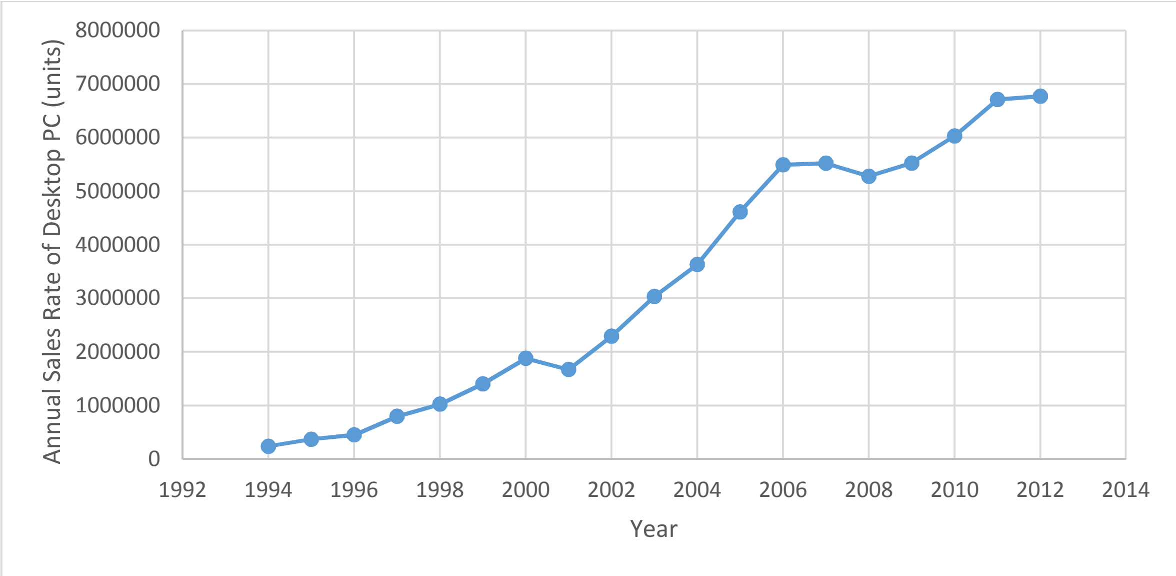

Figure 10. Annual Sales of Desktop PC in India between 1994 – 2012

This phenomenon inevitably triggered the emerging problems of WEEE generation. As has been mentioned in chapter 2, the total generation of WEEE in India have achieved 1.7 million tons of waste in absolute terms in 2014 only. However, if the number is presented at the relative quantity term, it reveals that the domestic generation rate is still limited; only yet to exceed 2 kg generated waste per capita. Hence, one could imagine the magnitude of the future waste generation in India, considering also of the presence of following characteristics (The Guardian, 2016; Premalatha et al., 2014):

- The second most populous country in the world,
- The highest economic growth in the world in 2015 at the level of 7.5%,
- a stable growth of IT-industry since the early 1990s, and
- yet a limited penetration level per capita of durable consumer goods

This notion is supported by two studies projecting the future trend of WEEE in India. Dwivedy and Mittal (2010) estimate that the level of WEEE in India is growing at 7% every year. Another study from the same authors, focusing on waste computer, shows that around 41–152 million units of computers will be obsolete by 2020 (Dwivedy and Mittal, 2010b).

There appear other factors escalating the WEEE problems in India. The first factor is the high level of illegal import of WEEE coming from the developed regions such as Germany (Li et al., 2013). This influx reached India through Mumbai and Chennai and then entered Delhi for further treatments (Pandey and Govind, 2014). Manomaivibool (2009) mentions a previous estimate that 50,000 tons of WEEE entered India's reverse stream annually. Most of the WEEE, almost 95%, were handled by the informal sector. His study also provides a roughly quantified number of imported used PCs becoming WEEE in the level of 1.65 million units. Another factor, as pointed out also by Manomaivibool (2009), is the existence of the huge grey market and assembling sector in India, producing "born-to-be-orphan" EEEs. These EEEs are associated with none of the identifiable producers and hence, would burden the systems once they become waste.

The complex interconnection among the aforementioned problems provides a landscape for the rise and – then – the domination of the informal recycling sector in India. Breivik et al. (2014) cite two different sources regarding the size of Indian informal workers: 25,000 and 1,000,000 people. They come from poor and marginalized social groups, migrating from their rural hometowns to seek alternative jobs (Pandey and Govind, 2014; Raghupathy and Chaturvedi, 2013). There are also cases when child labors were exploited in WEEE-related jobs (Pandey and Govind, 2014).

From the recovery process point of view, this sector is characterized by (1) the rapidness and efficiency in processing speed, (2) inefficiency in recovering the proportion of the precious metals from the waste, (3) loss of rare material, and (4) the unsafe procedures conducted by the workers. Though it remains insufficient if one compares with the presence of Chinese studies, it is still important to address the previous works dealing with the crude recycling in India. These studies discuss the poor situations when the presence of informal recycling is widespread, such as high contamination at WEEE recycling sites in Bangalore; high level of polychlorinated biphenyls (PCBs) in the soil of several cities; hydroxylated PCB congeners (OH-PCBs), polybrominated diphenyl ethers (PBDEs), hydroxylated PBDEs (OH-PBDEs), methoxylated PBDEs (MeO-PBDEs), and bromophenols (BPhs) in the body of recycling workers (Chakraborty et al., 2016; Eguchi et al., 2012; Ha et al., 2009). This recent study refers to Awasthi et al. (2016a, 2016b) for the detailed critical review on the human health risk and environmental pollution caused by the Indian informal recycling.

In the light of the aforementioned problems, it is imperative to address the situation of WEEE regulation in India. India has enacted three WEEE-related rules, regulations, policies and guidance (Step-Initiative, 2016b). However, the 2011 e-waste regulations are criticized for its limitations and the new 2016 rule is yet to have impacts. Shankar and Yadav (2015) identify several loopholes in the former legislation, including the absence of RoHS compliance for any stakeholders, provision for the bulk customer, and the penalty for non-compliance. Likewise, Pandey and Govind (2014) point out the inability of the government to enforce the law in the fields, especially for preventing the exploitation of child labors, limiting illegal import, and closing down the unauthorized recyclers. Dwivedy and Mittal (2012) raise concerns about the neglect of collection, recycling and reuse targets and the role of the secondary market in the regulation.

Lastly, the challenges to involve the producers and the consumers in the collection efforts in India also should be addressed. For the former, a report from Greenpeace (2008) finds that nine major brands of the electronic and electric equipment (EEE) provided no take-back services in India while the rest faced some drawbacks with the services. At that time, only three companies provided properly working take-back service. Also, the huge presence of grey market might discourage the producers to join the future EPR-based compliance scheme, avoiding themselves to waste their money for the free rider (Manomaivibool, 2009). For the latter, a study in the city of Pune shows that only 17% of the respondents were aware of the presence of WEEE policy in India and 57% of them mixed the WEEE discard together with general solid waste (Bhat and Patil, 2014). Similar to China, Indian consumers also expect an exchange money for their disposal of EEE (Dwivedy et al., 2015). Dwivedy and Mittal (2013) interestingly figures out that 59% of the respondents in their study were eager to participate in a mobile phone recycling scheme if the recycling fee takes place at a moderate level. This number is promising but one should be wary to over-generalize it.

3.2.3 Assessing Issues, Challenges, and Problems of WEEE Management Systems in Nigeria

It is important to start the discussion from the fact that Nigeria is often used as the destination to dump the waste coming from the developed countries. This illegal flows are generally caused by the existing huge gap between the Nigerian and developed WEEE management systems. Initially, Nigeria had already faced a major case of illegal dumping in 1988, when nearly 4,000 tons of waste –containing also polychlorinated biphenyl (PCB) – were dumped in the town of Koko (Terada, 2011). Later on, Nnorom and Osibanjo (2008) discuss a specific report from Basel Action Network which revealed an estimation of illegal import into Nigeria. This report figured out that, on average, 500 containers of used EEE arrive in Lagos port per month (with 800 second-hand or scrap monitors or PCs for each container). When the values are converted to the annual level, it is estimated that five million used PCs / monitors were imported to Nigeria via Lagos port only. Another study figures out that 600,000 tons of used EEE entered Nigeria by 2010 only; 30% of them were non-functioning products. Accordingly, this report roughly estimates that 100,000 tons of the used EEE could effectively be categorized as WEEE (Ogungbuyi et al., 2012). Ejiougu (2013) note several investigations from UK agency whereby a case of WEEE dumping from the UK to Ghana and Nigeria were revealed. To be fair, Nigerian government have shown a strong will to tighten the borders through several attempts such as the detainment of two containers containing used EEE from France without test certification and MV Marivia ship for importing two containers of WEEE from the UK (McCann and Wittmann, 2015; Obaje, 2013).

The large amount of WEEE helps the repair - refurbishment sector and the informal recycling sector in Nigeria to flourish. The former and the latter sector handled about 200,000 tons of used EEE and 360,000 tons of WEEE in 2010 only, respectively (Ogungbuyi et al., 2012). The former sector is a well-established business in Nigeria, generating income for more than 30,000 people in Lagos only with a wage between US$ 2.20 and US$ 22 per day (Basel Convention, 2011). The latter sector, however, is associated with the harsh situations. For instance, one study figures out that informal recycling in Lagos involves a list of high-risk and non-environmentally friendly activities such as breaking the tubes of waste CRTs, the open incineration of cables to recover copper, the burning of plastic parts to reduce waste volumes, and open-dumping around the recycling sites (Manhart et al., 2011). Also, two recent studies reveal the significant presence of heavy metals and pollutants in the waste storage sites, electronic workshops, road-sides, dumpsites, and dismantling sites; the places where a large proportion of WEEE are stored in Nigeria (Sindiku et al., 2015, 2014). Though it provides huge alternative jobs for 72,000 – 100,800 people, the daily income for the Nigerian informal WEEE workers remains on a limited level (Ogungbuyi et al., 2012). A study from Manhart et al. (2011) finds that the average daily income of a door-to-door collector and a collector collecting freely available wastes lie in the limited level of USD 1.68 – 3.36 and USD 0.22–0.45, respectively.

Besides those from the imports, the WEEE generated from the domestic users has just started to elevate the complexity of problems. Nigeria generates 220,000 tons of WEEE in 2014 only (Baldé et al., 2014). Unfortunately, this study finds no previous works comprehensively estimating the long-term trend of WEEE generation in Nigeria. Nevertheless, three following reasons seem to support the notion that Nigeria might generate an elevating level of WEEE:

- Nigeria is the most populous country in Africa.
- Nigeria is the largest economy in Africa and has enjoyed a steady economic growth around 7% annually for the last decade (African Development Bank, 2016).
- Nigeria has yet only limited level of EEE in society.

With the aforementioned complexity, Nigeria is yet to implement effective regulatory instruments. Nigeria enacted its WEEE specific regulation in 2011 and it covers a full scope of WEEE types. This regulation, National Environmental (Electrical and Electronic Sector) Regulations 2011, aims to "to prevent and minimize pollution from all operations and ancillary activities of the Electrical/Electronic Sector to the Nigerian environment. These Regulations shall cover both new and used Electrical/Electronic Equipment (EEE/UEEE)" (Step-Initiative, 2016c). However, there is a scarcity of data to evaluate the effectiveness of this instrument (McCann and Wittmann, 2015). It is also difficult to find any Nigerian author discussing in detail the current state of the implementation or the success / failure of take-back programs / initiatives. Other problems complicating the situation are also stated by several authors: lack of infrastructure, no proper data of EEE stock in society, significant role of property and corruption in Nigeria, inadequate funding, and lack of law enforcement (Babayemi et al., 2016; Ejiogu, 2013; Omole et al., 2015).

Lastly, it is essential to address the presence of previous studies, albeit limited, addressing the willingness of Nigerian consumers to dispose of WEEE. Nnorom et al. (2009) attempt to examine the behavior of Nigerian consumers to participate in waste mobile phone recycling. Interestingly, the study finds out that around 65% of respondents were eager to participate in such program – if available – and about 51% were ready to pay more than 20% premium price for getting "green" mobile phone. Quite contrary, a limited study from Okoye and Odoh (2014) figures out 55%, 41%, and 4% of their respondents preferred to store at home, dump in their surroundings, and dispose to the scavengers of their obsolete EEEs, respectively. This study also reveals that the majority of the respondents were not aware of the presence of Nigerian WEEE-specific regulation. Altogether; because of the limited presence of the previous studies, it is still difficult to generalize the findings from the consumers' attitude and awareness on WEEE in Nigeria. Still, it is not too stretched to assume that the present of such awareness is still limited in the Nigerian society.

3.3 Comparing and Examining the Presence of Issues, Challenges, and Problems within the Selected Developing Countries

This section tries to gather all the discussed issues, challenges, and problems from the previous sections and compares them accordingly. Afterwards, these issues will be examined in a more generic manner by assessing the drivers behind them. Table 8 illustrates this comparative effort.

Table 8. A Comparison of the Main Issues among China, India, and Nigeria

Main Issue	China	India	Nigeria
WEEE Generation from Domestic Users	6 million tons (2014) / 4.4 kg per inh. and increasing	1.7 million tons (2014) / 1.3 kg per inh. and increasing	220,000 tons (2014) / 1.3 kg per inh. and increasing
Transboundary movement of WEEE	2 million tons of illegal import (2010)	50,000 tons annually of illegal import	100,000 tons of illegal import (2010)
Status of the Informal Sector in WEEE Collection and Recycling	790,000 workers, dominating the sector, harmful recovery operations	25,000 -> 1,000,000 workers, dominating the sector, harmful recovery operations	72,000 - 100,800, dominating the sector, crude and unsafe operations, harmful recovery operations
Status of WEEE Specific Legislation	• long absence, • then, enacted 24 regulatory instruments, • the efficiency is questioned	• long absence, • then, enacted 3 regulatory instruments, • the effectiveness is questioned	• long absence, • then, enacted 1 regulatory instrument • the effectiveness is unknown
Consumer Behaviors	Seeking incentive for disposing of WEEE, lack of awareness	Seeking incentive for disposing of WEEE, lack of awareness	Seeking incentive for disposing of WEEE, lack of awareness
Take-Back Initiatives / Projects / Programs	Several Failures, Notable Success of the "Old-for-New" Program	Limited Information	Unknown

Firstly; China, India, and Nigeria currently face a similar nature of the increasing WEEE generation from the domestic users. Two characteristics appear here: a limited level of generation per inhabitant but with already a high number in the term of absolute quantity. These conditions hint to the future trend when an even higher magnitude of WEEE generation will be present in these three developing countries. This notion has been supported by the previous studies in China and India, estimating the outflow of WEEE from the society. It seems that Nigerian would face a similar situation. In a generic sense, the growing number of WEEE generation are influenced by several interrelated factors, i.e. (1) the growth of EEE consumption, (2) the declining lifespans of EEE, (3) the shift of customers' behavior, (4) the condition of the market that is far from being saturated, and (5) the consistency of technology innovations during the last decades (Dwivedy and Mittal, 2010b; Jiménez-Parra et al., 2014; Wang et al., 2013a). Accordingly, the presence of high economic growth and population in China, India, and Nigeria, will maintain such influences for a long period.

Second, the long and significant role of illegal WEEE import is undeniable in creating the initial landscape of the WEEE recycling sector in China, India, and Nigeria. Quite similarly and historically speaking, the dumping phenomenon of WEEE originally appeared in the late 1980s and the beginning of the 1990s because of the gap between waste legislation in the developed and developing countries; creating an economic incentive to avoid the waste responsibility (Ogungbuyi et al., 2012; Schmidt, 2006). As China, India, and Nigeria became Basel Convention signatories, the custom tightened the influx of waste via major ports. However, the significant illegal movement of WEEE still appears. Breivik et al. (2014) estimate, in average, five million tons (3.6 – 7.3 million tons) of WEEE were transported from Organisation for Economic Co-operation and Development (OECD) countries to China, India, Nigerian and four other West African countries. A recent report from "European Union Action to Fight Environmental Crime" (EFFACE) gathers the main drivers for the illegal shipment from EU to China as follow (Geeraerts et al., 2015):

- Demand-side factors: the lucrativeness of reuse-refurbishment business, the dominance of the informal recycling sector, high unemployment rate, the growing manufacturing industry; thus requiring a high level of materials and components, and
- Facilitating factors: low transportation cost in the destination countries, the nature of WEEE that can be easily mixed with reusable products, etc.

Though the report deals only with the illegal import into China, it is safe to assume that the majority of the aforementioned drivers also play important roles in India and Nigeria. Also, there is an additional factor complicating the effort to prohibit the transboundary movement of WEEE: the present difficulties and ambiguities to distinguish between Used Electrical and Electronic Equipment (UEEE) and WEEE (Khan, 2014).

Third, the informal sector plays a similar dominant role in WEEE management systems in China, India, and Nigeria. The presence of this sector is problematic for the decision makers. On the on hand, the crude informal operations – such as open air burning, chemical stripping, breaking and removal copper yoke, disordering and removing computer chips - possess potential occupational and environmental hazards (Sinha et al., 2009). Furthermore, the informal workers lack awareness concerning the risks of their works and prefer to be independent without any interference of the regulation (Orlins and Guan, 2015). On the other hand, this sector provides a high level of alternative job for a poor, marginalized, and less educated society group.

It seems that these conditions will be more complicated in the near future because of the steady growth of the informal sector (Pandey and Govind, 2014). This trend emerges in China, India, Nigeria, and possibly in more countries with a similar situation (Chi et al., 2011;

Wang et al., 2013b). The informal growth, exogenously, is affected by the unique trajectories of general solid waste management in the developing countries which are characterized by rapid urbanization, social inequalities, economic disparities, and lack of priority regarding the waste issues (Marshall and Farahbakhsh, 2013; Wilson, 2007). Furthermore, this growth could be observed from the increasing quantity of collected products, the vitality of reuse market, and the relatively huge number of informal workers. Some factors endogenously influence this phenomenon, i.e. (1) adequate input of WEEE from illegal imports and households, (2) low level of treatments and recovery cost; (3) stable growing demand for recovered products, components, and materials; (4) absence of WEEE-specific regulations and law enforcement for a long period, and (5) limited capacity of initial formal systems (Chi et al., 2011; Manomaivibool, 2009; Wang et al., 2013b; Widmer et al., 2005).

Fourth, in developing the WEEE-specific legislation, initially, all of these three countries faced an absent of WEEE-specific regulation for a relatively long time. If the foundation of Swiss SENS in 1990 and the enactment of German Packaging Ordinance in 1991 are set as the benchmarks of the initial WEEE management systems and the EPR-based legislation, subsequently; then, the beginning of the 1990s might become the baseline to measure how long the absence of WEEE-specific regulation. Since China, India, and Nigeria legislated their comprehensive WEEE-specific legislation in 2011, hence the length of absence period might be put on the 20 years of gap. Or if the enactment of Swiss Ordinance on the Return, Taking-back and Disposal of Electrical and Electronic Equipment (ORDEE) in 1998 become the baseline, the gap would be 13 years of absence. These long-term periods were enough to let the informal sector flourish.

However, it is noteworthy to state that China is currently leading the development of the WEEE legislation. China has already enacted several regulatory instruments prior to 2011 WEEE regulation and advances with 24 active rules, regulations, policies and guidance (Step-Initiative, 2016a). Whereas India and Nigeria are still struggling to have an effective regulatory approach to deal with the problems. The majority of the critics to the Chinese legislation are centered in the absence of some important aspects of the legislation and the efficiency in implementing the rules on the field, while Indian rules are dominantly criticized for its ineffectiveness. To date, the evaluation of the Nigerian case remains unknown. One may raise a question why China leads the development of the WEEE-specific approach to handling WEEE in the developing countries. Many answers can be provided, but this study highlights the role of academia to raise the WEEE issues within Chinese society. This study has attempted to measure the magnitude of Chinese publications using Scopus database with the keywords "e-waste" and affiliation country "China". It was found that the quantity of publication from China almost reaches two thousand publications – 1,993 to be precise – from the year of 2000 until the mid of 2016. Whereas there are only 355 and 65 documents found for India and Nigeria, respectively, during the similar period. It is safe to assume that the level of scientific publications of WEEE issues positively correlates with the development of the WEEE-specific regulatory instruments within a specific country.

Fifth, there appears a similarity on the disposal behavior of Chinese, Indian, and Nigerian consumers: they seek an economic incentive as an exchange for their disposal choice. Hence, the consumers generally are reluctant to deliver their WEEE to the official channels as the informal collectors could offer a higher price. "Waste as value" mentality seems to be the core problem (Orlins and Guan, 2015). Also, the consumers are generally unaware of the consequences of their choice to dispose of WEEE into informal channels. Sociocultural factors might play an important role to shape the attitude and behavior towards waste in developing countries. Waste remains a less important issue for the community unless the basic needs (food, shelter, security and livelihoods) have been fulfilled or the damage and impact of waste have emerged (Wilson, 2007). Waste workers also are considered "dirty" and "lowly" job (Marshall and Farahbakhsh, 2013; Wilson, 2007).

Finally, this study witnesses the failures of several formal initiatives in China. Some factors influence these failures, including but not limited to: (1) lack of collection networks to gather WEEE, as compared with effective door-to-door collection from scavengers, (2) a gap between incentive from the official collectors / subsidy from government and money offered by the informal sector, and (3) a higher collection and recycling cost (Chi et al., 2014, 2011). Chi et al. (2011) also mention the lack of interest / incentive of the multinational companies to initiate take-back scheme. However, though several projects faced failures and the notable "Old for New" program had its own problems, this study remarks the progressive efforts in China for setting up take-back schemes or official collection initiatives. Unfortunately, such discussion is limited in the Indian case and unknown in the Nigerian one.

3.4 Analyzing Structural Relationships within the WEEE Management Systems in the Developing Countries and Determining the Most Important Factors in the Systems

This study provides table 9 to summarize the discussion in the previous section about the problems and the main causes of the systems in China, India, and Nigeria. It, hence, argues that the problems would be also similar and relevant to any developing country, especially which has similar main causes within its society. Therefore, it is safe to state that such problems are the generic WEEE-related problems faced by the developing countries.

Table 9. The Summary of the Main Problems and Causes regarding WEEE Issues in the Developing Countries

Main Problems in WEEE Issues in Developing Countries	Main Cause(s)	Involved Stakeholder(s)
Increasing rate of WEEE generation	Increasing Rate of EEE Consumption	Producers, consumers
	Shortening Lifespan	
High level of illegal import	The present gaps between WEEE legislation in developed and developing countries	International community, the government from the source countries, the government of the destination countries, the custom, the importers and exporters
	Poor law enforcement	
	Difficulties and ambiguities to differentiate the used electric and electronic equipment (UEEE) and WEEE	
Domination of the informal sector containing crude operations	High level of illegal import since the early 1990s	The national government, the regional government, the informal sector, the formal sector, non-governmental agencies
	Long absence of WEEE-specific legislation	
	Lucrativeness of the business / industry	
	Economic disparities, limited education, inequality, urbanization	
Long absence of WEEE specific legislation	Waste issue generically is a less priority for the society	The national government, non-governmental agencies
Unawareness of the consumers	Waste as value mentality	Consumers, the national government
	Waste issue generically is of the least priority for the society	
Failure of Take-Back Initiatives / Pilot Projects	Domination of the informal sector in the collection activities	The national government, the collection channels, the recyclers, the producers
	A higher treatment and recycling cost	
	A limited involvement of the multinational companies	

Furthermore, this section attempts to conceptualize the structural relationships among the problems. This structure includes the endogenous variables, any variables which directly related to the WEEE management systems, and the exogenous variables, any variable that helps to create the landscape in which a particular WEEE-related situation may emerge. The characteristics were gathered from the variables presented in table 9 and any other relevant variables that appeared in the WEEE literature. An arrow in the figure represents a causal effect, links a cause with an effect variable. Figure 11 shows a causal map of the systems in the developing countries. An arrow in this figure represents a causal effect relation, links a cause with an effect variable. This figure captures the interconnection of the variables within the systems, i.e. the structure of WEEE management systems in the developing countries and shows that the WEEE issues are actually interrelated with many factors generally excluded from the discussion.

The crude recycling processes (in red box of figure 11) appears because of the interaction between the increasing level of the recovery operations in the informal sector and the high level of ignorance on how to treat the waste according to the environmental standards. Here, the increasing recovery activities are influenced by a crucial reinforcing loop (loop R1 in figure 11) within the informal sector, depicting the relationship between the profitability, the informal workforces, and the recovery operations (Chi et al., 2011; Manomaivibool, 2009; Wath et al., 2010). These three factors relate to the economic, social, and environmental factors of WEEE management systems in the developing countries. Moreover, the impact of loop R1 is maintained by the presence of an exogenous factor, i.e. the rapid urbanization (Marshall and Farahbakhsh, 2013). This factor provides the informal sector with a continuous influx of human resources that eventually become the sources of the capacity for the recovery operations. Also, the strong presence of loop R1 is supported by high level of demand for the second-hand EEE products (Chi et al., 2011; Ogungbuyi et al., 2012). Accordingly, increasing rapid urbanization and high level of demand in such market could be traced back to and correlated with the widening economic inequality, influenced, if not caused, by the uneven regional development within the developing countries (Chen and Wellman, 2004; Chinn and Fairlie, 2007; Marshall and Farahbakhsh, 2013; Shankar and Shah, 2003; Williams et al., 2008). The significance of loop R1 is also affected by the increasing level of WEEE generation and a significant level of illegal WEEE import. The former factor, on the one hand, is affected by several interrelated factors (which have been discussed in the previous section), especially by increasing market penetration of EEE and its declining life span (Wang et al., 2013a). The latter, on the other hand, is influenced by the existing gap of WEEE regulation, caused by the progressive regulatory efforts in the developed countries and the long-term absence of such regulation in the developing word (Li et al., 2013; Ogungbuyi et al., 2012).

Furthermore, there exists another reinforcing loop (loop R2 in figure 11) in the systems that ensures the domination of the informal sector in WEEE management systems of the developing countries. This loop limits the collection activities of the formal sector and helps to cause its failures. It is driven by the interaction between the increasing level of informal collection rate, the limited presence of the collection and recycling infrastructures, the absence of incentive to dispose WEEE via formal channels, and lack of consumer awareness. Accordingly, most of these factors are interrelated with or influenced by the long-term absence of WEEE-specific legislation in this region (Kojima et al., 2009; Osibanjo and Nnorom, 2007; Wath et al., 2010). In this loop, a limited level of collection rate in the formal sector restricts its profitability, discouraging more formal businesses to join the collection activities. The limited presence of the formal players further limits the level of formal collection rate.

If the ultimate problem - the crude recycling process – was used as the starting points and all variables were put in the places and connected, this study finds the presence of several exogenous factors which shape the landscape of the systems in the developing countries. They include the following factors:

- The general advancement of the information systems and technology,
- The globalization,
- The scarcity of virgin materials,
- High level of the economic and population growth in the developing world,
- A weak law enforcement and the difficulty in distinguishing UEEE and WEEE,
- Uneven region development, and
- A general lack of priority regarding waste issues in the society

The first three factors represent the general conditions of today's situation worldwide. The fourth and the fifth are actually not monopolized by the developing countries only, but their presence is obvious and influential in this region. The sixth and the seventh variables arguably can be attributed uniquely to the developing countries. Also, this study would argue the presence of three factors to become the most relevant defining factors, characterizing the WEEE management systems in the developing countries. They are the uneven regional development as the most defining exogenous factor and the long-term absence of the WEEE-specific legislation and the high level of illegal import as the most defining endogenous factors. Unbalanced regional development within a country arguably becomes the major driver in creating the landscape of the informal sector to flourish. A study from Wu (2008) found that substantial regional disparities exist in China and India – reflecting the gap between rich and poor regions – and correlates with the infrastructure development and the level of urbanization. Accordingly, it is known that the majority of the informal workers are coming from the rural migrants (Ezeah et al., 2013; Ni and Zeng, 2009; I. C. Nnorom and Osibanjo, 2008).

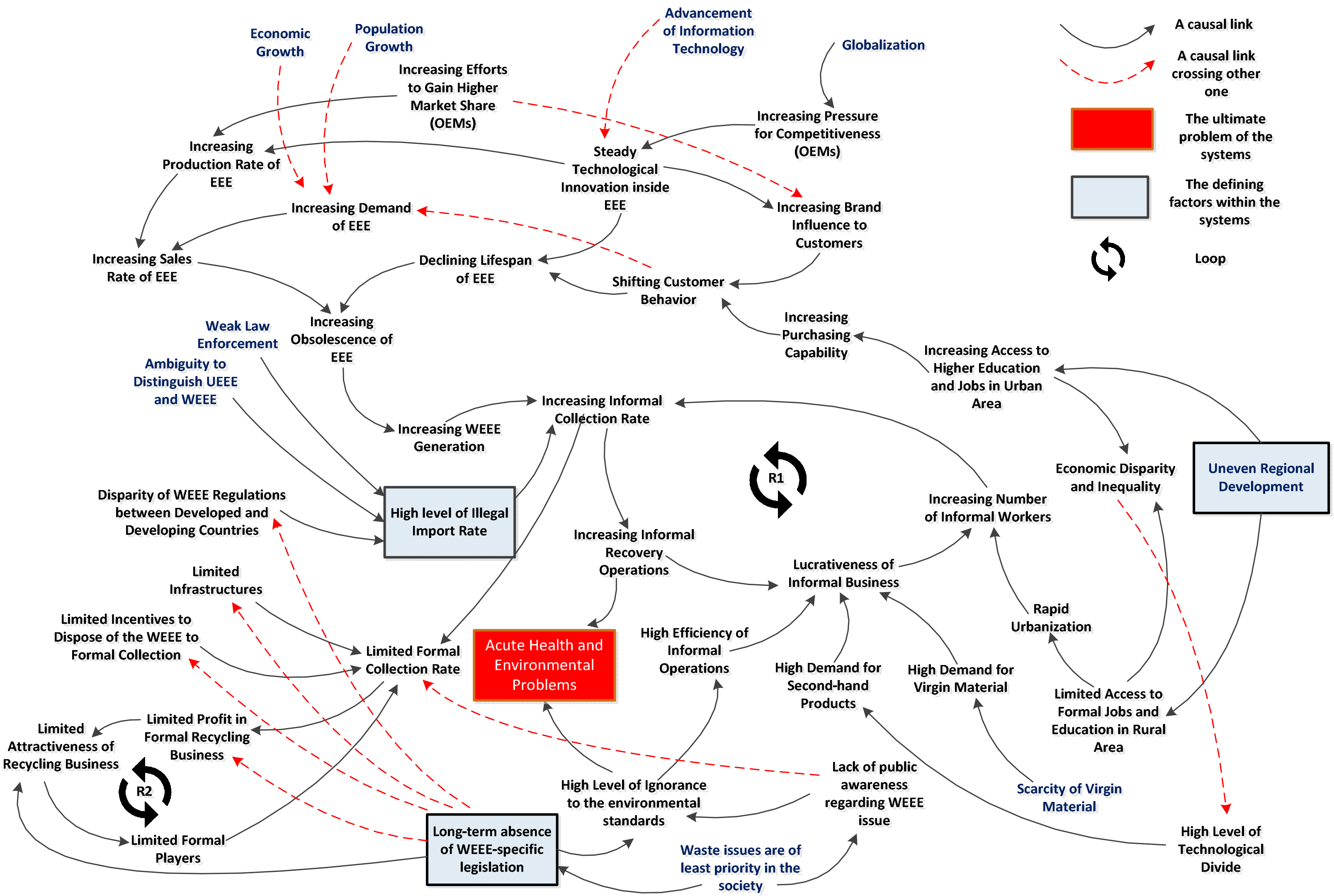

Figure 11. A Causal Map representing the characteristics of WEEE Management Systems in the Developing Countries

Furthermore, the absence of regulation in the developing countries had provided a financial incentive for evading the waste responsibility in the developed ones in the late 1980s, triggering the initial appearance of illegal WEEE transboundary movement (Ogungbuyi et al., 2012; Wang et al., 2013b). Since then, this influx has been pouring the developing countries with a huge volume of WEEE, providing a sufficient amount of waste for the informal sector to operate and to sustain its recycling business. The importance of the interaction between the WEEE illegal import and the regulation in the developing country has also been supported by a most recent article on WEEE appears in Nature (Wang et al., 2016). This article points out a steps need to be taken, including the initiation of a formal global protocol on WEEE trading, tightening the domestic regulation of the developing countries, and cracking down any illegal WEEE import in the developed ones.

3.5 Comparing the Situations of the WEEE Management Systems in the Developing and Developed Countries

This section aims at distinguishing and contrasting the extracted characteristics between the systems in the developing and the developed countries. It starts by recalling the sixth and the seventh exogenous factors of the developing countries discussed in the previous section, i.e. an uneven regional development and a lack of priority of the waste issue in the developing society. The discussion of the former is beyond the scope of the waste issue. It is safe to state that though the developed countries also face the problem of uneven development within the country and its neighborhoods, the level of regional disparities are still lower as compared to the developing regions. For the latter, Marshall and Farahbakhsh (2013) have provided a proper explanation of the socio-historical condition about the solid waste issues in the developed countries. They mention the presence of five key drivers on waste issue in this region, i.e.:

- The sanitary revolution since the industrial revolution between 18th and 19th century,
- The modernization of solid waste management after the Second World War,
- The resource scarcity and the value of waste, especially in the 1970s as the waste hierarchy concept emerged from the European Union in this period,
- The climate change issue since the beginning of the 1990s, and
- The rise of public concern and awareness, lead to behavioral changes.

If the aforementioned drivers are compared to the ones from the developing countries, one may find dissimilarities. The concern of waste issue has emerged in the developed countries decades ago, while currently, the developing countries are still struggling to move up the waste issue in the hierarchy of people's priority. This study further refers to the work of Wilson (2007) for a comprehensive comparative perspective for general waste management in the developed and the developing countries.

Then, this study uses the main issues appeared in table 8 as the points of reference for the comparison. These issues are the WEEE generation from the domestic user, the transboundary movement of WEEE, the status of the informal sector, the status of WEEE-specific legislation, the consumer behavior, and the presence of take-back initiatives.

First, the developed countries also face a similar increasing trend of WEEE generation, with a high level of relative quantity (kg/inhabitant). For instance, the review of previous EU Directive estimated that the EU27 generated about 7.2 million tons in 2005 only. It also predicted that the quantity will reach the level of 8.6 million tons by 2012 and 12.3 million tons by 2020 (Huisman et al., 2007). Later on, this prediction is confirmed by the recent finding of Countering WEEE Illegal Trade (CWIT) that 9.45 million tons of WEEE were generated in the EU28 + Norway and Switzerland in 2012 (Huisman et al., 2015). Other examples of high WEEE generation appear in other developed countries such as Norway, Switzerland, Japan, South Korea, the United States, and Canada which produced 146,000, 213,000, 804,000, 2.2 million, 7 million, and 725,000 tons of WEEE in 2014 (Baldé et al., 2014). Moreover, the concerns in developed countries have moved from merely focusing on the estimate of the WEEE generation to broadening the perspective on the measurement of the fates of WEEE towards multiple streams. The CWIT project finds the chains of 9.45 million tons of generated WEEE in the EU28 plus Norway and Switzerland in 2012 (Huisman et al., 2015). These waste chains consist of:

- 3.3 million tons entered official collection and recycling,
- 1.5 million tons were exported,
- 3.15 million tons were recycled under non-compliant schemes in Europe,
- 750,000 tons were scavenged, and
- 750,000 tons were thrown in mixed-bin.

Second, the recent situation of the WEEE illegal trade in the developed countries is worth to be discussed. The same CWIT project estimates that 900,000 tons of UEEE and 400,000 tons of WEEE were exported unofficially from the EU to the non-OECD countries in 2012. All of them were mainly driven by the reuse value and the avoidance of sorting, testing, and packaging cost. Another recent study from UNU provides a more detailed picture of the movement of several WEEE categories (i.e. waste refrigerators, freezers, laptops, desktop computers, televisions and monitors and flat panel displays) from EU (Baldé et al., 2016). This report figures out a decreasing trend of illegal export towards Eastern Asia, Western Asia, Southeast Asia and Eastern Africa and an increasing trend towards Central Asia, Southern Asia, Western Africa, Southern Africa, Northern Africa and non-EU Southern Europe. Here, several countries contribute the lion share of exported WEEE, including Germany, Great Britain, Latvia, and Estonia. Lastly, the aforementioned report from EFFACE also mentions the driving supply factors, influencing the presence of WEEE transboundary movement from EU towards China (Geeraerts et al., 2015). These factors include but are not limited to the increasing WEEE generation in EU member states, the tightened WEEE legislation across EU member states; thus increasing waste handling cost, poor enforcement, the complexity of WEEE flows and the competitiveness of the market, high unemployment rate, high material price, the lack of producer responsibility, and sociocultural relationship.

Third, the existence of the informal waste sector in the developed countries is generally ignored by the society; much more ignored than in the developing region. Ramusch et al. (2015), as one of the very few exceptions, attempts to measure the size of the informal collection of bulky waste, bulky waste wood, household scrap (excluding packaging) and WEEE in Austria. They estimate that 100,000 tons of waste were informally collected in Austria. Also, this study provides the relevant characteristics of the informal waste sector in Europe, as follows:

- 0.05 – 0.16% of population were involved
- Transboundary activities, bringing the waste from the western part of Europe such as Germany, the Netherlands, Austria, Italy, Belgium, England, and Switzerland to the eastern part such as Hungary and Poland,
- High mobility using car, trailer, or van,
- Collected up to 1000 kg per trip,
- Generating income in the level 50-300 Euro per month,
- Facing socioeconomic problems, environmental problems, and legal issues,
- Providing reusable goods for local markets, and

- Generating income for the most vulnerable social groups in Europe.

The study of Ramusch et al. (2015) is part of the project "TransWaste" which assessed the activities of the informal sector in collection and transshipment of solid waste in and to Central and Eastern Europe. This study further refers to the reports of this project for a more comprehensive information about the status of the informal waste sector in Europe. Unfortunately, this study could not find any work which focuses solely on the informal sector of WEEE in this region.

Fourth, the significant presence of the WEEE-specific legislation in the developed countries is undeniable. These regulatory measures have existed since the end of the 1990s – Swiss ORDEE in 1998, the Danish Statutory Order from the Ministry of Environment and Energy No. 1067 in 1999, the Dutch Disposal of White and Brown Goods Decree in 1999, and Norwegian Regulations regarding Scrapped Electrical and Electronic Products in 1999, the Japanese Specified Home Appliances Recycling Law (SHAR) in 2001 to name a few (Khetriwal et al., 2009). The EU WEEE Directive 2012, the most prominent one, has set an ambitious target for its member states to achieve the minimum collection rate, i.e. 45% of the quantity put on the market from 2016 until 2019 and 65% of the same market-based calculation or alternatively 85% of WEEE generation from 2019 onward. However, only five member states have achieved the 45% target and Sweden solely has exceeded the 65% target in 2010 (Ylä-Mella et al., 2015). Nevertheless, the target set by EU, overall, becomes the international benchmarking on how good a WEEE management system is.

One last point should be discussed here: there is a debate of the absence of the design incentive intention in the current EU legislation (Huisman, 2013; Lifset and Lindhqvist, 2008). The advocates of the design incentive and the individual producer responsibility state that the presence of EPR concept is not only a matter of diverting waste from the landfills, rather it should create an incentive for the manufacturers to design an environmental friendly EEE, on the one hand. They argue the feasibility of such approaches has been implemented in the Japanese SHARL and PC Recycling Systems, ICT Milieu Netherland, Maine, and Washington state of the USA(Dempsey et al., 2010; Sander et al., 2007). On the other hand, the critics of the design incentive argue the existing problems to implement IPR, such as the waste came back as mixed collection and it is expensive to sort the waste according to the brand (Huisman, 2013). Rotter et al. (2011) provide an example of this impracticality in their assessment of the systems in Germany.

Hence, the cons of IPR prioritize the systems development and waste management improvement as the means to solve the problem instead (Huisman, 2013; Huisman et al., 2007).

Fifth, consumer awareness is still becoming an issue in the developed countries. The review of the 2002 EU WEEE directive still mentioned the limited consumer awareness of the WEEE directive (Huisman et al., 2007). Even in a particular situation when the high awareness is present, it does not necessarily translate to the expected disposal behavior. This situation is particularly true for the small EEE. A study of the consumer awareness in Finland finds that though the majority of the respondents were unanimous regarding the importance of the recycling of mobile phones; most of them still stored their old phones at home (Ylä-Mella et al., 2015). Another study in Spain figures out that 67.1% of the respondents discard their waste e-toys in the mixed domestic bins (Pérez-Belis et al., 2015). SWICO Recycling records that only 15% of mobile phones in Swiss households were returned to the collection points (SWICO, 2008). Altogether, the efforts to increase consumer awareness and to influence the shift of behavior are still required in the developed countries, especially to achieve the collection target. However, due to the long establishment in prioritizing the waste issue in the society, it is adequate to state that the general awareness of the potential and the risk of WEEE in the developed countries are better than in the developing region.

Finally, the developed countries have been serving as the desirable model for take-back initiatives for more than two decades. The efforts of SENS and SWICO, two PROs in Switzerland, are the pioneers in this matter. They represent the initiatives from the producers and the manufacturers to set up the systems before the WEEE-specific legislation comes into force in a country. Similarly, EEE producers in Sweden, Belgium, Norway, and Netherlands also have initiated the systems prior to the legislation (Khetriwal et al., 2009). Here, the role of non-state actors is of central importance. On the contrary, previous studies have witnessed the failure of several pilot projects in China because of the presence of the informal sector with its complex networks. The Chinese government gradually developed the systems by empowering the formal actors; most of them are state-controlled recycling facilities (Salhofer et al., 2015). India and Nigeria have also enacted the regulations without having a prominent example of the take-back initiatives. By having two contrast situations, a question remains to be answered: who should take the first step to set up the systems in a developing country which has yet no take-back program at all? As waiting is not the solution, it is the job for the academia to approach the producers, understand their concerns, and promote the incentive mechanisms for them to start the take-back program for their own brand, while at the same time help the government in initiating the legal approach properly. Table 10 summarizes the comparison between the systems in the developed and developing countries by also adding several relevant factors.

Table 10. The Summary of Comparison between the WEEE Management Systems in the Developed and Developing Countries

Main Issue / Problem	Developing Country	Developed Country
Market Penetration of EEE	Growing State	Saturated for Many Types of EEE
Lifespan of EEE	A relatively longer-term period	A relatively shorter-term period
WEEE Generation from Domestic Users	Increasing WEEE Generation with limited level per capita	Increasing WEEE Generation with already high level per capita
Illegal Import of WEEE	Becoming the Destinations	Becoming the Sources
Status of the Informal Sector in WEEE Collection and Recycling	Dominating the Sector	Inferior to the formal systems, seeking opportunities in the collection rather than recycling
Status of WEEE Specific Legislation	Long-term absence, then developing the legislation and still focusing on the effectiveness	Well-established and focusing on the achievement of a much higher collection and recycling target, a notable debate of IPR and design incentive
Consumer Behaviors	General lack of unawareness; disposing the limited number of the waste to the formal sector	Lack of awareness, but generally still better than within the developing region; disposing the significant number of the waste to the formal sector
Take-Back Initiatives / Pilot Projects	Presence of several failures, relying on the state systems, lack of take-back initiative from the multinational company	Providing prominent examples, initiating the nationwide systems, high involvement of the non-state actors
Secondary / Reuse Market	Large and Lucrative	A profitable business but the magnitude seems lower within the country
Black and Grey Market	Large and Lucrative	Limited

Chapter 4 Comparative Analysis of WEEE Management Systems in the Developed and Developing Countries: A System Dynamics Approach

In Chapter 4, this study emphasizes the System Dynamics (SD) analysis on WEEE management systems, following the sequence of modeling processes from Sterman (2000). The analysis here has the following three objectives. First, it aims to provide a generic model for WEEE management systems for the developed and developing countries. Second, the SD approach attempts to assess the sensitivity of the model based on several selected indicators. Third, this particular work tries to compare and to distinguish, quantitatively, the behavior of the two models from both types of the country above.

4.1 System Dynamics Methodology for the Problems under Study

This chapter proceeds with a sequence of steps. Conceptualizing the generic model represents the first step. Here, this study develops the model boundary, the causal loop diagrams, and the stock-flow diagrams for the problem under study. In proposing the model, this study also benefits from personal interviews with two experts in the field: Prof. Dr. Maria Besiou from Kühne Logistics University, Hamburg, and Prof. Dr. Grit Walther from RWTH Aachen. In the second step, two SD models are developed to incorporate the different characteristics of the WEEE systems in the aforementioned countries. The differences take place in the model structures or parameter values synthesized for the models. The Swiss model is selected as the reference model for the developed country. For the developing country, the Indian model is captured as the reference. If there is an absent in a particular type of data or a specific structure of the WEEE recycling systems in India, this study looks to another reference, i.e. the Chinese recycling systems, to enhance the developing country model.

The third step applies the model testing procedures suggested by Sterman (2000). The procedures comprise with model boundary adequacy, structure assessment, dimensional consistency, parameter assessment, extreme conditions, integration error, and behavior reproduction tests. Afterwards, the fourth step consists of the base case and a sensitivity analysis. Here, this study utilizes different assumptions to the models, as will be presented in the proceeding section. Finally, as a note, parts of this chapter have appeared in Ardi and Leisten (2016).

4.2 Generic Conceptual Model

Figure 12 exhibits the simplified conceptual model of the system under study. It consists of one simplified sub-model of the forward logistics and five main sub-models: the domestic users, the reverse logistics of the formal sector, the reverse logistics of the informal sector, the dynamics within the formal sector, and within the informal sector. Initially, the domestic users sub-model represents the behaviors of the consumers, who buy and utilize the electronic products. Later on, the customers dispose of the products, as WEEE, which then flows into the reverse channels. The channels contain both the formal and informal WEEE recovery systems. The structure for both formal and informal sector includes different types of recovery operations, i.e. collection, reuse, refurbishment, recycling, and landfilling. On the one hand, the reverse logistics of the formal sector are connected with the forward logistics through refurbishment and recycling processes, closing the loop of the supply chain. On the other hand, the informal channels are linked to the consumers via the secondary market. This research further hypothesizes the endogenous dynamics that drive the growth of the formal and informal sector.

4.3 Domestic Users Sub-Model

This sub-section describes the sub-model of domestic users which illustrates the behavior of the customers in buying and utilizing the electronic products and then disposing of these products at their end-of-life. To capture the preceding behaviors, this study adopts the idea taken from Input-Output Analysis (IOA), the most common methodology to estimate WEEE generation in the literature, into SD modeling structures (Wang et al., 2013). IOA consists of three main variables: sales, stock, and lifespan.

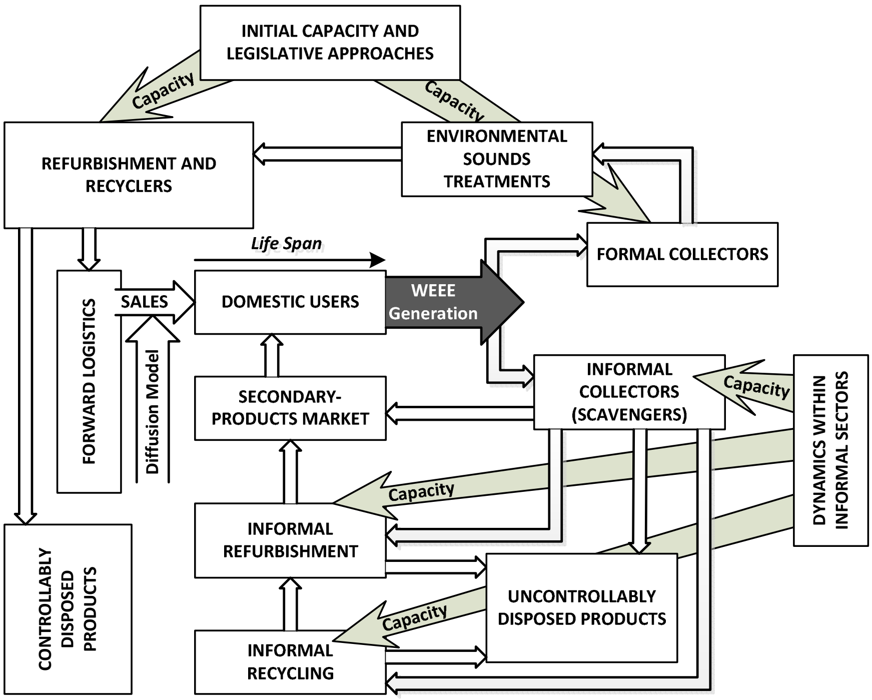

Figure 12. Simplified Conceptual Model for the System under Study

First, the “sales” variable is developed by adapting the structure of the Bass model (1969) taken from Sterman (2000). Second, the “stock” element is simply captured by utilizing the existing stock variable in SD modeling. Third, the “lifespan”, representing a specific time gap between the purchasing and disposal activities, is taken by combining the delay structure as Besiou et al. (2012) with the derived lifetime distribution from the Market Supply Model approach (Sinha, 2013). Figure 13 shows the domestic user sub-model that combines the causal-loop diagram and the stock and flow diagram. The variable names are presented in italics in the remaining parts of the thesis.

In figure 13, *Total_Population* symbolizes the total market population. It is influenced by *Initial_Population* and a *Growth_Fraction.* The population consists of *Potential_Adopters* and *Primary_Products_Adopters.* The latter affects the former and the former influences *Adoption_from_Advertising* and *Adoption_from_WOM*. *Adoption_Rate*, the sum of *Adoption_from_Advertising* and *Adoption_from_WOM,* accumulates in the stock of *Primary_Products_Adopters*. *Adoption_from_Advertising* characterizes the early innovative adoptions which come from a constant fraction (*Innovation_Fraction*) of the *Potential_Adopters*. *Adoption_from_WOM* depicts the adoption of word-of-mouth processes. This variable is influenced by a fraction of imitative adopters (i.e. *Adoption_Fraction*) from *Potential_Adopters* and the size of *Total_Population*. This study further incorporates the replacement purchase through *Initial_Purchase_Rate;* influenced by *Initial_Sales_per_Adopter*, and *Repeat_Purchase_Rate,* affected by *Average_Consumption_per_Adopter.* Both purchasing types sum up the *Total_Sales_Rate*.

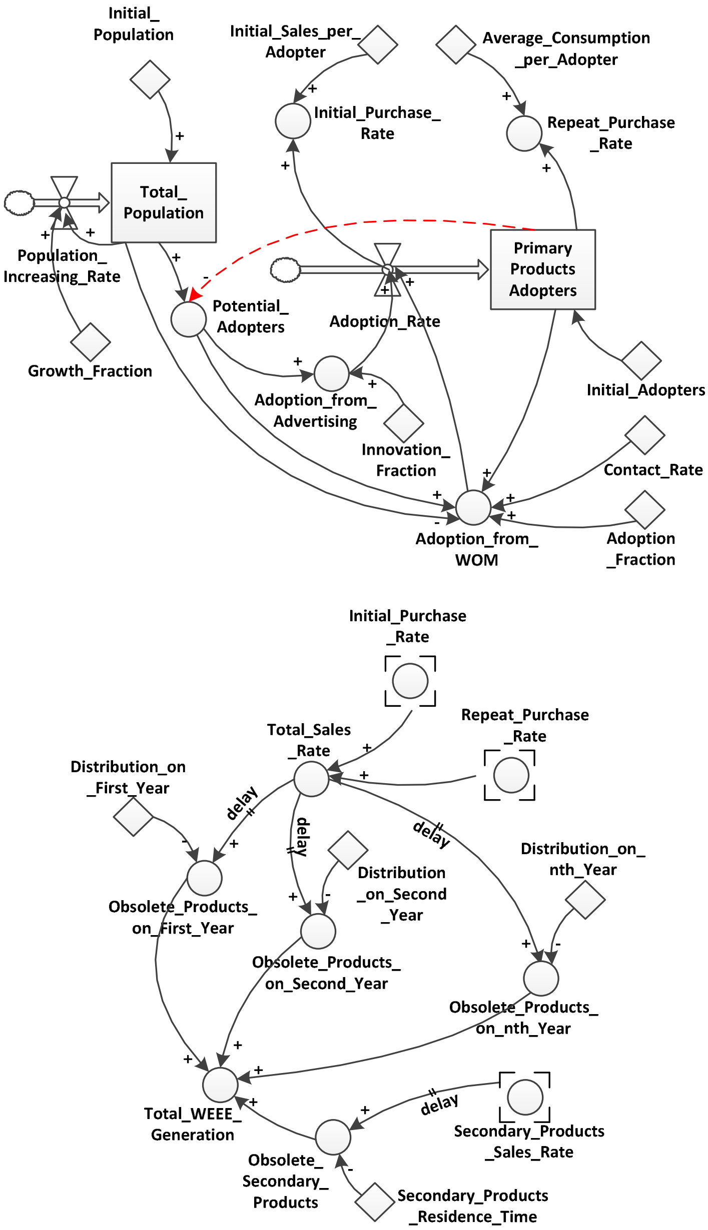

Figure 13. The Structure of Domestic Users Sub-Model

Total_Sales_Rate turns into obsolete products after a specific distribution of lifespan. *Obsolete_Products_on_First_Year,* influenced by *Distribution_on_First_Year*, symbolizes the products which become obsolete during the first year of their usage period. Similarly, *Obsolete_Products_on_Second_Year* captures the household disposal in the second year. These identical structures, i.e. *Obsolete_Products_on_nth_Year* and *Distribution_on_nth_Year,* are inserted into the model continuously until the last n^{th} year, in which the disposal activities still occur. The equation of *Obsolete_Products_on_nth_Year*, adapted from Vlachos et al. (2007), is as follows:

$$Obsolete\_Products\_on\_nth\_Year = DELAYMTR\ (Total\_Sales\_Rate\ *\ Distribution\_on\_nth\_year, n, 3, 0) \quad (5)$$

Additionally, the domestic users also produce *Obsolete_Secondary_Products* which is coming from *Secondary_Products_Sales_Rate* and *Secondary_Products_Residence_Time.* All of the obsolete products, then, determine *Total_WEEE_Generation.*

4.4 Reverse Logistics Sub-Model

Generated WEEE from the domestic users enters the reverse channels, either the formal channel or the informal channel. The nature of collection competition, between these two channels, determines the fate of the WEEE. This research proposes two conditions of collection competition. In the SD model of the developed country, the formal system is assumed to have superior access to WEEE collection, gathering WEEE as much as the highest capacity and leave the rest of WEEE, if any, to the informal channel. Besiou et al. (2012) and Streicher-Porte et al. (2007) also use this idea in their works. In the model of the developing country, the informal sector is captured as the superior actor in collection activities, representing the reality of collection in many developing countries. Accordingly, the informal sector can collect WEEE at its maximum capacity because of its effective door-to-door operations. In any case, if both formal and informal sectors could not collect all of the WEEE, the uncollected ones will flow directly to disposal. Figure 14 shows the comparison of the collection competition between the formal and the informal sectors in the developed and developing systems.

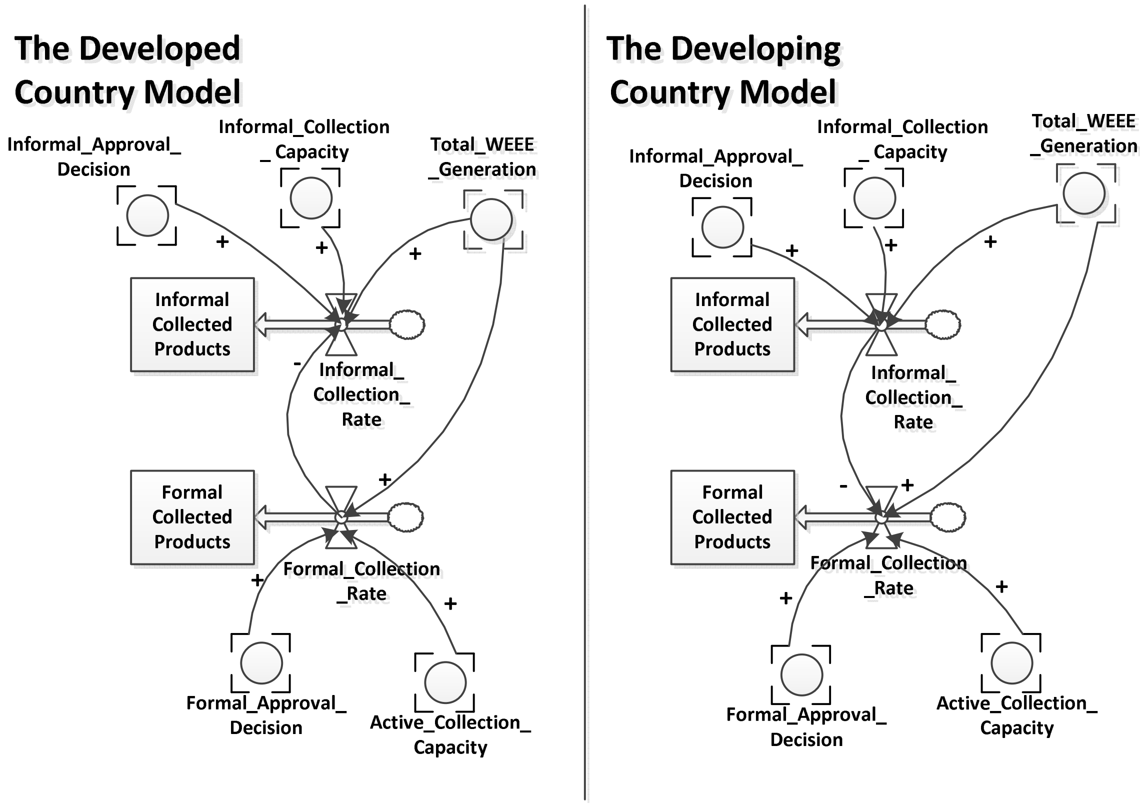

Figure 14. The Structure of Collection Competition between the Two Sectors in the Model

The equations of the collection rate of the formal and the informal sectors in the developed country model are as follows.

$$\begin{aligned} &Formal\_Collection\_Rate \\ &\quad = (MAX(MIN(Total\_WEEE\_Generation, Active\_Collection\_Capacity \\ &\quad * \ Total\_WEEE\_Generation), 0) \ * Formal\_Approval\_Decision \end{aligned} \tag{6}$$

$$\begin{aligned} &Informal\_Collection\_Rate \ = \\ &\quad = \ (MAX \ (MIN \ ((Total\_WEEE\_Generation - Formal\_Collection\_Rate), \\ &\quad Informal\_Collection\_Capacity), 0))) \ * Informal\_Approval\_Decision \end{aligned} \tag{7}$$

The collection rates for both sectors in the developing country model are:

$$Formal\_Collection\_Rate = (MAX(MIN(Total\_WEEE\_Generation - Informal\_Collection\_Rate, Active\_Collection\_Capacity * Total\_WEEE\_Generation), 0)) * Formal\_Approval\_Decision \quad (8)$$

$$Informal\_Collection\_Rate = ((MAX(MIN(Total\_WEEE\_Generation, Informal\_Collection\_Capacity), 0))) * Informal\_Approval\_Decision \quad (9)$$

One should notice the differences between equations 6 and 8 and between equations 7 and 9.

4.4.1 Reverse Logistics Sub-Model of the Formal Sector

Figure 15 depicts the generic version of the reverse logistics sub-model for the formal sector. Here, WEEE flows to the formal channels through *Formal_Collection_Rate*, which is influenced by *Active_Collection_Capacity.* This capacity arises from the influence of the legislative approach, i.e. *Legislative_Collection_Percentage.* The formal systems require time (*Time_to_Achieve_Collection_Target)* to adjust their initial collection capacity (*Initial_Collection_Percentage*) and match with the requirement of the regulation (*Legislative_Collection_Percentage*). This study incorporates one additional variable, namely *Time_without_Legislation.* This variable represents the length of a period when the WEEE-specific regulation is absent. If *Time_without_Legislation* applies, the formal systems can only collect WEEE as many as its *Initial_Collection_Percentage.* Otherwise, when the government eventually introduces a WEEE-specific legislation, then the systems finally can proceed the collection capacity from the initial percentage to the legislative target (*Legislative_Collection_Percentage*).

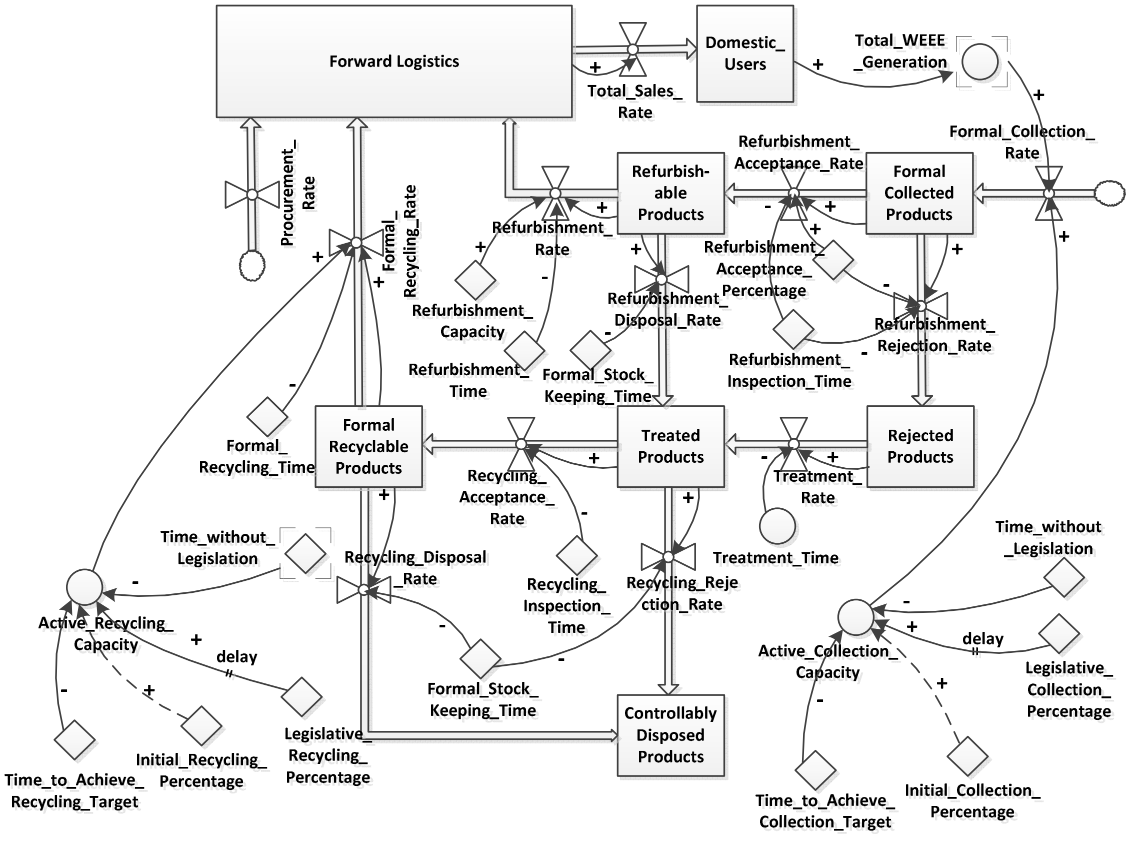

Figure 15. The Structure of Reverse Logistics Sub-Model for the Formal Sector

Sorting activity occurs in the collection centers to assess the quality of disposed products by applying *Refurbishment_Acceptance_Percentage*. This variable influences *Refurbishment_Acceptance_Rate* and *Refurbishment_Rejection_Rate*. The former rate accumulates in the inventory of refurbishment centers (*Refurbishable_Products).* *Refurbishment_Rate* then depletes *Refurbishable_Products*, flowing the products to the forward logistics. The latter rate enters the inventory of *Rejected_Products*. As a further note, the aforementioned variable concerning refurbishment can be replaced by another type of any recovery process above the recycling option in the waste management hierarchy. Environmentally sound treatments, as represented by *Treatment_Rate*, depletes *Rejected_Products*, and then increases the inventory of *Treated_Products. Treated_Products* is drained by *Recycling_Acceptance_Rate* and *Recycling_Rejection_Rate.* The former enters the formal recycling centers *(Formal_Recyclable_Products)* and the latter flows into the controlled landfills sites, represented by *Controllably_Disposed_Products.*

The systems satisfy the requirement of the material flow requirement through *Formal_Recycling_Rate,* draining *Formal_Recyclable_Products.* The recycling rate is influenced by *Active_Recycling_Capacity.* Similar to the collection capacity structure, the determination of this capacity variable is based on four variables, i.e. *Initial_Recycling_Percentage, Legislative_Recycling_Percentage, Time_to_Achieve_Recycling_Target,* and the absence period, i.e. *Time_without_Legislation.* Finally, after a pre-determined time of *Formal_Stock_Keeping_Time,* the systems dispose the rest of the recyclable products into *Controllably_Disposed_Products* through *Recycling_Disposal_Rate.*

4.4.2 Reverse Logistics Sub-Model of the Informal Sector

Figure 16 represents the reverse logistic sub-model of the informal sector. Here, the sector gathers WEEE through *Informal_Collection_Rate,* which depends on *Informal_Collection_Capacity. Informal_Collection_Capacity* is calculated from *Scavenger_Collection_Capacity, Informal_Collectors_Percentage*, and the size of *Informal_Workers. Informal_Collection_Rate* increases *Informal_Collected_Products,* which represents the stock of collection centers. This stock has additional inflow from *WEEE_Import_Rate*. Figure 17 shows the detailed structure of the illegal import in the model.

The sector conducts sorting to classify WEEE. The first sorting separates the WEEE into two flows: (a) the separation of WEEE that might be still working, through *Informal_Acceptance_Rate,* (b) the separation and the disposal of WEEE that is completely unusable through *Illegal_Disposal_a.* The second sorting appears to separate between the products that are reusable, refurbish-able, and recyclable. First, the reusable products flow into *Secondary_Products_Inventory* through *Informal_Reuse_Rate*. Second, the refurbish-able products enter the stock of *Informal_Refurbishable_Products* through *Informal_Refurbishment_Acceptance_Rate.* Third, the recyclable products move into *Informal_Recyclable_Products* through *Informal_Recycling_Acceptance_Rate. Informal_Reuse_Percentage*, *Informal_Refurbishment_Percentage,* and *Informal_Recycling_Percentage,* determine the number of WEEE that is accepted as “reusable”, “refurbish-able”, and “recyclable”, subsequently.

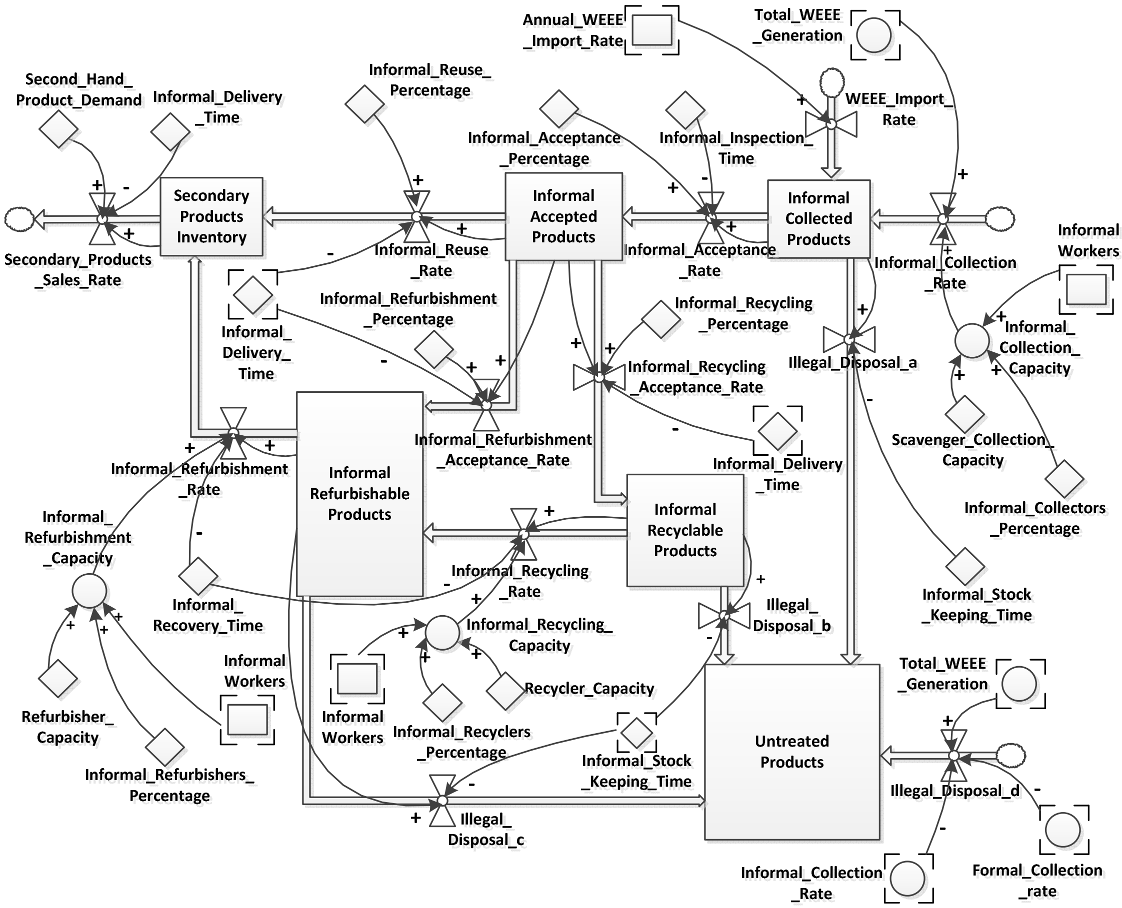

Figure 16. The Structure of Reverse Logistics Sub-Model for the Informal Sector

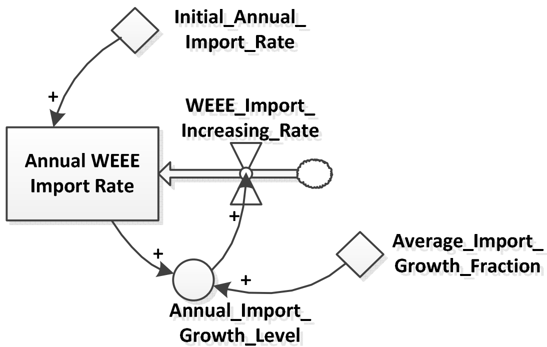

Figure 17. The Structure of WEEE Import in the Model

Informal_Recycling_Acceptance_Rate, affected by *Informal_Recycling_Percentage,* accumulates into the stock of informal recycling centers, namely *Informal_Recyclable_Products.*

Influenced by *Informal_Recycling_Capacity,* *Informal_Recycling_Rate* drains *Informal_Recyclable_Products* and increases *Informal_Refurbishable_Products* which represents the informal refurbishment centers. This particular flow is a hypothetical flow in an idealized situation for the informal sector. "Idealized" means that the informal sector is able to sort the waste perfectly and then categorize it into "refurbishable" and "recyclable". The refurbishable products could be well-utilized by the informal sector in the refurbishment process – except some of them that will eventually be discarded into final landfilling- and would not enter the recycling operation. Through this hypothetical flow, the informal sector could maximize its revenue from the recovery process. This particular scenario is then labeled as "Type I of the recovery process". This study employs the Type I of the recovery process to understand how far could the systems, especially of the formal sector, response to such idealized situation of the informal sector. The real-world scenario, however, presents a different type of flow, i.e. instead flowing from recycling to refurbishment processes, the movement of the waste is exactly the opposite: from the refurbishment to the recycling process (Figure 18). It happens because there exists a certain amount of waste -which is ready to be refurbished- but stay too long in the inventory and then eventually become broken. This waste is then discarded to the inventory of recyclable products and finally, is recycled through *Informal_Recycling_Rate*. This real-world scenario is labeled as "Type II of the recovery process". This study considers both scenarios in the preceding base case and scenario analysis. *Informal_Refurbishment_Rate,* influenced by *Informal_Refurbishment_Capacity,* reduces the level *Informal_Refurbishable_Products* and then enters *Secondary_Products_Inventory.* Recycling (refurbishment) capacity is calculated from *Recycler_Capacity* (*Refurbisher_Capacity),* the level of *Informal_Recyclers_Percentage (Informal_Refurbishers_Percentage*), and the size of *Informal_Workers.* Afterward, *Secondary_Products_Sales_Rate* satisfies *Second_Hand_Products_Demand,* and the products flow, once again, into the households, closing the loop of informal channels.

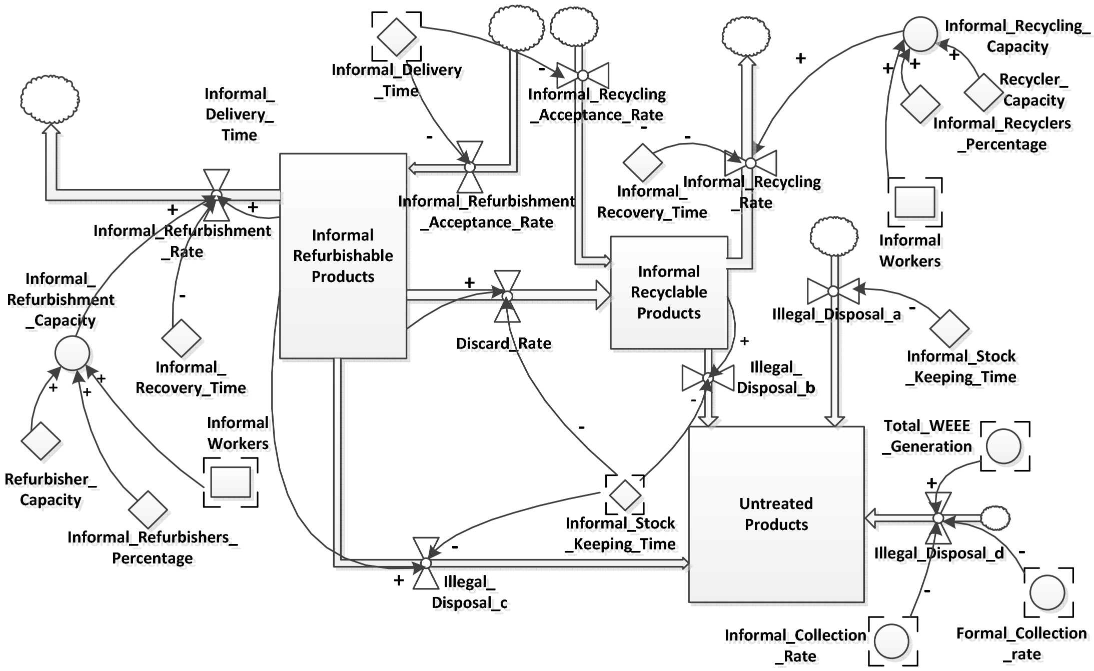

Figure 18. Flow from the Refurbishment to the Recycling Processes (Type II of the Recovery Process) in the Informal Sector

This study also incorporates the final destinations of the WEEE entering the reverse streams: *Untreated_Products*. *Untreated_Products* represents the reality in which WEEE is treated in the least favored options in the waste hierarchy. For the developing country model, this stock variable characterizes the illegal landfilling phenomena within the region. For the developed country model, this stock variable depicts the accumulation of two disposal options: the disposal in the mixed bin and the export of the WEEE to the developing regions. Accordingly, the informal sector disposes the remaining useless products from all of the three recovery centers (collection, recycling, and refurbishment) into *Untreated_Products* through *Illegal_Disposal_a, Illegal_Disposal_b,* and *Illegal_Disposal_c.* Together, these three disposal activities are affected by *Informal_Stock_Keeping_Time,* a specific period when the informal sector decides to empty their inventories. Also, *Untreated_Products* has another inflow from the uncollected WEEE by both formal and informal sectors, through *Illegal_Disposal_d.*

4.5 Sub-Model: Dynamics within the Formal and Informal Sectors

This research hypothesizes the endogenous dynamics that occurs within the formal and the informal sector. These dynamics further become the source of the capacity in running the collection, refurbishment, and recycling activities. In shorter periods, the dynamics ensure the continuity of the daily operations and on the longer run, they help to maintain the sustainability for both sectors.

4.5.1 Causal-Loop Diagram of the Dynamics within the Formal Sector

Figure 19 depicts the simplified causal-loop diagram of the endogenous dynamics in the formal sector. It comprises two reinforcing loops and one balancing loop. Initially, one endogenous variable (*Total_WEEE_Generation*) and one exogenous variable (*Initial_Collection_Percentage*) trigger the formal sector to apply *Formal_Collection_Rate.* After a specific period of *Time_without_Legislation, Legislative_Collection_Percentage* comes to influence the formal collection rate. Loop R1 exhibits the material flows in the closed-loop supply chain of the formal sector. In this loop, an increase in *Total_WEEE_Generation* rises *Formal_Collection_Rate,* climbing up the level of inventory of *Refurbishable_Products* and *Recyclable_Products*. This relationship causes the rise of *Refurbishment_Rate* and *Recyling_Rate,* further affecting the rise of the inventory in the forward logistics and *Total_Sales_Rate.* After a time-delay, the products within *Total_Sales_Rate* becomes obsolete, driving the increase of *Total_WEEE_Generation* into even a higher level.

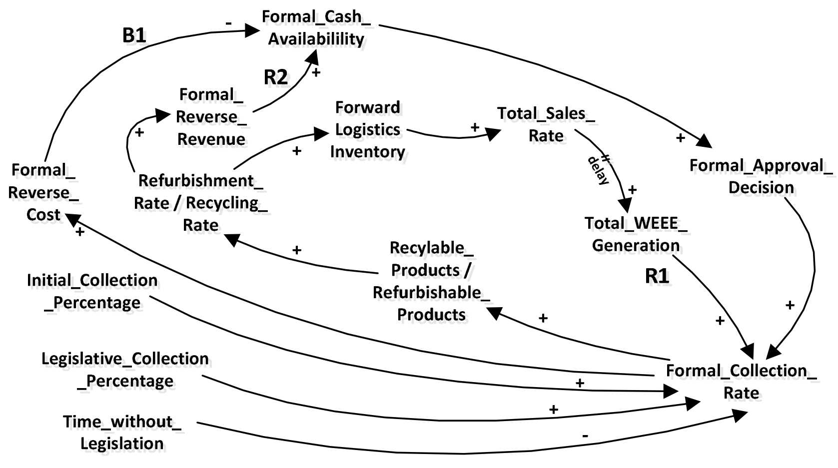

Figure 19. Simplified Causal-Loop Diagram of Dynamics within the Formal Sector

Loop R2 represents the impact of the formal sector's profitability on its future operations. An increase of the *Formal_Collection_Rate* will further increase *Refurbishment_Rate* and *Recyling_Rate,* triggering the increase of *Formal_Reverse_Revenue.* Under a certain circumstance, an increasing state of *Formal_Cash_Availability* ensures the formal decision makers to increase their *Formal_Collection_Rate* through *Formal_Approval_Decision*. Meanwhile, the increase of *Formal_Collection_Rate* causes the rise of *Formal_Reverse_Cost,* decreasing *Formal_Cash_Availability.* Under certain limited conditions, the low level of the cash pushes this sector to adjust their *Formal_Collection_Rate* via *Formal_Approval_Decision*, thus closing the loop as a balancing one (B1).

4.5.2 Causal-Loop Diagram of the Dynamics within the Informal Sector

Figure 20 shows the simplified causal-loop diagram of the endogenous dynamics in the informal sector. The diagram consists of five reinforcing (R) loops and four balancing (B) loops. Loop R1 characterizes the role of the secondary market to absorb the recovered products from informal channels and to satisfy the demand for second-hand products. In this loop, an increase in *Informal_Collection_Rate* increases *Secondary_Products_Inventory,* influencing the rise of *Secondary_Products_Sales_Rate*. After the time equals to *Secondary_Products_Residence_Time,* the secondary products become obsolete, raising *Total_WEEE_Generation.* Hence, loop R1 causes *Informal_Collection_Rate* to increase even higher.

Loops R2, R3, and R4, modified from Vlachos et al. (2007), represent the dynamics of the informal capacity. In these loops, the informal sector estimates the future capacity using smoothing factor to the level of current routines and then adjusts the current number of informal workers by hiring more workers. These loops have similar structures that include collection (R2), refurbishment (R3), and recycling (R4) activities. In loop R2, an increase in *Total_WEEE_Generation,* rises *Desired_Informal_Collection_Capacity,* triggering *Informal_Collection_Capacity_Discrepancy* to grow up. Hence, *Desired_Additional_Informal_Workers* increases, further affecting the increase of *Desired_Employment_Rate*. This condition influences the increasing number of *Informal_Workers* through *Net_Employment_Rate.* The growing size of workers causes the rise of *Informal_Collection_Capacity,* increasing *Informal_Collection_Rate.* This relationship then affects the increase of *Secondary_Product_Inventory*, increasing the number of

Secondary_Products_Sales_Rate. After a specific usage period, the *Total_WEEE_Generation* increases again, closing the loop of R2.

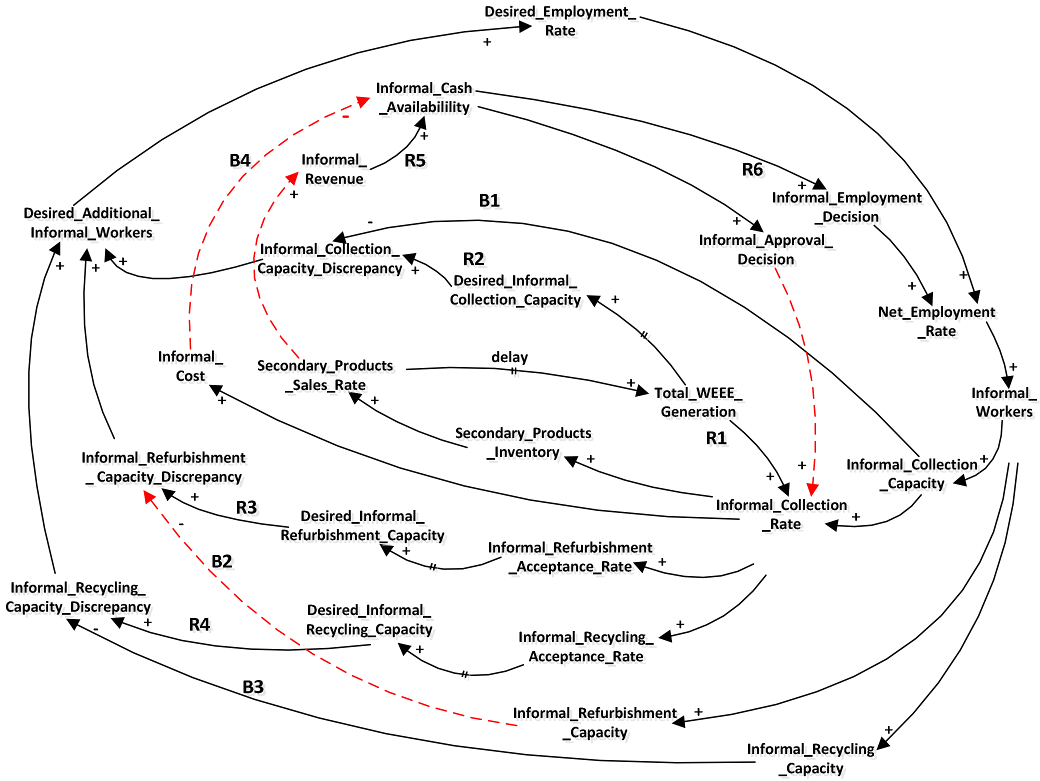

Figure 20. Simplified Causal-Loop Diagram of Dynamics within the Informal Sector

Loop R5 signifies the influence of the informal revenue into the informal recovery operations. In loop R5, an increase of *Informal_Collection_Rate,* increases the availability of *Secondary_Products_Inventory,* influencing the rise of *Secondary_Products_Sales_Rate.* Hence, informal sector receives higher *Informal_Revenue,* growing the stock of *Informal_Cash_Availability.* The raising cash availability maintains the routines of the informal collection, increasing *Informal_Collection_Rate* even higher.

In loop R6, the causal links depict the influence of cash availability on the rise of informal capacity. Again, an increase in *Informal_Collection_Rate* raises *Secondary_Products_Inventory* and further increases the stock of *Secondary_Products_Sales*. Thus, the level of *Informal_Revenue* raises, increasing the number of *Informal_Cash_Availability*. The cash availability further affects *Informal_Employment_Decision* to increase the number of *Net_Employment_Rate*, causing the rise of *Informal_Workers*. Hence, *Informal_Collection_Capacity* increases, influencing the higher rise of *Informal_Collection_Rate* and closing the loop.

The balancing loops consist of loop B1 to B3 and depict the fulfillment of capacity discrepancy after the hiring process has taken place. In B1, an increase of *Informal_Capacity_Discrepancy* increases *Desired_Additional_Informal_Workers.* Hence, *Desired_Employment_Rate* increases, pushing informal actors to increase the number of *Informal_Workers* through *Net_Employment_Rate*. The raising level of *Informal_Workers* causes the rise of *Informal_Collection_Capacity*, closing the occurred gap in *Informal_Collection_Capacity_Discrepancy*. Lastly, loop B4 highlights the influence of informal cost in balancing the informal recovery operations. In this loop, an increase of *Informal_Collection_Rate* increases *Informal_Cost,* thus, decreasing the stock of *Informal_Cash_Availability.* Under a certain condition that will be addressed in the subsequent sections, the decreasing cash stock pushes the informal sector to limit its recovery operations.

4.5.3 Stock-Flow Diagram of the Dynamics within the Formal Sector and Its Decision-Making Structures

Figure 21 represents the stock-flow diagram of the dynamics in the formal sector, accompanied by its decision-making structures. Initially, this diagram shows the financial structure of the formal sector. The calculation of revenue and cost faced by the formal sector are as follows.

$$\begin{aligned} Formal\_Reverse\_Revenue \\ &= Value\_per\_Refurbished\_Product * Refurbishment\_Rate \\ &+ Value\_per\_Formal\_Recycled\_Product * Formal\_Recycling\_Rate \\ &+ Total\_Recycling\_Fee \end{aligned} \tag{10}$$

$$\begin{aligned} Formal\_Reverse\_Cost \\ &= Formal\_Collection\_Cost * Formal\_Collection\_Rate \\ &+ Treatment\_Cost * Treatment\_Rate \\ &+ Refurbishment\_Cost * Refurbishment\_Rate \\ &+ Formal\_Recycling\_Cost * Formal\_Recycling\_Rate \end{aligned} \tag{11}$$

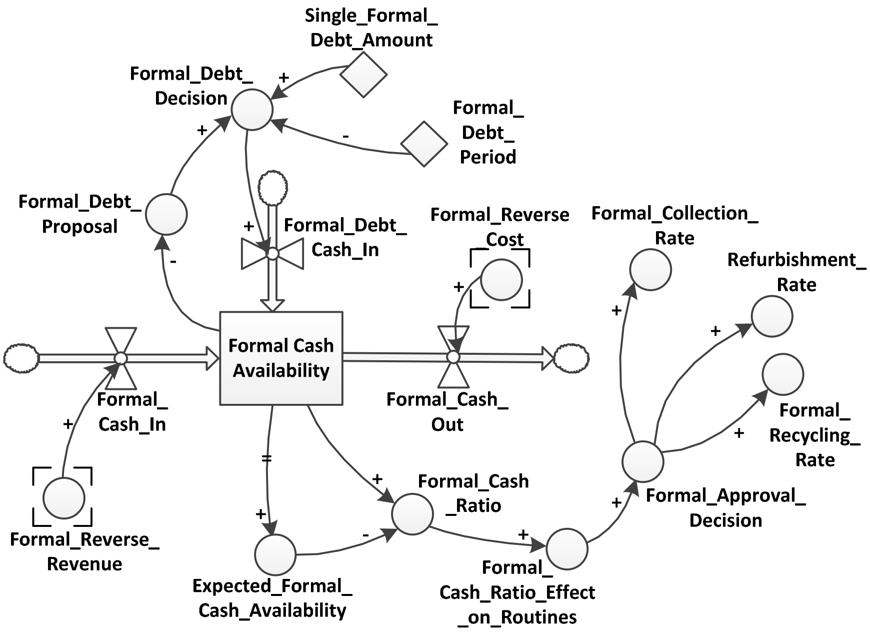

Figure 21. The Generic Stock-Flow Diagram of the Dynamics within the Formal Sector

Total_Recycling_Fee in equation 10 takes a form in the developed country model as an advanced recycling fee with fixed value (*Fixed_ARF*) and in the developing country model as a government subsidy (*Recyling_Subsidy*). The equations of these additional incomes for the formal sector are as follows.

$$Total\_Recycling\_Fee = IF(TIMEIS(STARTTIME, Time\_without\_Legislation), 0 \ll USD/WK \gg, Total\_Sales\_Rate * Fixed\_ARF) \quad (12)$$

$$Total\_Recycling\_Fee = IF(TIMEIS(STARTTIME, Time\_without\_Legislation), 0 \ll USD/WK \gg, Formal\_Recycling\_Rate * Recycling\_Subsidy) \quad (13)$$

The presence of *Time_without_Legislation* in equations 12 and 13 imply that *Fixed_ARF* and *Recycling_Subsidy* will be absent in the model from the beginning of the simulation up to the year when the government finally introduces a WEEE-specific regulation. Afterwards, *Time_without_Legislation* ends in the model, thus, the formal sector could collect *Fixed_ARF* or *Recycling_Subsidy* and then accumulate the gathered fee in the *Formal_Cash_Availability*. One should notice here that, on the one hand, *Fixed_ARF* is calculated based on the amount of the sales rate and on the other hand, *Recycling_Subsidy* is determined based on the amount of the formal collection.

Furthermore, the decision-making structures in figure 21 consist of two types of decisions, i.e. *Formal_Approval_Decision* and *Formal_Debt_Decision,* responding to two types of cash availability: declining and limited states. First, if the amount of cash comes to the declining state, the formal sector would adjust their collection, refurbishment, and recycling operations through *Formal_Approval_Decision*. Second, if the limited state of the cash appears, this sector would access the loan option from any sources. This debt decision aims (1) to ensure the continuity of the future operations and (2) to give a chance for the formal sector to reappear again when it faces bankruptcy. In reality, when a case of a bankruptcy happens for a particular business / sector, the business / sector will still have a chance to re-emerge, especially if the business is lucrative. Then, the declining state of *Formal_Cash_Availability* is tracked by *Cash_Ratio,* which represents the comparison between the current and the expected future value of cash. These decision structures are represented as follows.

$$Expected\_Formal\_Cash\_Availability = DELAYINF(Formal\_Cash\_Availability, a\_EFC, 3, Formal\_Cash\_Availability) \quad (14)$$

$$Formal\_Cash\_Ratio = IF(Formal\_Cash\_Availability <= 0 \ll USD \gg, 0, Formal\_Cash\_Availability \, / \, Expected\_Formal\_Cash\_Availability) \quad (15)$$

$$Formal\_Cash\_Ratio\_Effect\_on\_Routines = IF\ (Formal\_Cash\_Ratio > 1, 100 << \% >>, GRAPH) \quad (16)$$

$$Formal\_Approval\_Decision = Formal\_Cash\_Ratio\_Effect\_on\_Routines \quad (17)$$

GRAPH function in equation 16 represents three plausible adjustment behaviors by the formal and the informal sectors, i.e. proportional, highly sensitive, and insensitive behaviors (Figure 22). Here, it is assumed that the formal sector is highly sensitive to its cash condition.

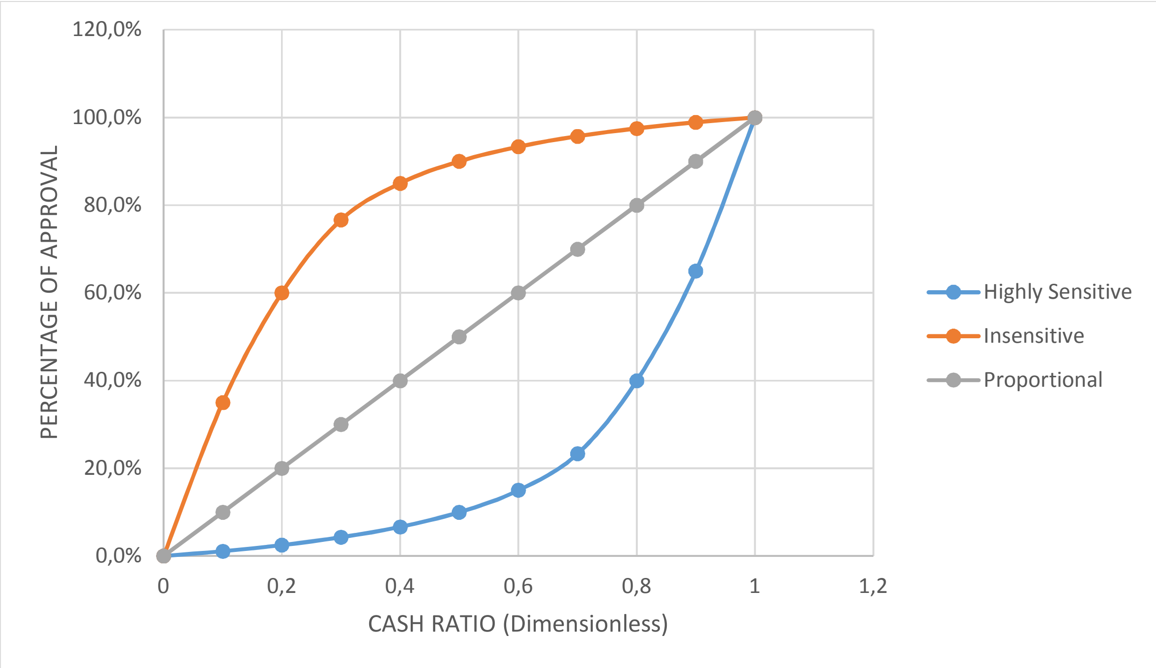

Figure 22. Three Plausible Adjustment Behaviors

Finally, *Formal_Debt_Decision* is determined by the following equations:

$$Formal\_Debt\_Proposal \;=\; IF(Formal\_Cash\_Availability \;<=\; 10000 \ll USD \gg, 1, 0) \tag{18}$$

$$\begin{aligned} Formal\_Debt\_Decision \\ &= Formal\_Debt\_Proposal \;*\; (PULSE(Single\_Formal\_Debt\_Amount, \\ &STARTTIME + Formal\_Debt\_Period, Formal\_Debt\_Period)\,) \end{aligned} \tag{19}$$

4.5.4 Stock-Flow Diagram of the Dynamics within the Informal Sector and Its Decision-Making Structures

The generic stock-flow diagram of the dynamics in the informal sector is presented in Figure 23. In this figure, the stock of *Informal_Workers* is increased by *Employment_Rate* and decreased by *Unemployment_Rate*. *Employment_Rate* depends on *Desired_Employment_Rate,* which is influenced by *Desired_Additional_Informal_Workers, Informal_Employment_Decision,* and *Time_to_Adjust*. The equations of this relationship are as follows:

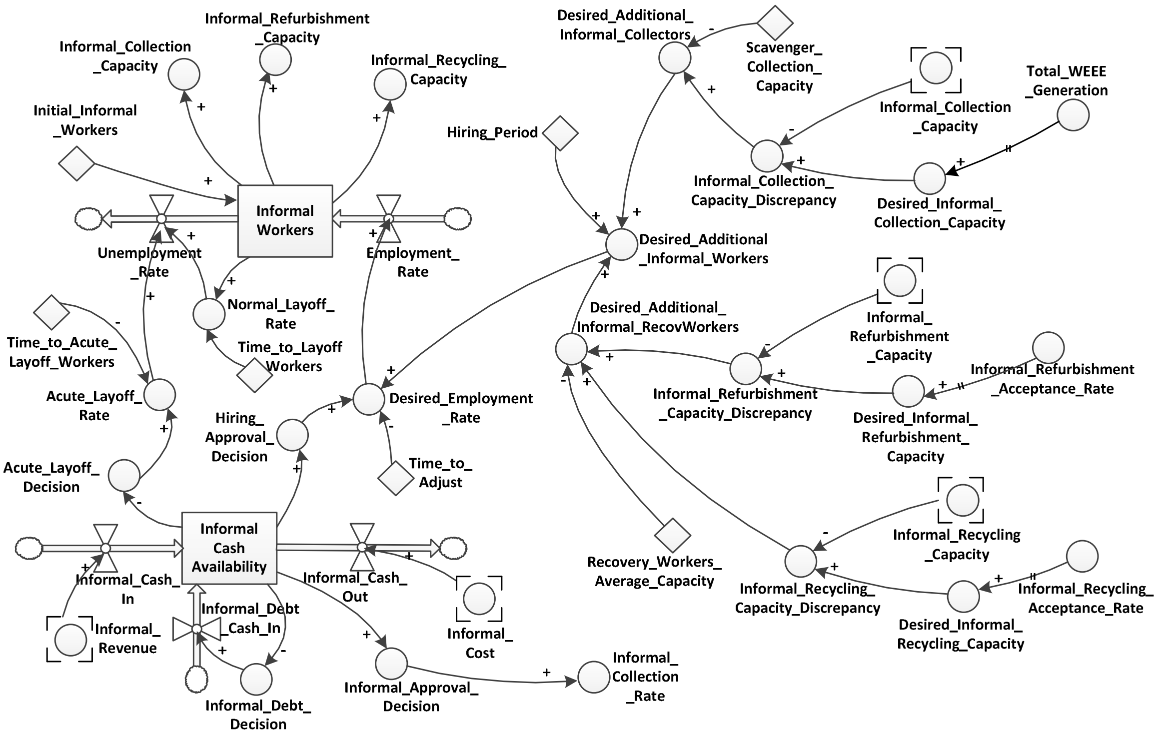

Figure 23. The Generic Stock-Flow Diagram of the Dynamics within the Informal Sector

$$Desired\_Employment\_Rate = (Desired\_Additional\_Informal\_Workers\ /\ Time\_to\_Adjust) * (Hiring\_Approval\_Decision) \quad (20)$$

$$Desired\_Additional\_Informal\_Workers = PULSE((Desired\_Additional\_Informal\_Collectors + Desired\_Additional\_Informal\_RecovWorkers), STARTTIME + Hiring\_Period, Hiring\_Period) \quad (21)$$

Furthermore, *Unemployment_Rate* comprises two types of layoff: (1) *Normal_Layoff_Rate,* which is influenced by *Time_to_Layoff_Workers,* and (2) *Acute_Layoff_Rate,* which is affected by *Time_to_Acute_Layoff_Workers* and *Acute_Layoff_Decision.* Figure 23 also illustrates the financial structure of the informal sector. *Informal_Cash_Availability* is influenced by *Informal_Revenue* and *Informal_Cost.* Subsequently,

$Informal\_Cash\_Availability$ affects $Informal\_Collection\_Rate$ through $Informal\_Approval\_Decision$. Total revenue and total cost faced by the informal sector are simply calculated from:

$$Informal\_Revenue = Value\_per\_Informal\_Refurbished\_Product * Secondary\_Sales\_Rate + Value\_per\_Informal\_Recycled\_Product * Informal\_Recycling\_Rate \quad (22)$$

$$Informal\_Cost = Informal\_Refurbishment\_Cost * Informal\_Refurbishment\_Rate + Informal\_Recycling\_Cost * Informal\_Recycling\_Rate + Informal\_Wage * Informal\_Workers \quad (23)$$

Unlike its formal counterpart, the model of the informal sector incorporates four decision-making processes (Figure 24). These processes are affected by a declining state and a limited stock of informal cash availability. First, if the level of the informal cash diminishes, the informal sector would adjust their collection operations and approval of the regular employment through $Informal\_Approval\_Decision$ and $Hiring\_Approval\_Decision$, subsequently. Second, if the limited state of the cash occurs, the informal sector would activate two measures to save the sector from being bankrupt, i.e. through $Acute\_Layoff\_Decision$ and $Informal\_Debt\_Decision$. Similar to the debt decision in the formal sector, $Informal\_Debt\_Decision$ attempts to give the informal sector a chance to reappear if this sector goes bankrupt. Figure 24 captures the detailed stock-flow diagram of these decision-making structures.

Here, the declining state of $Informal\_Cash\_Availability$ is tracked by $Informal\_Cash\_Ratio$. These decision structures are represented as follows:

$$Expected\_Informal\_Cash\_Availability = DELAYINF\ (Informal\_Cash\_Availability, a\_EIC, 3, Informal\_Cash\_Availability) \quad (24)$$

$$Informal\_Cash\_Ratio = IF(Informal\_Cash\_Availability <= 0 \ll USD \gg , 0, Informal\_Cash\_Availability / Expected\_Informal\_Cash\_Availability)$$

(25)

$$Informal\_Cash\_Ratio\_Effect\_on\_Routines = IF\ (Informal\_Cash\_Ratio > 1,\ 100 << \% >>, GRAPH)$$

(26)

$$Hiring\_\_Approval\_Decision = Informal\_Cash\_Ratio\_Effect\_on\_Routines$$

(27)

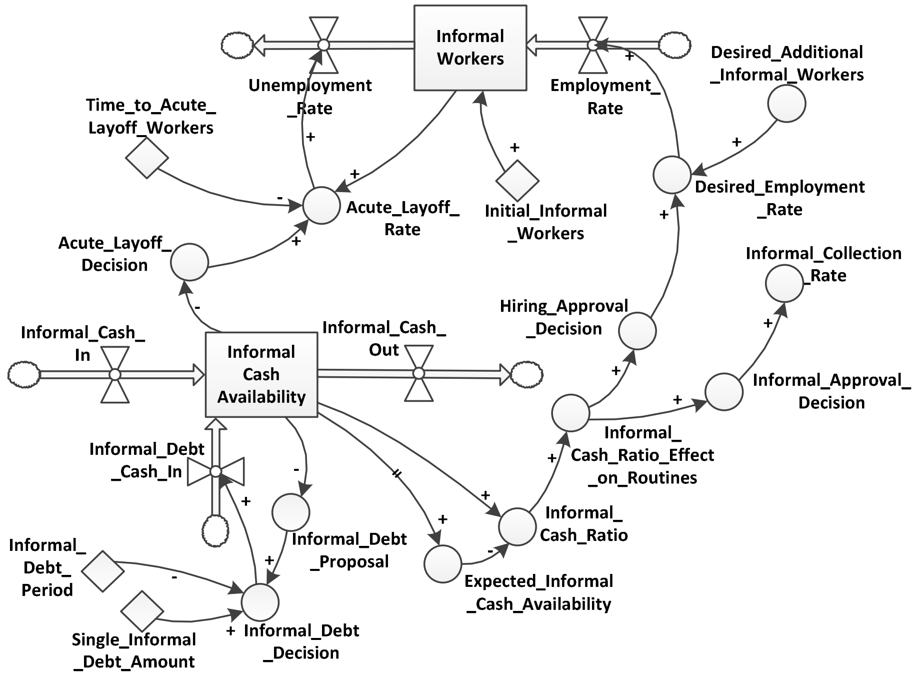

Figure 24. The Decision-Making Structures based on the Level of Informal Cash Availability

$$Informal\_Approval\_Decision = Informal\_Cash\_Ratio\_Effect\_on\_Routines$$

(28)

GRAPH function in equation 26 also refers to the figure 22. Here, the informal sector is assumed to behave insensitively on its cash availability.

Finally, the decision-making structures in the informal sector are complemented by *Acute_Layoff_Decision* and *Informal_Debt_Decision.* In this structure, if the declining state passed a certain low level of *Informal_Cash_Availability*, this sector would activate both of these decisions. The equations of these relationships are as follows:

$$Acute\_Layoff\_Decision = IF\ (Informal\_Cash\_Availability < 10000 << USD >>, 1, 0) \quad (29)$$

$$Acute\_Layoff\_Rate = (MAX\ ((Informal\_Workers\ /\ Time\_to\_Acute\_Layoff\_Workers), 0)) * Acute\_Layoff\_Decision \quad (30)$$

$$Informal\_Debt\_Proposal = IF(Informal\_Cash\_Availability <= 10000 \ll USD \gg, 1, 0) \quad (31)$$

$$Informal\_Debt\_Decision = Informal\_Debt\_Proposal * (PULSE(Single\_Informal\_Debt\_Amount, STARTTIME + Informal\_Debt\_Period, Informal\_Debt\_Period)) \quad (32)$$

4.6 Formal Model Formulation and Testing

This study employs the data from Switzerland and India to assess the behavior of the model under consideration. Swiss and India systems are selected because of the following reasons:

- Past authors have already developed the foundation of the international comparison between Switzerland and India. Widmer et al. (2005) provide a graphical comparison of WEEE management systems in the selected countries, including the Swiss and the Indian systems. Wath et al. (2010) propose a development roadmap of WEEE management in India in light of the best practice of the Swiss system. Ongondo et al. (2011) select Switzerland and India as part of the country examples in their global review of current WEEE management practices.
- The existence of relatively huge scientific works in WEEE from each of the countries.
- The characteristics of both countries provide a solid basis to contrast two different WEEE management systems. The differences occur in the market condition of electronic products (saturated and growing), the existence of recovery systems (well-developed and developing), the enactment of WEEE-specific regulation (well-developed and developing), the absence of regulation (short and long-term period), and the existence of informal sectors (none to very small and huge).

4.7 Data Gathering and Parameter Setting

This research utilizes and synthesizes data from various sources to assess the behaviors of the model subject to the purpose of the study, including published scientific papers, published reports, census data, and regulation text. The data is treated, adapted and modified if necessary. To estimate the parameter of innovation fraction (p) and adoption fraction (q) in the Bass Model, this study conducts the GRG non-linear method in Excel Solver using historical sales of personal computers (PCs) stocks and penetration rate in Switzerland and India from 1988 to 2008. The data was received from the corresponding author of Yu et al. (2010b) via personal contact and enriched by additional data taken from the International Telecommunication Union (ITU).

In conducting non-linear method estimation, this study adopts the steps from Lim et al. (2012) as follows. First, sign constraints are inserted on p and q. The initial value of p and q were taken from the work of Dewan et al. (2010), working with the analysis of global PC diffusion. For the market potential, the value was taken from the population data from the census. Second, the Excel Solver was run to estimate p and q, aiming to minimize the sum of the squared difference between the historical and the calculated data. The estimated p and q, then, were transferred to the SD model to run the simulation. Table 11 provides the selected parameter values for the developed country and developing country model, respectively.

4.8 Model Testing

This sub-section incorporates the model testing steps taken from Sterman (2000). First, a model boundary adequacy and structure assessment tests were conducted through literature reviews and a set of colloquia. These tests clarify the importance of incorporating the informal sector as an endogenous element in the model. Second, the study inspected directly the mathematical equations behind the model to assess the dimensional consistency and found no suspect variables. Third, to reveal flaws in the model and to assess its robustness, the extreme condition test was performed by putting an extreme value to several selected variables. For instance, if there were no innovative adopters at the beginning of life-cycle, i.e. *Innovation_Fraction* is “0”, there would be no adopters of the products in all of the life-cycles; thus sales rate would remain on zero level through the entire simulation horizon. Additionally, if the domestic users had disposed none of the WEEE and at the same time there is no imported WEEE from developed countries, the number of informal workers would never grow.

Table 11. Parameter Values for Model Testing

Variable	Description	Value for the Developed Systems	Value for the Developing Systems	Data Source
Innovation_Fraction	Coefficient of Innovation in Bass Model	0.0161	0.0002	Yu et al. (2010b)
Adoption_Fraction	Coefficient of Imitation in Bass Model	0.2112	0.3113	
Distribution_on_First_Year (%)	Percentage of products that obsolete in the first year of usage period	0	0	Yu et al. (2010b)
Distribution_on_Second_Year (%)	Percentage of products that obsolete in the second year of usage period	5	0	
Distribution_on_Third_Year (%)	Percentage of products that obsolete in the third year of usage period	15	0	
Distribution_on_Fourth_Year (%)	Percentage of products that obsolete in the fourth year of usage period	15	20	
Distribution_on_Fifth_Year (%)	Percentage of products that obsolete in the fifth year of usage period	65	70	
Distribution_on_Sixth_Year (%)	Percentage of products that obsolete in the sixth year of usage period	0	10	
Initial_Collection_Percentage and *Initial_Recycling_Percentage (%)*	Collection and recycling percentage at the beginning of simulation period	5	5	Authors' own assumption
Legislative_Collection_Percentage (%)	Collection percentage imposed by regulation	85	85	EU WEEE Directive 2012

Table 11. Parameter Values for Model Testing (continued)

Variable	Description	Value for the Developed Systems	Value for the Developing Systems	Data Source
Legislative_Recycling_ Percentage (%)	Collection percentage imposed by regulation	75	75	EU WEEE Directive 2012
Time_without_Legislation (Years)	The gap time between the start of simulation and the time when the WEEE legislation finally comes into force	6	20	For Swiss: from the gap between 1988 (the start of simulation period) and 1994 (the year when SWICO was founded), for Indian: authors own estimation
Time_to_Achieve_ Collection_Target and *Time_to_Achieve_ Recycling_Target (Year)*	The gap time required by the systems to comply with regulation after the enactment of legislation	15	20	For Swiss: SWICO Recycling (2008), for Indian: authors' own estimation
Secondary_Products_ Residence_ Time (Years)	Time of second-hand EEE to become obsolete	2	3	Dwivedy and Mittal (2010b)
Second_Hand_Product_ Demand (Unit / week)	Weekly demand for second-hand PC in reuse market	266	5502	Streicher-Porte et al. (2005)
Formal_Collection_Cost (Dollar / Unit)	Cost per collected WEEE	3	10	For Swiss: SWICO (2008, 2010, 2012, 2013, 2014), for India: Liu et al. (2009)
Value_per_Refurbished_ Product (Dollar / unit)	Revenue per refurbished product sold in formal channel	204.3	204,3	ebay.ch, renewit.in
Refurbishment_Cost (Dollar / unit)	Cost per product for recovery activities in the formal channel	164	164	local.which.co.uk
Value_per_Informal_ Refurbished_Product (Dollar / unit)	Revenue per refurbished product sold in market	286.366	286.366	Streicher-Porte et al. (2005)
Informal_Refurbishment_ Cost (Dollar / unit)	Cost per product for recovery activities in informal channel	172.05	172.05	Streicher-Porte et al. (2005)
Value_per_Formal_ Recycled_Product (Dollar / unit)	Revenue of recycled material per product in the formal channel	10.51	10.51	Streicher-Porte et al. (2007)

Table 11. Parameter Values for Model Testing (continued)

Variable	Description	Value for the Developed Systems	Value for the Developing Systems	Data Source
Formal_Recycling_Cost _per_Product (Dollar / unit)	Cost per product for recycling activities in the formal channel	3	6	For Swiss: SWICO (2007, 2008, 2009, 2010, 2011), For Indian : Liu et al. (2009)
Value_per_Informal_ Recycled_ Product (Dollar / unit)	Revenue of recycled material per product in the informal channel	5.35	5.35	Streicher-Porte et al. (2007)
Informal_Recycling_ Cost_ per_Product (Dollar / unit)	Cost per product for recycling activities in the informal channel	3	3	Streicher-Porte et al. (2007)
Initial_Informal_Workers (Workers)	The number of informal workers in the beginning of simulation period	671	28215	For Swiss: Ramusch et al. (2015), For India: Chikarmane et al. (2008)
Informal_Wage (USD / month)	The salary for an informal worker	15	15	Duan and Eugster (2007), Vats and Singh (2014), Ramusch et al. (2015)

Fourth, a numerical integration test was carried out to assess the acceptability of the selected integration method, i.e. Euler integration. Euler method is selected because it is simple and sufficient in the modeling of human and social systems, as in the case of the models under study (Sterman, 2000). The test was executed by choosing a time step one-fourth of the smallest time constant and running the model. After that, the time step was cut to half, and the model was run again. The result showed no significant differences between the observed behaviors. Hence, it can be concluded that the use of Euler integration is adequate.

Finally, a behavior reproduction test was done to assess the ability of the model to reproduce the historical time series or reference modes. This research selects *Primary_Product_Adopters* and *Total_WEEE_Generation* as the main indicators. First, the test compared *Primary_Product_Adopters* with the historical data of Swiss PC stock from 1990 – 2008 for the developed country model and of Indian stock from 1990 – 2005 for the developing country model (Figures 25 and 26). With Mean Absolute Percentage Error (MAPE) of 8.04% and 20.71% for the former and the latter, the models showed fairly good predictive ability in this particular variable (Table 12). The high level of bias and variation components derived from Theil Inequality

Statistic test seem to indicate that both models contain a systematic error for corresponding the model point-by-point with data (Sterman, 2000). Also, it is found that the MAPE of the developing country model is still relatively high. However, this study suffices the behavior reproduction test because of the following arguments: (1) the aim of incorporating the Bass Model in the SD models is simply to generate the typical behavior mode of the diffusion process which has been achieved, (2) the developing country model used fewer data points in the parameter estimation process, as compared to the developed one, and (3) India has limited penetration level of PCs in the society. Our study further compared the behavior of *Total_WEEE_Generation* with the results from other studies dealing with Swiss and Indian PC waste generation (Dwivedy and Mittal, 2010a, 2010b; Streicher-Porte, 2006). This assessment test found that the SD model produced similar modes with the reference studies as partly shown in Table 13.

Table 12. Historical Fit

Parameter	MAPE	R-Square	Bias	Unequal Variation	Unequal Covariation
Primary_Product_Adopters in the Developed Country Model	8,04%	0,993229	0,509481	0,232249	0,25827081
Primary_Product_Adopters in the Developing Country Model	20,71%	0,997659	0,283018	0,703377	0,0136051

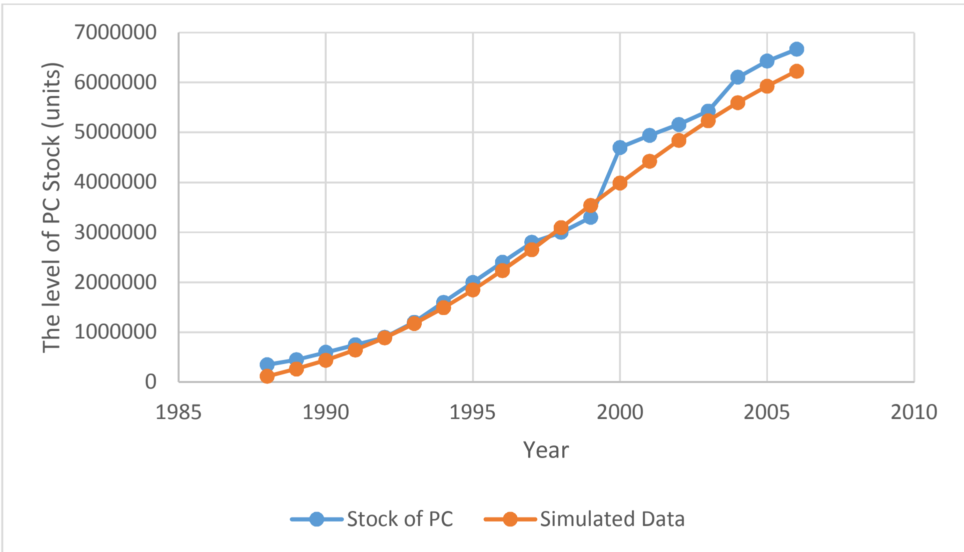

Figure 25. Comparison between Historical and Simulated Data of Swiss PC Stock

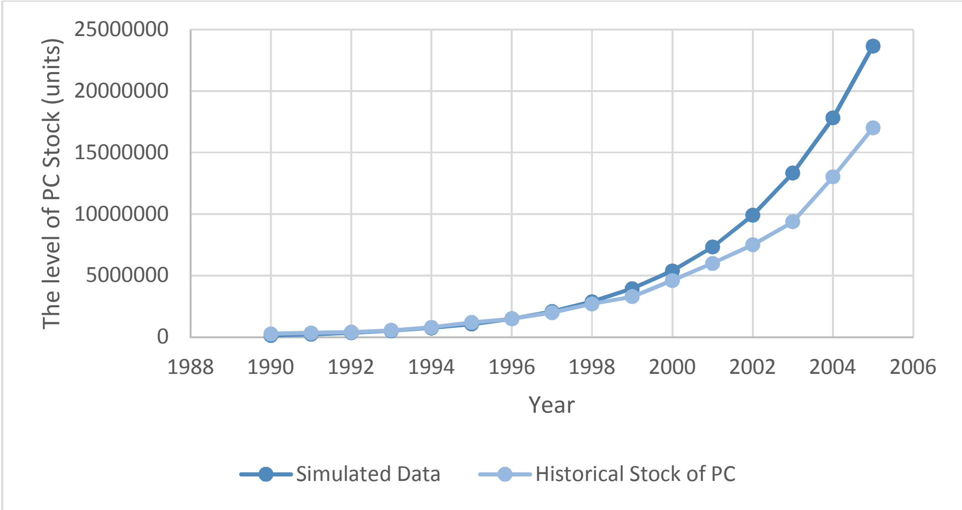

Figure 26. Comparison between Historical and Simulated Data of Indian PC Stock

Table 13. Comparison between Estimated Values of the Developing Country Model and the References

Parameter	*Total_WEEE_Generation*[a] - in units	Estimated Obsolete PC Generation (Dwivedy and Mittal, 2010b)[b] – in units	Estimated Obsolete PC Generation (Dwivedy and Mittal, 2010a)[c] - in units
Estimated Value for 2010	11.34 million	10.66 million	5.52 million
Estimated Value for 2015	31.28 million	52.58 million	-
Estimated Value for 2020	54.55 million	79.98 million	-
Estimated Value for 2025	70.68 million	92.14 million	-

[a]Desktop PC and Notebook PC, considering no store phase

[b]Desktop and Notebook PC, considering store phase

[c]Desktop PC only, considering no store phase. The store phase is showed separately.

4.9 Simulation Analysis

Simulation analysis consists of the base case and the scenario analysis. Different assumptions were put in each of them. The SD models were simulated using *Powersim* 10 ® for 30 years of the simulation period. Then, the results were analyzed using several selected indicators. As a further note, the simulation analysis considers two different kinds of flow in the recovery process of the informal sector (please refer to the section of the reverse logistics sub-model of the informal sector, especially the differences appeared in figure 16 and 18).

4.9.1 Base Case Analysis

In the base case analysis, this study runs the model using the basic parameters from table 11. One should note that one important parameter is relaxed in this particular analysis: *Second_Hand_Product_Demand* is assumed to have constant value during the entire simulation horizon. This assumption aims to assess how would the system behave if the secondary market for used products is stagnant.

4.9.1.1 Base Case Analysis for the Developed Country Model

Figures 27 to 31 exhibit the behavior of selected indicators in the base case analysis for the developed country model.

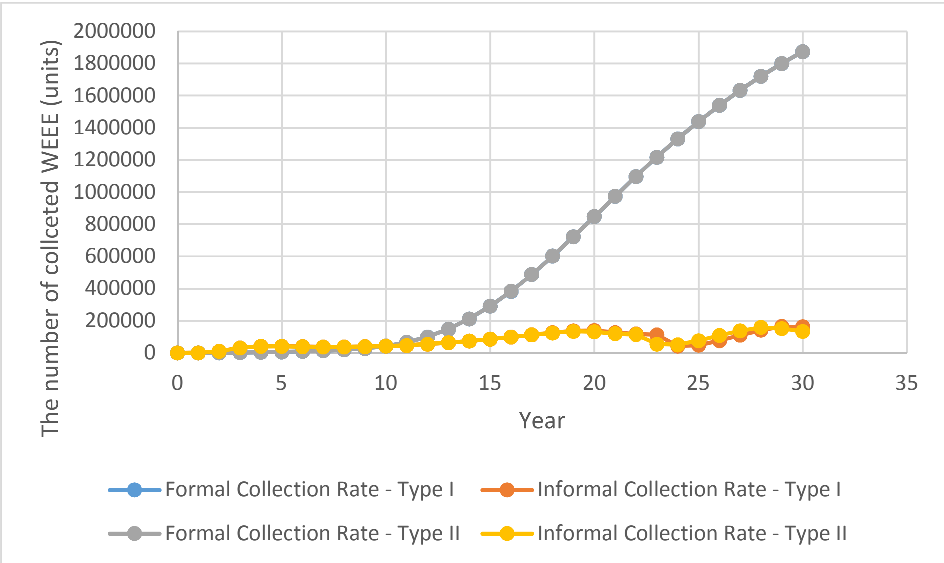

Figure 27. Comparison between *Formal_Collection_Rate* and *Informal_Collection_Rate* in the Base Case Analysis for the Developed Country Model
(the blue dots and line overlap with the gray ones)

Figure 27 highlights the domination of the formal sector over its informal counterpart. At the beginning, the informal sector collected waste in a relatively high number in the initial period. While the formal one only collected around 22,096 units, the informal sector could gather up to

124,400 units. However, the latter could not anymore afford its leading after the first decade, starting its lag behind the formal collection. The collection rate of the former increased significantly in the remaining years, enjoying 24.58% of compound annual growth rate (CAGR). Whereas the latter only grew at the level of 6.13% per year up to the 20th year of the simulation period. In the last decade, the collection rate of the informal sector oscillated, reflecting the presence of an instability period. As a further note, there are no significant differences in the systems' behaviors under the Type I and Type II of the recovery processes,

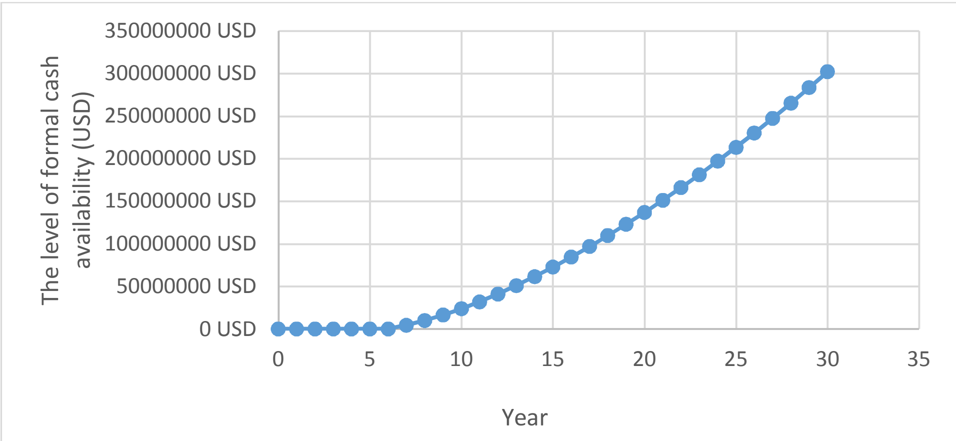

Figure 28. The Level of *Formal_Cash_Availability* in Base Case Analysis for the Developed Country Model

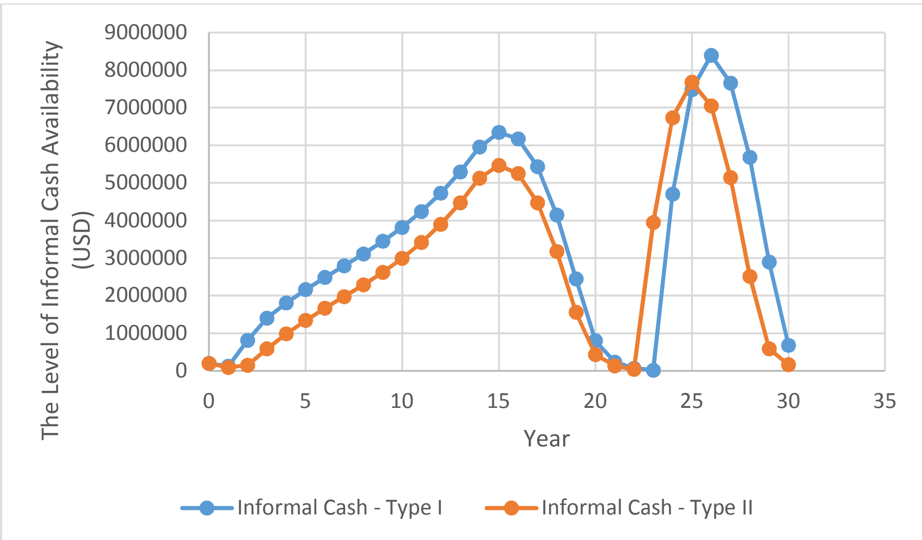

Figure 29. The Level of *Informal_Cash_Availability* in Base Case Analysis for the Developed Country Model

Figures 28 and 29 depict two different behaviors of the formal and the informal cash availability: the general increasing state of cash for the former and the unstable nature of the latter (recognize also the different scales on the y-axes.). For the formal cash availability under Type I and II of the recovery process, the increasing state appears at the same level with 48.59% of average annual growth rate, as shown in figure 28. For the informal cash availability, the systems oscillate, showing an extreme nature of running the informal WEEE business in the developed systems. Being more specific, an early increasing state appears in the informal cash between the third and the 15th year of the simulation period, with 17.99% of average annual growth rate for the systems under the case of Type I and with a slightly lower level under Type II. This condition, however, would not stand forever as eventually, the informal sector faces the first declining state of the cash stock, diminishing its level by an average level of 44.61% per year – under Type I - up until the 23rd year. Soon, the informal sector adjusts the number of its workers (Figure 30). Hence, the level of informal cash climbs up again, only to face another crash, with a decreasing rate of 40% per year. The informal cash level under the case of Type II produces a similar nature of behavior as well. It appears that the stagnant nature of *Second_Hand_Product_Demand* influences the presence of these two crashes, limiting the growth of the informal sector. This notion will be further discussed within the base case of the developing country model.

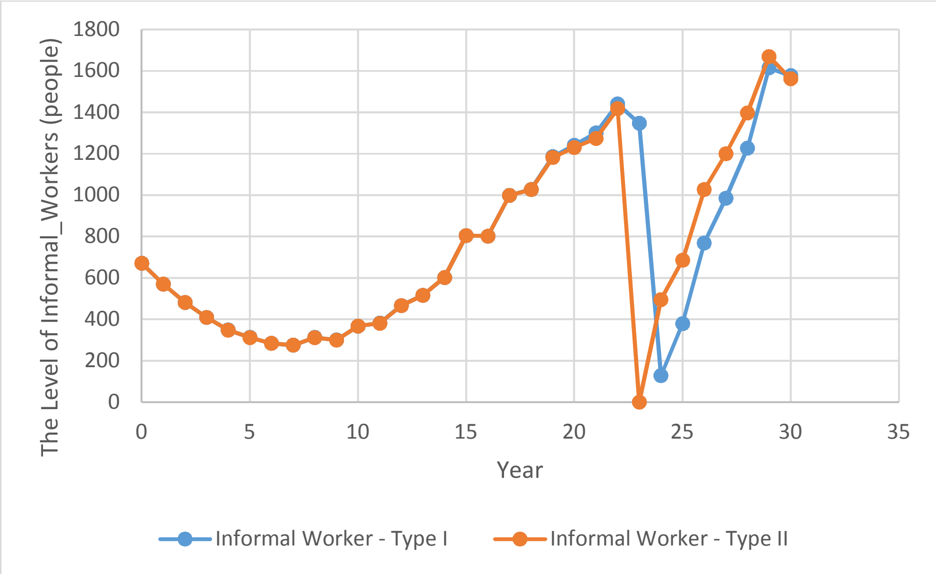

Figure 30. The Level of *Informal_Workers* in Base Case Analysis for the Developed Country Model

Figure 30 illustrates an unstable nature of the informal workforces in the developed country systems. The informal sector starts its initial years with the adjustment to the level of the workforces, considering then the limited presence of waste in the society. Soon, the level of waste disposal increases, influencing this sector to rehire the workers. The increasing rate from the lowest level until the highest peak of the informal workforces stands around 13% of average annual growth rate. However, the informal sector could maintain its growth only for a very short period. Eventually, this sector faces a limited condition of cash (in Figure 29), forcing the informal sector to conduct a rapid layoff of its workers in the 24th year of simulation under the case of Type I and in the 23rd year under the case of Type II.

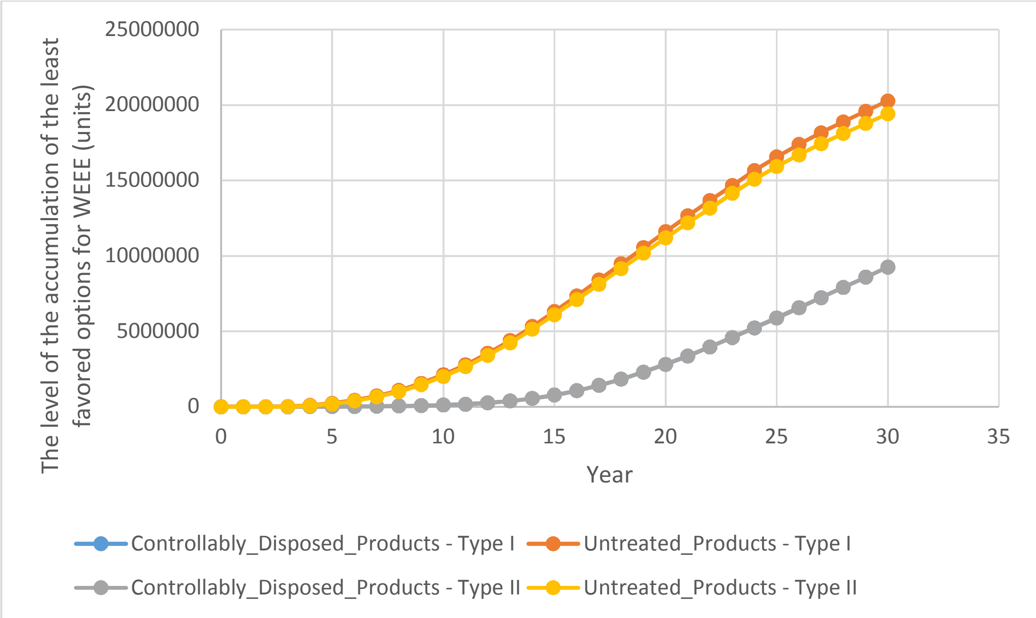

Figure 31. Comparison between *Controllably_Disposed_Products* and *Untreated_Products* in Base Case Analysis for the Developed Country Model
(the blue dots and line overlap with the gray ones)

Lastly, figure 31 depicts the least favored disposal options from the formal and the informal sector in the developed country systems. For the first five years, 3,700 and 66,000 units of waste entered the final stocks of the formal and informal sector, respectively. Then, the increasing state emerges at both sides, with 32.18% and 21.32% of average annual growth rate for the former and the latter under the case of Type I of the recovery process. The systems under Type II behaves similarly as well. Here, the high and increasing level of *Untreated_Products* confirms the reality in the developed countries in which the significant number of the WEEE were not treated according to the compliance of the regulations, e.g. exported to the developing countries or thrown to the mixed bin (Huisman et al., 2015).

4.9.1.2 Base Case Analysis for the Developing Country Model

Figures 32 to 36 illustrate the results of the annual WEEE collection rate, the availability of formal - informal cash, the number of informal workers, and the final disposal destinations of the waste in base case analysis for the developing country model.

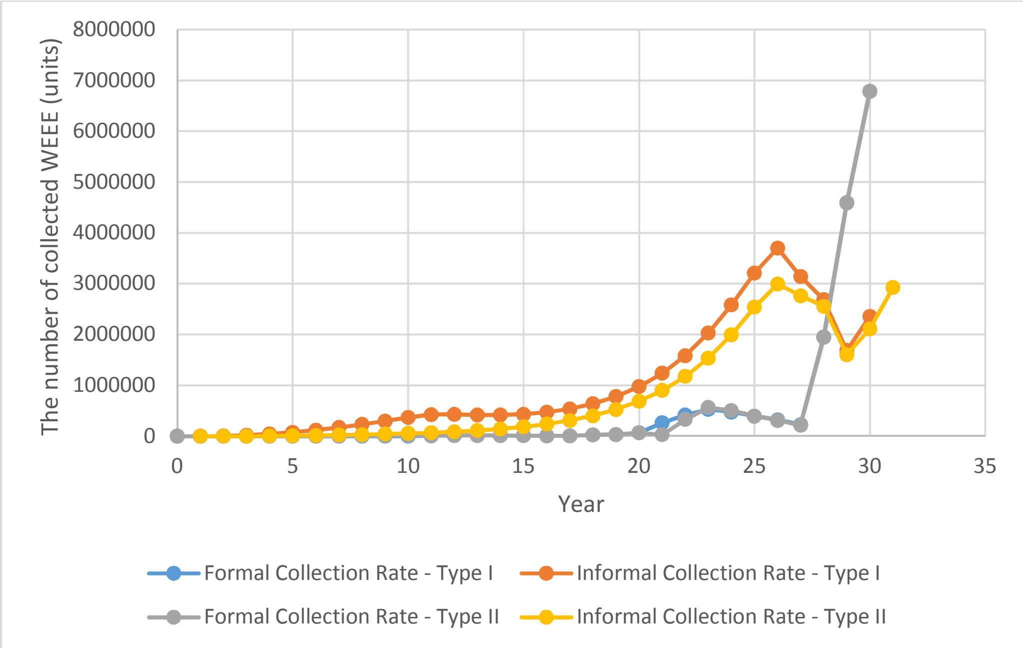

Figure 32. Comparison between *Formal_Collection_Rate* and *Informal_Collection_Rate* in Base Case Analysis for the Developing Country Model
(the blue dots and line overlap with the gray ones)

In general, figure 32 illustrates a domination of the informal sector in collection activities for almost all of the simulation period. From the beginning up to the 26^{th} year, the informal sector, on the one hand, gathers a significant number of WEEE, with the average growth of 35.5% per year under Type I of the recovery process and with a slightly lower level under Type II. The formal sector, on the other hand, faces a shortage of input in the first decade and gathers only a limited number of WEEE in the next 15 years. Not until the 28^{th} year, finally, the formal collection rate increases rapidly and outperforms the level of its counterpart in the ongoing years. This phenomenon happens at the time when the formal sector finally has a support from the WEEE-specific legislation, enforcing this sector to develop the collection capacity. Practically, it implies that the formal sector in the developing countries requires a relatively long period to establish itself and finally finds its way to becoming a dominant player in the collection.

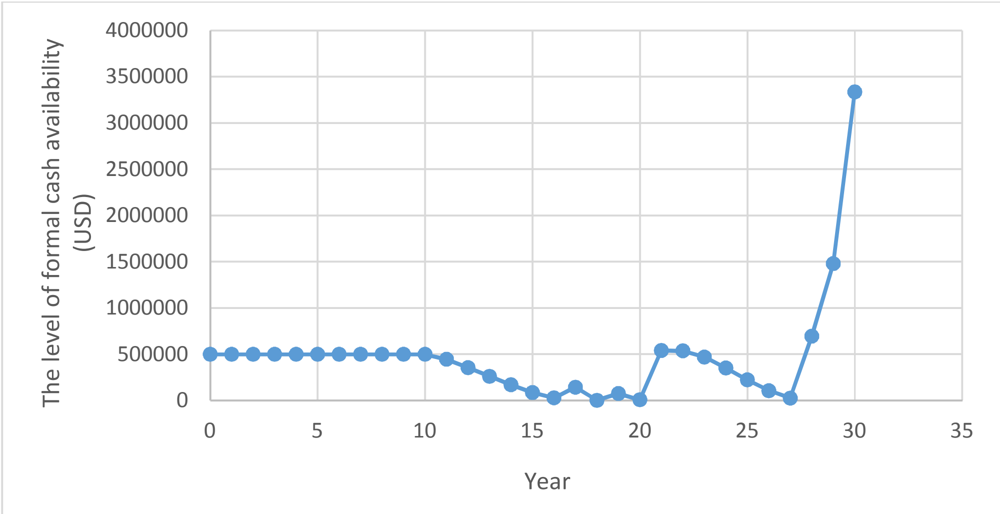

Figure 33. The Level of *Formal_Cash_Availability* in Base Case Analysis for the Developing Country Model

Figure 33 exhibits the behavior of the formal cash availability under Type I and II of the recovery processes. Being unable to collect WEEE, the level of the cash remained stagnant in the first decade of the simulation period. When the number of obsolete products finally raises up in the society, this sector increases the collection activities. Counterintuitively, this growing operation, in general, declines the stock of formal cash until the last year of the second decade. The beginning of the third decade marks the end of *Time_without_Legislation,* thus, the formal sector finally is driven to expand its activities. This sector eventually finds its way to becoming profitable in the 28th year. For the last note, the formal sector has utilized three million US dollars of the formal debt during the simulation period to keep the business active.

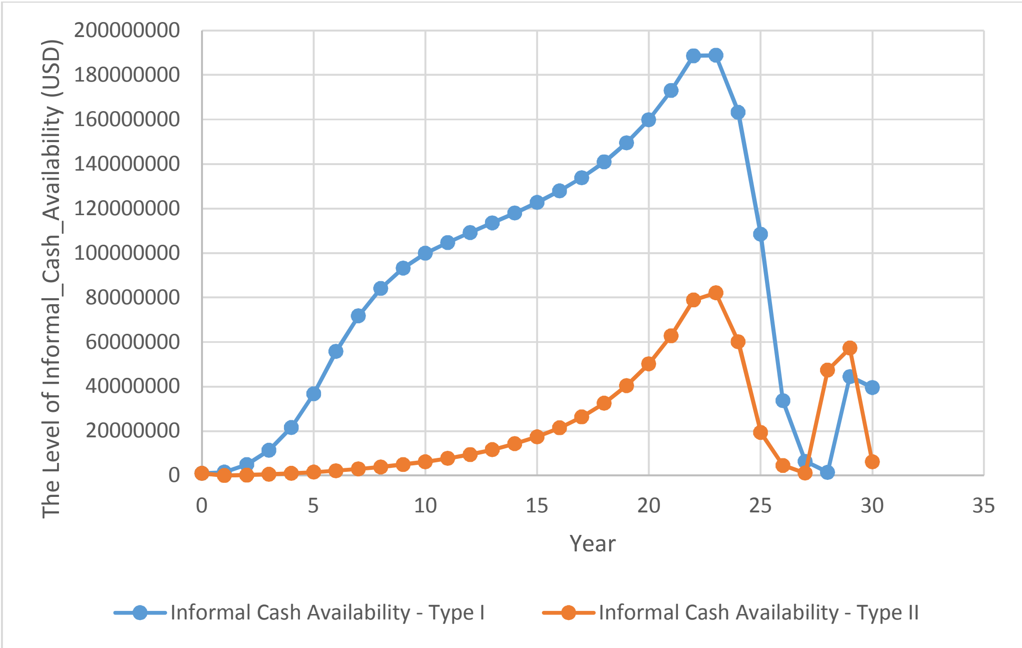

Figure 34. The Level of *Informal_Cash_Availability* in Base Case Analysis for the Developing Country Model

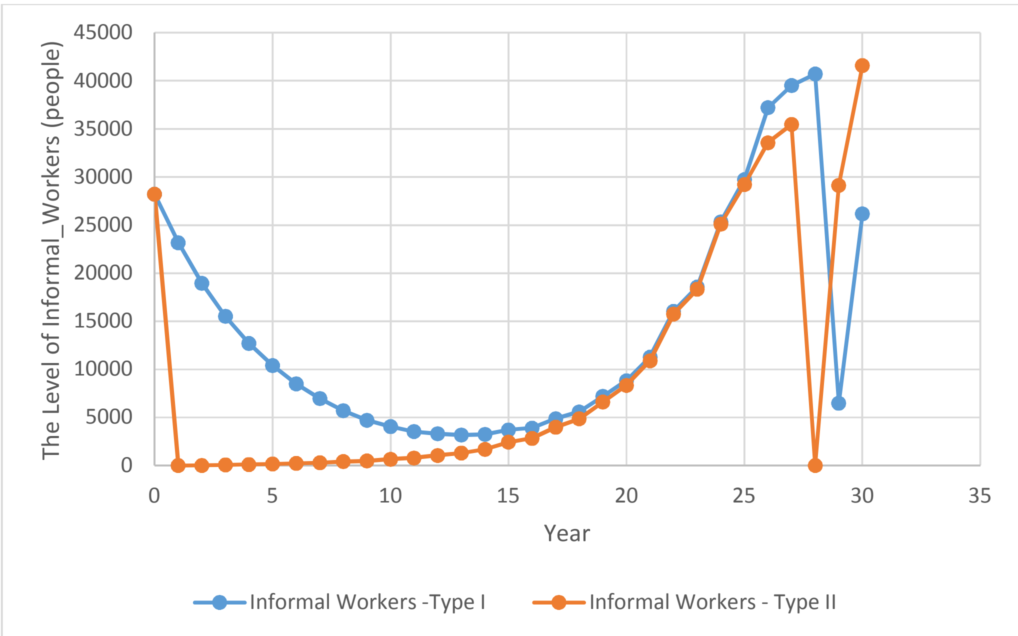

Figure 35. The Level of Informal_Workers in Base Case Analysis for the Developing Country Model

Figures 34 and 35 depict interesting behaviors of the informal sector dealing with its finance and workforces. At the beginning, this sector has too many workers with a still limited number of available waste in the society. Hence, it slowly adjusts the level of workers to keep its cash safely, right at the earlier years. Afterwards, the informal actors find out that finally, there are so many disposed of WEEE coming from domestic disposal and illegal import. The informal sector decides to change its direction, expanding its work and rehiring the workers and even more. The employment rate grows continuously up to the 28^{th} year, in average with the growth level of 19.1% and 18.65% per year for the systems under Type I and Type II of the recovery process, respectively.

However, the continuous growth would not last forever in the base case analysis of the developing country model, as figure 34 shows clearly that there is a limit in the informal growth. After the rapid growth in the first three-quarters of the simulation period, the level of informal cash reaches a peak level and starts to decline drastically. Being insensitive with the cash level, the informal actors realize that the workers' adjustment should reappear and finally does the massive layoff at the 29^{th} and 28^{th} year for the systems under Type I and Type II, respectively, to save the business. Type II of the recovery process gives a lower level of profitability to the informal sector, but its magnitude is still much higher when it is compared with the level of formal cash availability.

A joint examination of the sub-models, especially on "Dynamics within the Informal Sector", shows that the constant level of *Second_Hand_Product_Demand* appears to be the limit of the informal growth. While the cost continues to rise because of the increasing state of the recovery operations and employment activities, the constant demand restricts the revenue. Hence, the loop dominance shifted from the reinforcing to the balancing state and, inevitably, the informal sector would face its failure. For the last point, the informal sector has accessed the informal debt by 150,000 US dollars during the entire simulation period.

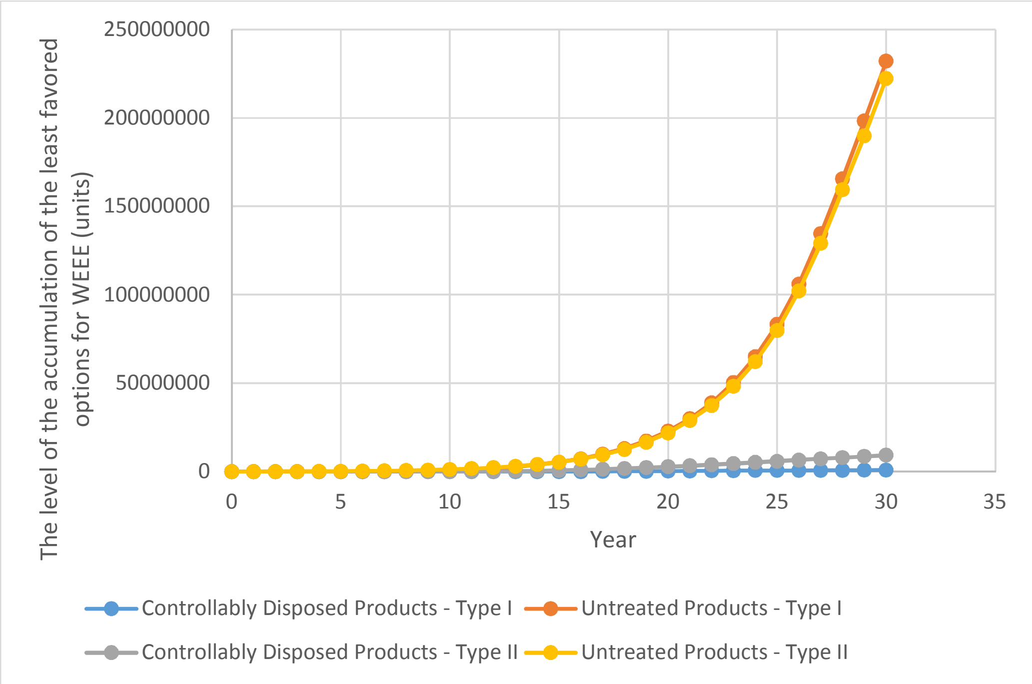

Figure 36. Comparison between *Controllably_Disposed_Products* and *Untreated_Products* in Base Case Analysis for the Developing Country Model

Finally, the results in figure 36 demonstrate a rapid growth of the *Untreated_Products* during the entire horizon; while at the same time, the formal disposal, *Controllably_Disposed_Products,* remains in the limited state. On the one hand, the level of *Untreated_Products* emerges significantly with the average growth rate of over 50% per year. On the other hand, the formal disposal has just started to climb up after the fifth year and continues to a stable annual increasing state.

4.9.2 Scenario Analysis

Scenario analysis is developed to investigate the effect of changes in parameter values and model structure. Particularly, this analysis aims to assess the influence of growing the second-hand market to the behaviors the systems. It is carried out by giving a minor modification to the structure of *Second_Hand_Product_Demand*, so its value will grow every year (Figure 37).

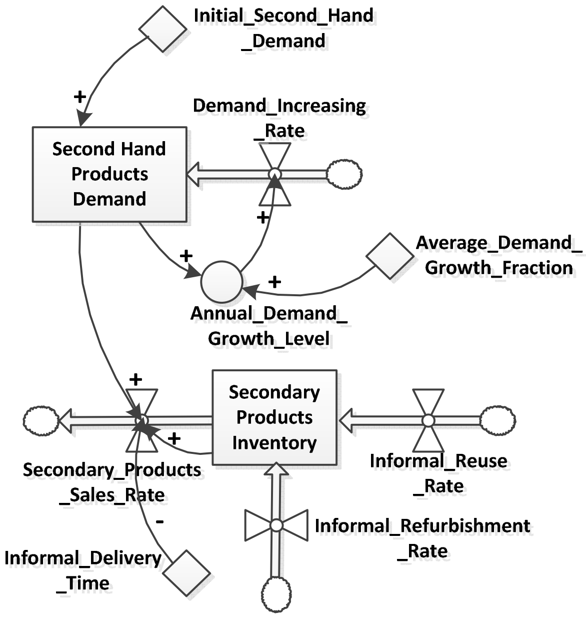

Figure 37. The Structure of *Second_Hand_Product_Demand* in Scenario Analysis

Instead of being a constant, *Second_Hand_Products_Demand* is treated as stock and increased by *Demand_Increasing_Rate.* This rate depends on *Annual_Demand_Growth_Level*, calculated from the current level of *Second_Hand_Product_Demand* and annual growth rate of the secondary market (*Average_Demand_Growth_Fraction*). This study follows Suryani et al. (2010) that added random exponential distribution to the average demand growth in their case. The equation of the growth rate is as following:

$$Demand\_Increasing\_Rate\ = Annual\_Demand\_Growth\_Level \quad (33)$$

$$Annual\_Demand\_Growth\_Level = Second\_Hand\_Products\_Demand * (Average\_Demand\_Growth\_Fraction\ + EXPRND(1 \ll \%/year \gg)) \quad (34)$$

"EXPRND (1 <<%/year>>)" is used as a command in *Powersim* ® to generate random numbers that are exponentially distributed with 1% as the mean value.

To implement this scenario, the study employs a growth rate of 12% and 15% per annum for *Average_Demand_Growth_Fraction* in the developed and the developing country model, respectively. The former value was estimated from the growth of used PC market in the United States, as appeared in Williams et al. (2008). The latter one was taken from a report published by the Associated Chamber of Commerce and Industry of India about the market for second-hand and recycled products (ASSOCHAM, 2014). One should pay attention to the nature of these values. For the former, it is mentioned that there was no follow-up study to assess the nature of used PC market and an indication that this market has suffered by the declining PC price (Williams et al., 2008). For the latter, the value is generic in nature since the specific number for second-hand PC market was not found elsewhere.

4.9.2.1 Scenario Analysis for the Developed Country Model

Figures 38, 39, and 40 illustrate the comparison of the selected behaviors from the stagnant and the growing used market in the developed country systems.

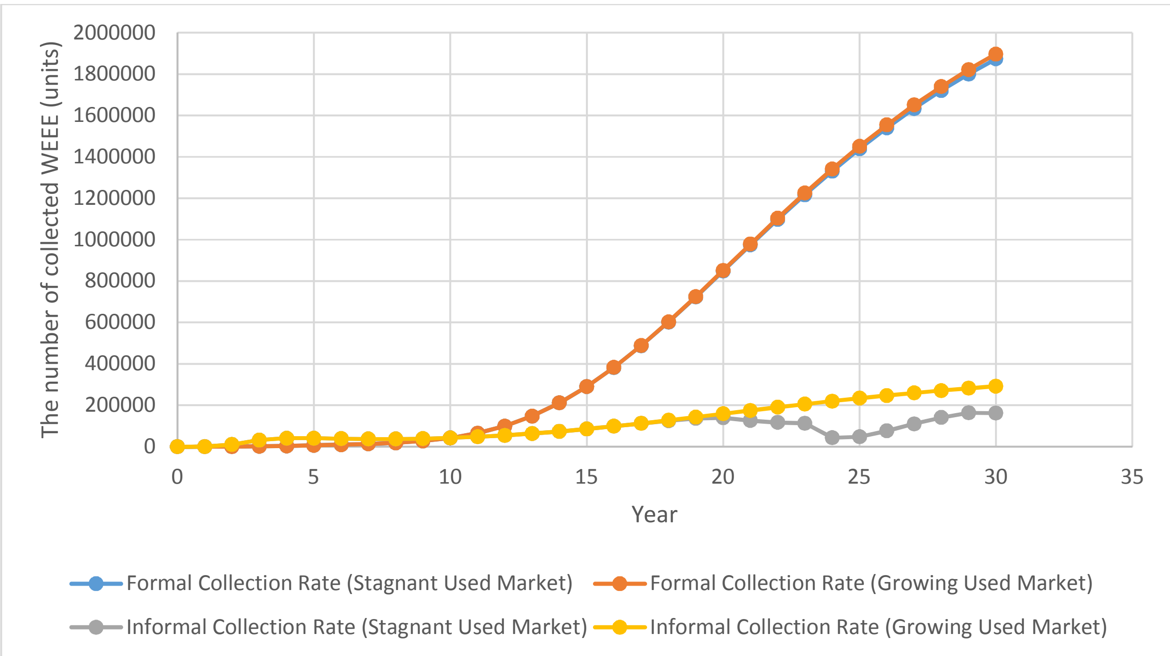

Figure 38. Comparison of Collection Activities between Stagnant and Growing Used Market in the Developed Country Model
(in this graph, the blue line and dots overlap with the orange ones)

In general, figure 38 shows an increasing state of the formal and informal collection in the growing secondary market, albeit with different levels of growth under Type I of the recovery process. Both in the stagnant and the growing used market, the formal sector controls the collection activities in all of the simulation horizon, collecting the waste up to five times higher than its informal counterpart. Figure 38 also captures a merely minor difference in the behaviors of the formal collection in these two cases of the secondary market. Hence, it implies that the nature of the second-hand market has no influence on the level of the formal collection in the developed country model. On the contrary, it appears that the lucrativeness of the secondary market impacts the level of informal collection. The informal collection rate seems to be firmer in the growing secondary market rather than in the stagnant one. However, this influence would not change the fate of the informal sector as the inferior collection actor in the developed country systems. As a further note, the collection rates behave almost in the same nature under Type II of the recovery process.

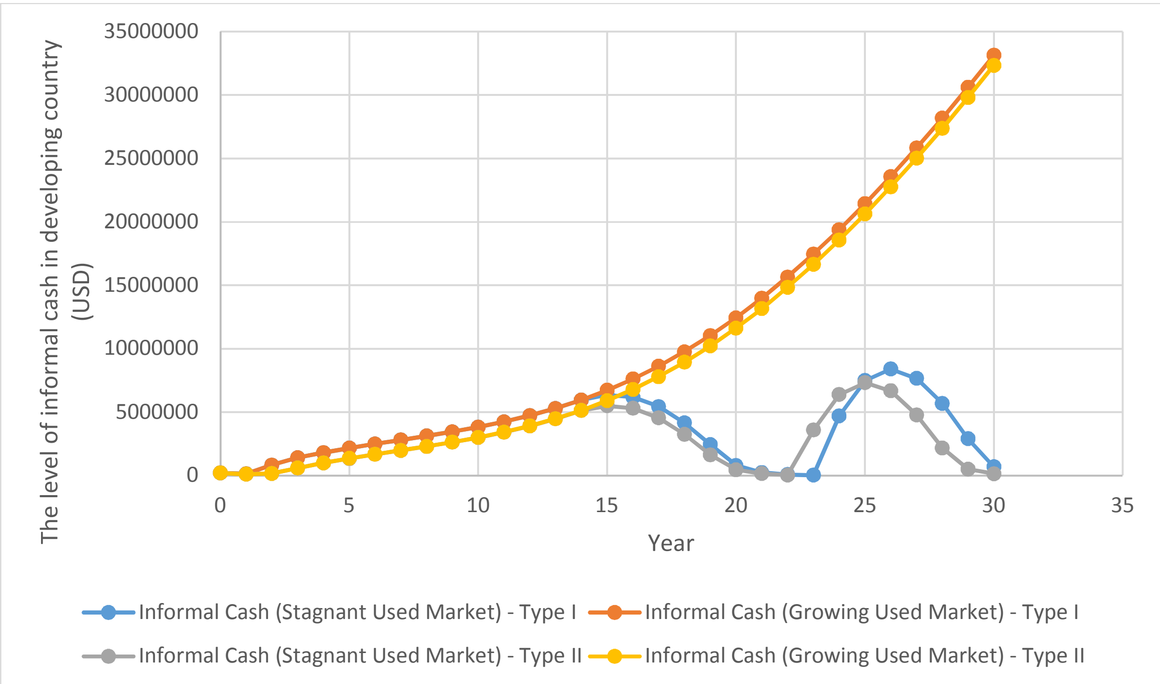

Figure 39. Comparison of the Level of *Informal_Cash_Availability* between Stagnant and Growing Used Market in the Developed Country Model

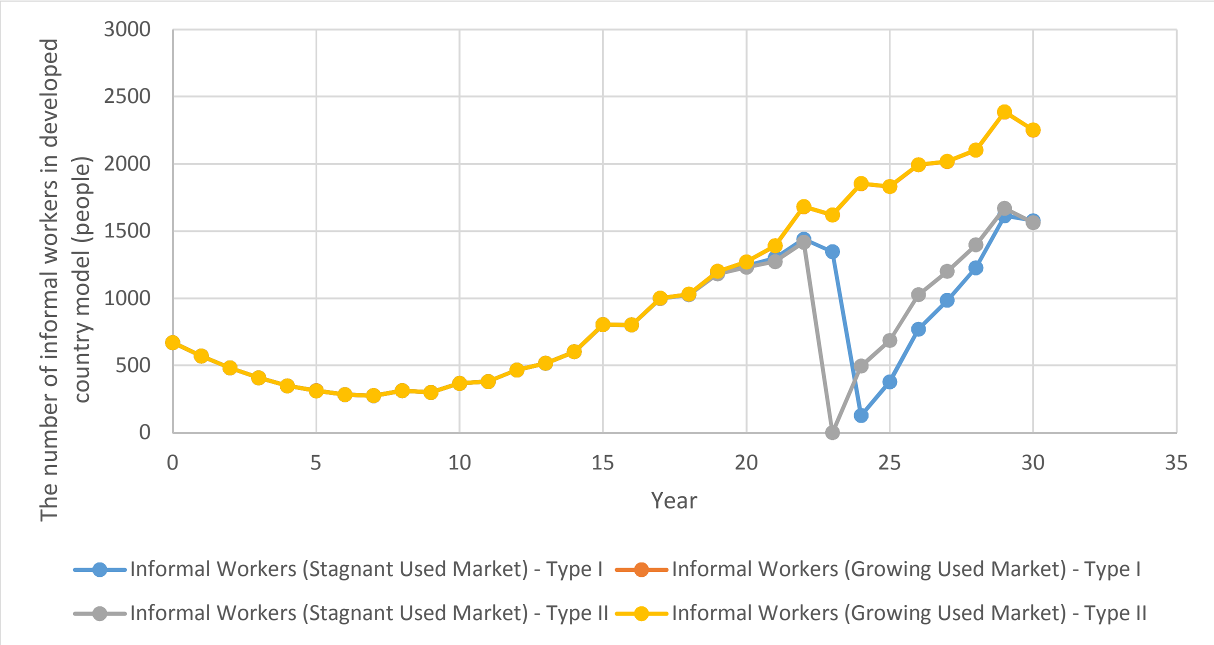

Figure 40. Comparison of the Level of *Informal_Workers* between Stagnant and Growing Used Market in the Developed Country Model

Figures 39 and 40 show the increasing state of informal sectors in the growing used market. In this kind of market, the number of informal cash grows on the average level of 32.4% and 27.3% under Type I and Type II of the recovery process, respectively. For the level of informal workers, the growing rate appeared at a lower level, around 7% of annual average growth level for Type I and Type II, respectively. In contrast to the growing case, this study observes the unstable nature of the informal business in a stagnant market as the level of informal cash fluctuated and the informal workforces have experienced a rapid drop in the last decade of simulation horizon. Here, it can be concluded that the secondary market impacts the level of the informal cash and workers, even in the developed country systems.

4.9.2.2 Scenario Analysis for the Developing Country Model

Figures 41, 42, and 43 represent the comparison of the selected behaviors from the stagnant and the growing used market in the developing country systems.

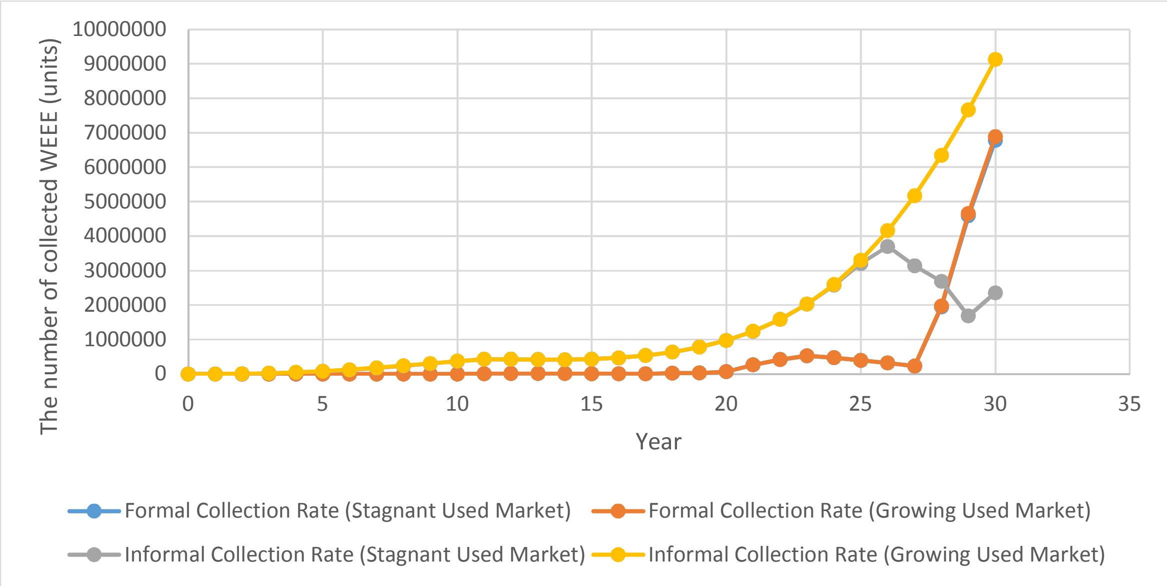

Figure 41. Comparison of Collection Activities between Stagnant and Growing Used Market in the Developing Country Model

(in this graph, the blue line and dots overlap with the orange ones)

Initially, figure 41 shows the indifferent fate of the formal collection in the stagnant and growing used market under the case of Type I of the recovery process. This condition suggests that the condition of the used market has no direct influence on the behavior of the formal collection. On the contrary, the informal collection produced similar behaviors only until the 25th year for both cases. At the 26th year, the informal collection behaves differently. While it continues to grow in the growing case, the collection level reaches its peak and then declines afterwards under the stagnant one. The collection rates also behave similarly under Type II. This phenomenon implies that the secondary market affects the behavior of informal collection in the developing country. A more detailed examination is required to answer why the formal collection behaves indifferently, even though its informal counterpart changes its direction during the last five years. It appears that the first rapid rise of the formal collection has just occurred after *Time_without_Legislation* ceased to exist. In this time, the number of obsolete products is already too high, even the full capacity of the informal sector could not handle all of the waste. At the same time, the formal collection could only gather a limited amount of waste because the formal capacity has not yet reached the full capacity.

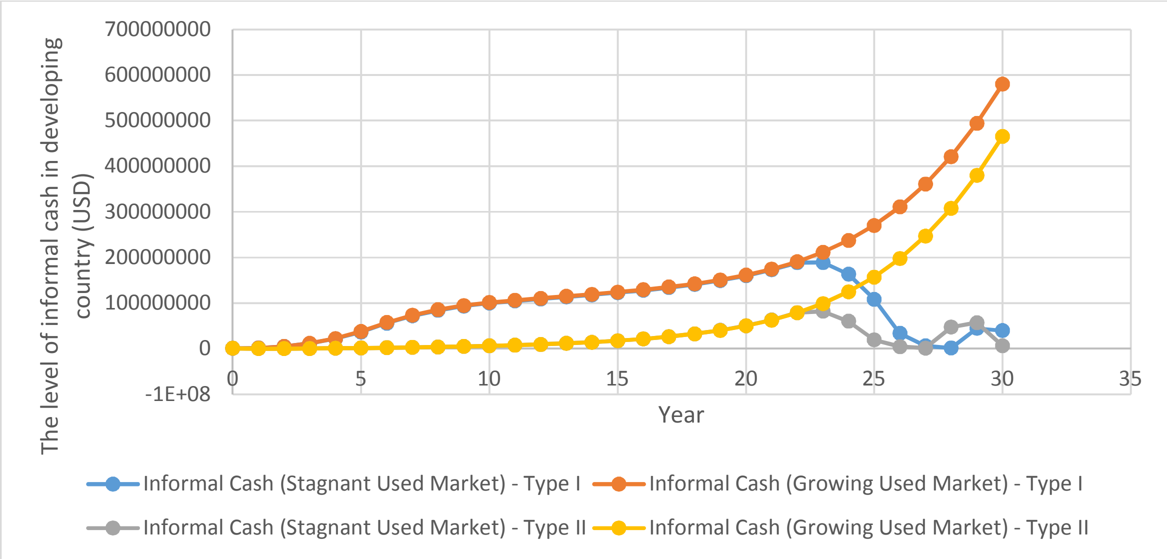

Figure 42. Comparison of the Level of *Informal_Cash_Availability* between Stagnant and Growing Used Market in the Developing Country Model

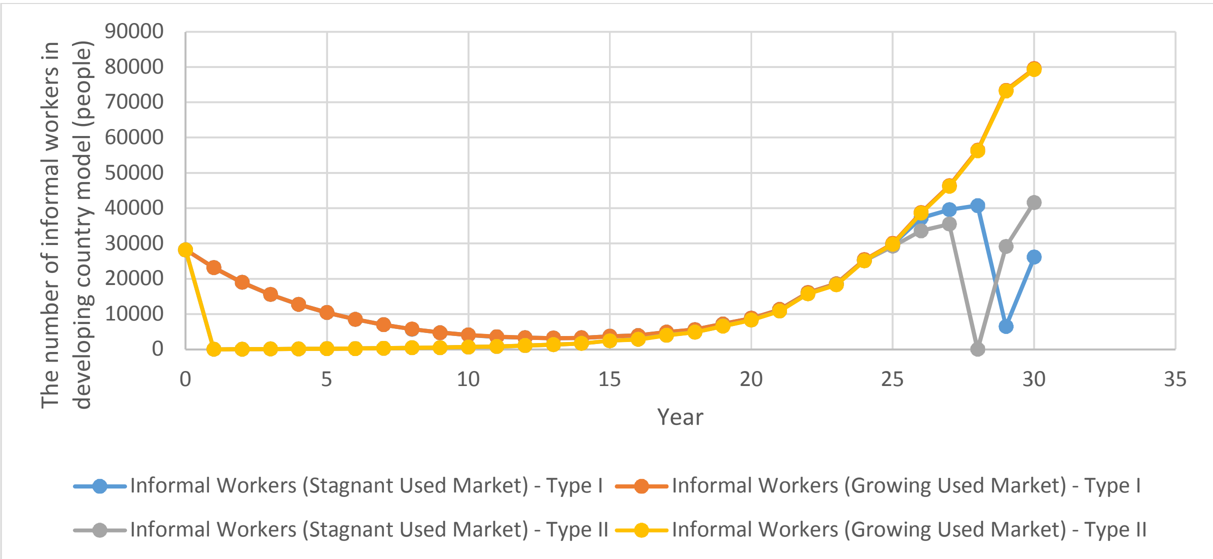

Figure 43. Comparison of the Level of *Informal_Workers* between Stagnant and Growing Used Market in the Developing Country Model

Figures 42 and 43 depict the lucrative nature of the informal sector in the growing used market, as compared with the appearance of a growth limit in the stagnant used market. The informal cash grows steadily at the average level of around 30% per year in the growing case for Type I and Type II of the recovery process. On the contrary, this study observes a collapse of the informal cash under stagnant market at the 24th year. It falls during the next three consecutive years, pushing the informal actors to acute layoff the workers between the 28th and 29th year and 27th and 28th year under Type I and Type II, respectively. These conditions suggest that the nature of the secondary market influences the level of the informal cash and workers.

4.10 Comparing the Behavior of the Systems in the Developed and Developing Country Model

This section attempts to highlight several differences which have appeared in the previous sections. Tables 14 and 15 emphasize this comparative perspective, both in the stagnant and in the growing secondary market cases.

Table 14. Comparison between the Behaviors of the Systems in the Developed and in the Developing Country Models in the Case of the Stagnant Used Market

Variable for Comparative Indicator	Generic Behavior in the Case of Stagnant Used Market	
	in the Developed Country Model	In the Developing Country Model
Formal_Collection_Rate	a generic increasing state	An absence in the first decade, a stagnant state in next 15 years, and an exponential growth in the last five years
Formal_Cash_Availability	a generic increasing state	A stagnant in the first decade, an unstable nature in the next 15 years, and an exponential growth in the last five years
Informal_Collection_Rate	Limited growing state in the first two decades & oscillation in the last decade	a generic increasing state for the first 25 years and an unstable state in the years onward
Informal_Cash_Availability	The presence of two oscillations shape	a generic increasing state over two decades and a steep declining state with a small recovery in the last decade
Informal_Workers	U-curve shape for the first half of period and an oscillation shape for the last period	U-curve shape for the first 25 years and a steep declining state with a small recovery in the last decade
Controllably_Disposed_ Products	a generic increasing state	An absence in the first five years and a generic increasing state, albeit limited, in the remaining years
Untreated_ Products	a generic increasing state	a generic increasing state with a relatively higher level

Table 15. Comparison between the Systems Behavior in the Developed and in the Developing Country Models in the Case of the Growing Used Market

Variable for Comparative Indicator	Generic Behavior in the Case of Growing Used Market	
	in Developed Country Model	in Developing Country Model
Formal_Collection_Rate	a generic increasing state	An absence in the first decade, a stagnant state in next 15 years, and an exponential growth in the last five years
Informal_Collection_Rate	a generic increasing state, albeit limited	a generic increasing state
Informal_Cash_Availability	a generic increasing state, albeit limited	a generic increasing state
Informal_Workers	U-curve shape for the first half of period and an oscillation shape for the remaining one	U-curve shape for the first half of period and a generic increasing state for the remaining one

The formal sector enjoys its steady increasing state and dominance in the collection activities in the developed country model whereas this sector suffers from limited collection rate in the developing country case. It appears that the preference to dispose the waste to either formal / informal channel provides a landscape for the emergence of a different behavior. The formal recycling business becomes profitable in the former systems, as compared to the appearance of the limited cash for many years in the latter.

Moreover, though the influence of the stagnant used market similarly limits the growth of the informal sector in both systems, it is somehow fair to say that the informal sector might reach a higher level of collection rate, profitability, employment if they operate within the structure of the developing systems. Here, the informal sector maintains its lucrative state for a long period, whereas the formal systems require relatively long to finally become profitable. It is even clearer when this study analyzes the growing secondary market to the systems: the informal sector enjoys its continuous growth during all of the simulation period.

The phenomena mentioned in the previous paragraph indicate that the conditions in the second-hand market significantly affect the existence of the informal sector. Particularly, the second-hand market appears as both the limit (when it is constant) and the leverage of the informal growth (when it is growing) for the informal sector in the developing country. On the practical level, the results confirm the influential position of the second-hand market as the determinant for the informal WEEE recycling in the developing countries, as can be seen in the cases of India and

China (Manomaivibool, 2009 and Chi et al., 2011). However, one should be careful to generalize the impact of the secondary market in the developed countries, especially when one attempts to compare the results with the reality. This notion appears because of the fact that the studies on the informal sector and the secondary market in the developed systems remain limited, especially if they become exclusive only for the WEEE-specific theme. In the developed systems, the formality and the good law enforcement generally take place as the norms, potentially blocking the means for the informal sector to flourish. It is also unclear whether the secondary market – which absorbs the goods produced from the informal sector – might truly and significantly exist within the developed countries, as the purchasing power remains high to adopt the current or even future innovation of EEE.

Finally, the final disposal options in the both regions require more attention from the stakeholders. The long absence of the formal systems and the huge existence of the informal sector in the developing countries provide the landscape for the continuous growing state of the illegal disposal. These results confirm the alarming nature of the illegal landfilling in this region. While the model under study had incorporated no limit into its disposal stocks; in reality, landfill capacities, either secure landfill sites or backyard landfills, are limited and will be exhausted in the foreseeable future. Also, the significant level of the accumulation of the least favored disposal options in the developed countries, i.e. exporting to the developing region and throwing in the mixed bin, implies that the huge proportion of the WEEE volume were not treated according to the compliance. Hence, the policy makers should promote the ways to increase the official collections, e.g. collection points through retailers and post services, and tighten the flow of the WEEE leaving the developed systems.

Chapter 5 An Enhanced Quantitative Approach: Factorial Design – Analysis of Variance (ANOVA) and Policy Analysis

The selected numerical analysis in this chapter aims to extract the determinants within the developed and developing country model. Initially, Factorial Design from Design of Experiment (DoE) is used to determine the factors and the levels that will be further analyzed. Then, an extensive number of experiments are performed through simulation. To achieve the aim in this stage, the simulation results are further analyzed using Analysis of Variance (ANOVA). Here, the analysis only considers Type I of the recovery process to assess the dynamics of the systems in responding the idealized situation of the informal sector.

5.1 Factorial Design and ANOVA

This section attempts to identify the influential factors that impact the behaviors of WEEE management systems. Particularly, it aims to extract the significant variables within the developed and the developing country models under study. To achieve this objective, the study employs the 2^n Factorial Design and ANOVA analysis.

5.1.1 The Framework for Factorial Design and ANOVA

This study proceeds with the steps of Design and Analysis of Simulation Experiment procedure (Lorscheid et al., 2012) as follows:

a. *Determining the factors to be observed.* This study incorporates ten factors as the independent variables for the analysis. These ten factors are captured from the constant variables which exist within the System Dynamics models. Each factor has two levels: low and high. The values of low and high levels are derived 50% lower and 50% higher than the parameter values in the base case analysis. Table 16 shows the selected factors, levels, and values for the analysis.

Table 16. Selected Independent Variables with the Values for Factorial Design and ANOVA

Variable	Applied in		Description	Value for Developed Country		Value for Developing Country	
	Developed Country Model	Developing Country Model		Low Level	High Level	Low Level	High Level
Ratio between *Initial_Informal_Workers* per *Initial_Population* - *Ratio_Worker_per_Population* (dimensionless)	v	v	The ratio between the number of informal workers and total population at the beginning of simulation period.	0,00005	0,00015	0,0001	0,0003
Time_without_Legislation (year)	v	v	The length of period when the WEEE-specific regulation was absent in the systems	3	9	10	30
Time_to_Achieve_Collection _Target (year)	v	v	The length of period for the systems to comply with the collection target imposed by the regulation	7,5	22,5	10	30
Fixed_ARF / *Recycling_Subsidy* (USD / product)	v	v	The amount of recycling fee / subsidy per product	3	9	5	15
Scavenger_Collection_Capacity (unit / week /worker)	v	v	The collection capacity of a waste picker	2	6	2	6
Formal_Collection_Cost (USD / product)	v	v	The amount of collection cost per product	1,5	4,5	5	15
Formal_Recycling_Cost (USD / product)	v	v	The amount of recycling cost per product	1,5	4,5	3	9
Refurbishment_Acceptance _Percentage (%)	v	-	The level of reuse / refurbishment acceptance in the formal systems	0,025	0,075	-	-
Initial_Collection_Percentage (%)	v	v	The level of formal collection at the beginning of the simulation	0,025	0,075	0,025	0,075
Time_to_Layoff_Workers (year)	v	v	The job duration for informal worker	1	3	2,5	7,5
Average_Import_Growth _Fraction (% / year)	-	v	The annual growth level of illegal WEEE import	-	-	5	15

b. *Determining the response variables*. This study includes the following six dependent variables as the indicators of the systems' behavior. They are *Formal_Collection_Rate, Formal_Cash_Availability, Informal_Collection_Rate, Informal_Cash_Availability, Informal_Workers,* and *Untreated_Products.*

c. *Developing 2^{10} Factorial Design with Replication.* This study utilizes the Minitab Software ® to create design points, containing the factor level combinations to be simulated. Since there exist ten variables with two replications for each model (this study has two models), altogether the number of experiments that should be executed is:

$$2^{10} * 2 * 2 = 4096 \text{ experiments}$$

d. *Running the Experiment.* Each experiment order created by the previous step was executed by inputting the combined variables into the System Dynamics models with the growing used market assumption and simulating the model for 30 years as the simulation horizon. The outcomes of the response variables are recorded in a separate worksheet.

e. *Analyzing ANOVA Results.* All recorded data then were imported again to the Minitab software. This study proceeds with the ANOVA using 95% as the confidence level. Prior to the analysis, three ANOVA assumptions are checked. These assumptions include normality, constant variance, and independence assumptions. If these assumptions were satisfied, this study proceeds by examining the R^2, representing the proportion of systematic variance explained by the selected ten factors, and the p-values. Then, the results are interpreted using the following perspective which will be mentioned in the beginning of the next section.

5.1.2 The Results of ANOVA

The utilization of ANOVA will reveal the significant individual factors and interactions between two factors (i.e. two-way ANOVA) existing within the models. If any factor or any interaction between two factors have a p-value < 0.05, this factor / interaction will be considered as a significant / main / influential / decisive effect. If any interaction is considered as a significant one, the impact of one individual effect to the response variable depends on the level of another factor. Such case requires a comprehensive assessment of both the significant individual effects and the significant interaction effects.

In general, there are two types of significance. The first type considers any factor or interaction that would inevitably be considered as "significant" on a particular response variable. This significance happens because the independent variables are connected directly each other with the response variable in the structure of the model. In other words, both of them form a chain of cause-effect relationship. Hence, the significance would be obvious to emerge. For instance, table 17 informs the reader that three independent factors from within the formal sector, i.e. *Time_without_Legislation, Time_to_Achieve_Collection_Target,* and *Initial_Collection_Percentage* appear as the significant individual factors for the response variable *Formal_Collection_Rate.* Since the complete calculation of *Formal_Collection_Rate* requires the values from the three aforementioned variables, this kind of result is expected. The second type deals with any main effect which appeared in a non-direct cause-effect relationship.

If the latter type of significance appeared, this study would attempt to place a deeper analysis. It is because of the fact that such significance plays a unique role in the behavior of the systems, i.e. how this kind of factor / interaction could be significant to a particular variable even though they are not connected directly within the models. This study also concerns to three other situations: (1) a significant individual factor which requires no other variable to influence the response variable, (2) a significant interaction formed by at least one insignificant variable (any variable which was absent in the following tables), (3) a significant interaction constructed by variables from the opposite sector, e.g. when a particular independent variable within the structure of informal sector influences the response variable of the formal one.

5.1.2.1 The Results of ANOVA for the Developed Country Model

Tables 16 to 21 show the significant individual factors and the significant interaction within the developed country case, influencing each of the response variables. Here, it appears that there is a relatively limited number of significances, as later compared with those from the developing systems, thus suggesting the stable nature of the developed systems.

Table 17. ANOVA Results for Significant Individual Factors and Interactions for *Formal_Collection_Rate* in the Developed Country Model

Response Variable	**Significant Variable**	**Adjusted MS**	**F**	**P-Value**
Formal_ Collection_Rate	*Time_without_Legislation*	7,20765E+17	116347.48	0.000
	Time_to_Achieve_Collection_Target	1,14074E+19	1841405.22	0.000
	Scavenger_Collection_Capacity	5,48468E+16	8853.49	0.000
	Initial_Collection_Percentage	1,18547E+16	1913.60	0.000
	Time_to_Layoff_Workers	1,3526E+16	2183.40	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Time_without_Legislation * Time_to_Achieve_Collection_Target*	7,02E+17	113279.63	0.000
	*Time_without_Legislation * Initial_Collection_Percentage*	5984357981	96.6	0.000
	*Time_to_Achieve_Collection_Target * Scavenger_Collection_Capacity*	7785766494	125.68	0.000
	*Time_to_Achieve_Collection_Target * Time_to_Layoff_Workers*	1,16E+16	1879.99	0.000
	*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*	1,24E+16	2007.56	0.000

First, table 17 indicates five significant individual main effects which affect *Formal_Collection_Rate*, Furthermore, each of the main individual effects also forms all the significant interactions. There exist two significant interactions formed by the variables within the formal sector, two significances coming from the cross-sectors interaction, and one main interaction appeared from the variables within the informal sector. A further look at the main interaction suggests that the variables within the formal sector, i.e. *Time_without_Legislation, Time_to_Achieve_Collection_Target,* and *Initial_Collection_Percentage* significantly influences *Formal_Collection_Rate*, depending on the other factors. As has been mentioned before, this kind of relationship would be definitely important for the response variable. Furthermore, the relationship between *Time_to_Achieve_Collection_Target* and *Formal_Collection_Rate* depends on the value of two variables within the informal sector, i.e. from *Scavenger_Collection_Capacity* or *Time_to_Layoff_Workers.* In practical terms, if the scavenger has a higher capacity or the informal sector has a longer job duration, a long term to achieve the collection target would significantly hold the level of *Formal_Collection_Rate.*

Also, the interaction between *Scavenger_Collection_Capacity* and *Time_to_Layoff_Workers* has a significant impact on *Formal_Collection_Rate*. Notice here that both of the former and the latter independent variables are exclusively coming from the informal sector and separated from *Formal_Collection_Rate* in the structures of the model. The former is structured in the model as the main determinant of *Informal_Collection_Capacity*.

Whereas the latter is placed as the driver of *Unemployment_Rate*, influencing the level of *Informal_Workers.*

Table 18. ANOVA Results for Significant Individual Factors and Interactions for *Informal_Collection_Rate* in the Developed Country Model

Response Variable	**Significant Variable**	**Adjusted MS**	**F**	**P-Value**
Informal_ Collection_Rate	*Scavenger_Collection_Capacity*	7,60517E+17	4982.09	0.000
	Time_to_Layoff_Workers	1,78E+17	1163.09	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*	1,77E+17	1162.78	0.000

Furthermore, as can be clearly seen from table 18, the aforementioned interaction also significantly influences the level of *Informal_Collection_Rate.* One might suggest that the level of *Informal_Collection_Rate* correlates with *Formal_Collection_Rate* because both of them are affected by the interaction of two same variables. It should be remembered that based on the equation 6 in Chapter 4, the calculation of *Formal_Collection_Rate* in the developed country model requires no value from *Informal_Collection_Rate.* Hence, if the correlation exists, this condition would support the notion that "correlation does not imply causation". Still, it implies that at the systems level, the informal collection rate might significantly affect the formal one, absorbing any waste that could not be collected by the formal sector.

Second, table 19 shows five significant individual effects for *Formal_Cash_Availability*. Altogether, the individual main effects form nine significant interactions from the variables within the formal sector. As clearly seen in the table, each of the main individual effects requires the value from another factor to influence *Formal_Cash_Availaibly.* Remarkably, table 19 reveals the presence of one significant interaction, formed by a relationship between two insignificant individual factors coming from cross-sectors, i.e. *Refurbishment_Acceptance_Percentage* and *Time_to_Layoff_Workers*. In other words, though individually these two factors are minor; together, they become influential to the level of *Formal_Cash_Availability.* In practical terms, the government might create a significant additional income to the formal sector by increasing the recovery acceptance outside the recycling option and promoting any measurement attracting the workers to leave their job.

Table 19. ANOVA Results for Significant Individual Factors and Interactions for *Formal_Cash_Availability* in the Developed Country Model

Response Variable	Significant Variable	Adjusted MS	F	P-Value
Formal_Cash_ Availability	*Time_without_Legislation*	2,19816E+22	238.07	0.000
	Fixed_ARF	1,01243E+25	109648.82	0.000
	Formal_Collection_Cost	7,23383E+23	7834.44	0.000
	Formal_Recycling_Cost	2,38008E+23	2577.69	0.000
	Initial_Collection_Percentage	6,00479E+20	6.5	0.011
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Time_without_Legislation * Time_to_Achieve_Collection_Target*	1,59E+21	17.19	0.000
	*Time_without_Legislation * Fixed_ARF*	7,92E+21	85.73	0.000
	*Time_without_Legislation * Formal_Collection_Cost*	5,98E+21	64.77	0.000
	*Time_without_Legislation * Formal_Recycling_Cost*	1,87E+21	20.22	0.000
	*Time_to_Achieve_Collection_Target * Formal_Collection_Cost*	4,74E+22	513.06	0.000
	*Time_to_Achieve_Collection_Target * Formal_Recycling_Cost*	1,52E+22	164.34	0.000
	*Fixed_ARF * Formal_Collection_Cost*	4,02E+20	4.35	0.037
	*Formal_Collection_Cost * Initial_Collection_Percentage*	6,57E+20	7.12	0.008
	*Refurbishment_Acceptance_ Percentage * Time_to_Layoff_Workers*	4,49E+20	4.86	0.028

Table 20. ANOVA Results for Significant Individual Factors and Interactions for *Informal_Cash_Availability* in the Developed Country Model

Response Variable	Significant Variable	Adjusted MS	F	P-Value
Informal_Cash_ Availability	*Ratio_Workers_per_Population*	3,35E+18	81.28	0.000
	Scavenger_Collection_Capacity	1,73E+22	419716.30	0.000
	Initial_Collection_Percentage	2,14E+17	5.18	0.023
	Time_to_Layoff_Workers	3,22E+21	78105.71	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Ratio_Workers_per_Population * Scavenger_Collection_Capacity*	3,20E+18	77.68	0.000
	*Ratio_Workers_per_Population * Time_to_Layoff_Workers*	1,37E+18	33.16	0.000
	*Fixed_ARF * Time_to_Layoff_Workers*	2,19E+17	5.3	0.021
	*Scavenger_Collection_Capacity * Initial_Collection_Percentage*	2,17E+17	5.25	0.022
	*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*	3,22E+21	78120.85	0.000

Third, the ANOVA in table 20 reveals four significant individual main effects, forming five significant interactions for *Informal_Cash_Availability*. There exists a relatively limited presence of the main effects. Also, there appears only limited influential factors coming from the formal sector. The former and the latter results point out the stable but quite isolated nature of *Informal_Cash_Availability* in the developed country model.

Table 20 also shows the appearance of two significant cross-sector interactions. One of them was formed by two individual main effects, i.e. *Scavenger_Collection_Capacity* and *Initial_Collection_Percentage*. This interaction implies that the capacity of the scavenger would be influential to the level of informal cash, only when the initial capacity of the formal sector is limited. One might say, from another perspective, that the magnitude of collection initiatives prior to enactment of the WEEE-specific regulation would be potentially decisive to hold the rise of the cash of the informal sector. The other significance, which is more remarkable, is emerged from an interaction between one main effect from the informal sector (*Time_to_Layoff_Workers)* and one non-main effect from the formal sector *(Fixed_ARF)*. This interaction implies that the government might limit the rise of informal cash through the combination of a certain high level of ARF and an indirect approach appealing the informal workers to leave their job.

Table 21. ANOVA Results for Significant Individual Factors and Interactions for *Informal_Workers* in the Developed Country Model

Response Variable	**Significant Variable**	**Adjusted MS**	**F**	**P-Value**
Informal_Workers	*Scavenger_Collection_Capacity*	1283507971	174009.98	0.000
	Initial_Collection_Percentage	30048	4.07	0.044
	Time_to_Layoff_Workers	480691620	65169.16	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Fixed_ARF * Scavenger_Collection_Capacity*	30203	4.09	0.043
	*Fixed_ARF * Initial_Collection_Percentage*	29971	4.06	0.044
	*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*	479270773	64976.53	0.000
	*Refurbishment_Acceptance_Percentage * Time_to_Layoff_Workers*	29494	4	0.046

Fourth, the ANOVA results in table 21 inform the reader about the emergence of the individual main effects, creating four significant interactions for *Informal_Workers.* The limited appearances of the main effects support the previous notion that the situation of the informal sector in the developed country is associated with stability (albeit limited) and isolation.

Of the significant interactions, three of them require the values of non-significant factors, coming from the formal sector. These particular factors are *Fixed_ARF* and *Refurbishment_Acceptance_Percentage.* It is also worth to note the appearance of a significant interaction between *Fixed_ARF* and *Initial_Collection_Percentage* – two variables within the formal sector –, influencing the level of *Informal_Workers.* In other words, the combination of a high level of recycling fee and a high amount of the initial collection would negatively influence the level of informal workforces. This condition supports the conclusion in the previous paragraph that the formal collection initiatives are essential in the developed country case, pointing out the plausible correlation between the success of SENS and SWICO initiatives with the limited presence – if not none – of the informal WEEE recycling sector in Switzerland.

Finally, table 22 reveals the appearance of five significant individual factors, forming six significant interactions for *Untreated_Products*. There exists one additional significant interaction, formed by an interaction between two individual non-significant cross-sector factors. Of the former, two interactions depend on the condition of non-significant variables within the formal sector, i.e. *Formal_Recycling_Cost* and *Refurbishment_Acceptance_Percentage.* For the latter, two non-significant cross-sectors factors would impact the response variable if they interact with each other. Such variables include *Ratio_Worker_per_Population* from the informal sector and *Refurbishment_Acceptance_Percentage* from the formal sector. It implies that, though these variables individually were not significant, together they were decisive to influence the level of the accumulation of least favored options. Also, one might suggest that the level of refurbishment acceptance, or in more general sense, the recovery level outside the recycling process would be influential –under certain conditions – to divert the waste from the landfilling.

5.1.2.2 The Results of ANOVA for the Developing Country Model

Tables 22 to 28 exhibit the significant individual factors and the significant interaction within the developing country case, influencing each of the response variables. In general, the results show a relatively high number of significances for the formal sector and a low number for the informal one, pointing out the opposite natures of the behaviors within the both sectors.

Table 22. ANOVA Results for Significant Individual Factors and Interactions for *Untreated_Products* in the Developed Country Model

Response Variable	Significant Variable	Adjusted MS	F	P-Value
Untreated_ Products	*Time_without_Legislation*	2,48E+21	13515.43	0.000
	Time_to_Achieve_Collection_Target	2,25E+22	122730.62	0.000
	Scavenger_Collection_Capacity	3,05E+19	166.44	0.000
	Initial_Collection_Percentage	5,13E+19	279.83	0.000
	Time_to_Layoff_Workers	5,35E+18	29.19	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Ratio_Worker_per_Population * Refurbishment_Acceptance_Percentage*	7,30E+17	3.98	0.046
	*Time_without_Legislation * Time_to_Achieve_Collection_Target*	9,66E+19	526.84	0.000
	*Time_without_Legislation * Initial_Collection_Percentage*	2,15E+18	11.75	0.001
	*Scavenger_Collection_Capacity * Refurbishment_Acceptance_Percentage*	2,18E+19	118.94	0.000
	*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*	7,71E+17	4.21	0.040
	*Formal_Recycling_Cost * Time_to_Layoff_Workers*	4,17E+18	22.73	0.000

Table 23. ANOVA Results for Significant Individual Factors and Interactions for *Formal_Collection_Rate* in the Developing Country Model

Response Variable	Significant Variable	Adjusted MS	F	P-Value
Formal_Collection_ Rate	*Time_without_Legislation*	2,65E+22	4970.49	0.000
	Time_to_Achieve_Collection _Target	6,95E+21	1302.90	0.000
	Recycling_Subsidy	1,14E+22	2137.56	0.000
	Average_Import_Growth_Fraction	3,97E+20	74.46	0.000
	Scavenger_Collection_Capacity	4,17E+20	78.23	0.000
	Formal_Collection_Cost	1,14E+22	2141.71	0.000
	Formal_Recycling_Cost	7,11E+20	133.4	0.000
	Time_to_Layoff_Workers	3,68E+20	69.05	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Time_without_Legislation * Time_to_Achieve_Collection _Target*	3,39E+19	6.36	0.012
	*Time_without_Legislation * Recycling_Subsidy*	2,06E+21	385.68	0.000
	*Time_without_Legislation * Average_Import_Growth_Fraction*	2,53E+20	47.53	0.000
	*Time_without_Legislation * Scavenger_Collection_Capacity*	1,13E+20	21.15	0.000

Table 23. ANOVA Results for Significant Individual Factors and Interactions for *Formal_Collection_Rate* in the Developing Country Model (continued)

Response Variable	Significant Interaction	Adjusted MS	F	P-Value
Formal_Collection_Rate	*Time_without_Legislation * Formal_Collection_Cost*	2,04E+21	383.31	0.000
	*Time_without_Legislation * Formal_Recycling_Cost*	7,11E+20	133.43	0.000
	*Time_without_Legislation * Time_to_Layoff_Workers*	2,47E+20	46.23	0.000
	*Time_to_Achieve_Collection_Target * Recycling_Subsidy*	1,17E+21	218.91	0.000
	*Time_to_Achieve_Collection_Target * Average_Import_Growth _Fraction*	2,12E+20	39.69	0.000
	*Time_to_Achieve_Collection_Target * Scavenger_Collection_Capacity*	4,50E+19	8.45	0.004
	*Time_to_Achieve_Collection_Target * Formal_Collection_Cost*	1,16E+21	216.66	0.000
	*Time_to_Achieve_Collection_Target * Formal_Recycling_Cost*	3,58E+20	67.09	0.000
	*Time_to_Achieve_Collection_Target * Time_to_Layoff_Workers*	2,09E+20	39.15	0.000
	*Recycling_Subsidy * Average_Import_Growth _Fraction*	4,76E+19	8.92	0.003
	*Recycling_Subsidy * Scavenger_Collection_Capacity*	5,87E+19	11.01	0.001
	*Recycling_Subsidy * Formal_Collection_Cost*	6,39E+21	1198.06	0.000
	*Recycling_Subsidy * Time_to_Layoff_Workers*	4,41E+19	8.28	0.004
	*Average_Import_Growth _Fraction * Scavenger_Collection_Capacity*	3,61E+20	67.73	0.000
	*Average_Import_Growth _Fraction * Formal_Collection_Cost*	4,89E+19	9.17	0.002
	*Average_Import_Growth _Fraction * Time_to_Layoff_Workers*	2,13E+20	40.04	0.000
	*Scavenger_Collection_Capacity * Formal_Collection_Cost*	5,66E+19	10.61	0.001
	*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*	1,14E+20	21.32	0.000
	*Formal_Collection_Cost * Time_to_Layoff_Workers*	1,14E+20	8.32	0.004

The ANOVA results in table 23 show eight individual main effects, forming 23 significant interactions. This relatively high number of interactions reveals a high level of interdependency between factors influencing *Formal_Collection_Rate.* This condition suggests the dynamics of the formal collection in the developing country case. Of these 23 significant interactions, twelve interactions depend on one factor coming from the informal sector and three interactions rely on a relationship between two factors exclusively within the informal sector. It implies that the situation of the informal sector in the developing country would have significant impacts on the level of formal collection. Finally, *Time_without_Legislation* appears as the most influential factor, because any interaction created by this factor would be associated with a different level of *Formal_Collection_Rate.*

Table 24. ANOVA Results for Significant Individual Factors for *Formal_Cash_Availability* in the Developing Country Model

Response Variable	Significant Variable	Adjusted MS	F	P-Value
Formal_Cash_ Availability	*Time_without_Legislation*	1,22E+26	3639.33	0.000
	Time_to_Achieve_Collection_Target	2,52E+25	751.80	0.000
	Recycling_Subsidy	1,33E+26	3984.28	0.000
	Average_Import_Growth _Fraction	2,54E+23	7.58	0.006
	Scavenger_Collection_Capacity	3,82E+23	11.40	0.001
	Formal_Collection_Cost	1,33E+26	3965.46	0.000
	Formal_Recycling_Cost	1,56E+25	465.49	0.000
	Initial_Collection_Percentage	1,82E+23	5.43	0.020
	Time_to_Layoff_Workers	3,82E+23	11.41	0.001
Response Variable	**Significant Interaction**	**Adjusted MS**	**F**	**P-Value**
Formal_Cash_ Availability	*Time_without_Legislation * Time_to_Achieve_Collection _Target*	9,66E+24	288.33	0.000
	*Time_without_Legislation * Recycling_Subsidy*	6,70E+25	2001.07	0.000
	*Time_without_Legislation * Average_Import_Growth _Fraction*	2,28E+23	6.79	0.009
	*Time_without_Legislation * Scavenger_Collection_Capacity*	2,30E+23	6.85	0.009
	*Time_without_Legislation * Formal_Collection_Cost*	6,66E+25	1987.74	0.000
	*Time_without_Legislation * Formal_Recycling_Cost*	1,38E+25	411.39	0.000
	*Time_without_Legislation * Time_to_Layoff_Workers*	3,75E+23	11.18	0.001
	*Time_to_Achieve_Collection_Target * Recycling_Subsidy*	1,71E+25	511.36	0.000
	*Time_to_Achieve_Collection_Target * Average_Import_Growth _Fraction*	2,01E+23	6.01	0.014
	*Time_to_Achieve_Collection_Target * Formal_Collection_Cost*	1,69E+25	505.23	0.000
	*Time_to_Achieve_Collection_Target * Formal_Recycling_ost*	1,50E+24	44.73	0.000
	*Time_to_Achieve_Collection_Target * Time_to_Layoff_Workers*	3,83E+23	11.43	0.001
	*Recycling_Subsidy * Scavenger_Collection_Capacity*	2,55E+23	7.62	0.006
	*Recycling_Subsidy * Formal_Collection_Cost*	7,27E+25	2170.58	0.000

Table 24. ANOVA Results for Significant Individual Factors for *Formal_Cash_Availability* in the Developing Country Model (continued)

Response Variable	*Significant Interaction*	Adjusted MS	F	P-Value
Formal_Cash_ Availability	*Recycling_Subsidy * Formal_Recycling_Cost*	1,83E+24	54.65	0.000
	*Recycling_Subsidy * Time_to_Layoff_Workers*	1,95E+23	5.82	0.016
	*Average_Import_Growth _Fraction * Scavenger_Collection_Capacity*	2,05E+23	6.12	0.013
	*Average_Import_Growth _Fraction * Formal_Collection_Cost*	1,47E+23	4.37	0.037
	*Average_Import_Growth _Fraction * Time_to_Layoff_Workers*	1,32E+23	3.95	0.047
	*Scavenger_Collection_Capacity * Formal_Collection_Cost*	2,30E+23	6.87	0.009
	*Formal_Collection_Cost * Formal_Recycling_Cost*	1,77E+24	52.71	0.000
	*Formal_Collection_Cost * Initial_Collection_Percentage*	1,49E+23	4.45	0.035
	*Formal_Collection_Cost * Time_to_Layoff_Workers*	2,21E+23	6.59	0.010

Similar to the main effects influencing *Formal_Collection_Rate*, table 24 reveals nine significant factors and 23 significant interactions for *Formal_Cash_Availability.* Of these significant interactions, twelve interactions involve one significant factor from the informal sector and three interactions include a combination of two factors within the informal sector. Hence, it implies that the condition of the informal sector significantly influences the level of formal cash. These results also support the notion discussed in the previous paragraph about the influential position of the informal sector. Finally, *Time_with_Legislation* emerge as the most significant factors, outside the financial variable, in influencing the level of formal cash.

Table 25. ANOVA Results for Significant Individual Factors and Interactions for *Informal_Collection_Rate* in the Developing Country Model

Response Variable	**Significant Variable**	**Adjusted MS**	**F**	**P-Value**
Informal_Collection_ Rate	*Average_Import_Growth _Fraction*	1,67E+22	13017.55	0.000
	Scavenger_Collection_Capacity	2,30E+20	179.85	0.000
	Time_to_Layoff_Workers	8,90E+21	6950.36	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Average_Import_Growth_Fraction * Scavenger_Collection_Capacity*	1,35E+22	10526.70	0.000
	*Average_Import_Growth_Fraction * Time_to_Layoff_Workers*	2,80E+21	2185.51	0.000

Table 25 depicts three significant factors, forming two significant interactions for *Informal_Collection_Rate*. All of them involve *Average_Import_Growth_Fraction.* This condition suggests that the level of WEEE illegal import rate is essential in driving the rise of the informal collection. Moreover, the presence of main effects in table 25 is rather limited and formed by factors exclusively within the informal sector. The former condition implies the stable nature of the informal collection. In practical terms, this condition confirms the dominant position of the informal collection in the developing countries. The latter suggests the superiority position of the informal sector in the collection activities.

Table 26. ANOVA Results for Significant Individual Factors for *Informal_Cash_Availabilty* in the Developing Country Model

Response Variable	**Significant Variable**	**Adjusted MS**	**F**	**P-Value**
Informal_Cash_ Availability	*Ratio_Worker_per_Population*	1,45E+22	42.19	0.000
	Average_Import_Growth _Fraction	2,49E+25	72595.86	0.000
	Scavenger_Collection_Capacity	7,40E+26	2153576.95	0.000
	Time_to_Layoff_Workers	5,13E+25	149386.81	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Ratio_Worker_per_Population * Time_to_Layoff_Workers*	8,45E+21	24.61	0.000
	*Average_Import_Growth_Fraction * Scavenger_Collection_Capacity*	1,66E+24	4829.84	0.000
	*Average_Import_Growth_Fraction * Time_to_Layoff_Workers*	6,63E+21	19.31	0.000
	*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*	5,85E+25	170278.37	0.000

Similar to the results for *Informal_Collection_Rate,* ANOVA produced four significant factors and four significant interactions for *Informal_Cash_Availability* (Table 26). Here, there exists one additional main effect, i.e. *Ratio_Worker_per_Population,* which depends on the level of *Time_to_Layoff_Workers*. In practical terms, if the number of informal workers in the earlier period is high enough while at the same time the length of informal job duration is long; this combination would influence the rise of informal cash. Likewise, the limited appearance of the main effects here suggests the stable nature of informal cash in the developing country case. Combined with the discussion from previous paragraphs, the results here imply the superior position of the informal sector in WEEE management systems in the developing countries. Thus, it can be concluded that the informal sector plays an important role in developing countries, potentially influencing the rise and fall of its formal counterpart.

Table 27. ANOVA Results for Significant Individual Factors and Interactions for *Informal_Workers* in the Developing Country Model

Response Variable	Significant Variable	Adjusted MS	F	P-Value
Informal_Workers	*Time_without_Legislation*	5573219796	15.11	0.000
	Average_Import_Growth _Fraction	6,55E+17	17753.37	0.000
	Scavenger_Collection_Capacity	2,66E+18	72074.09	0.000
	Time_to_Layoff_Workers	1,25E+18	33781.27	0.000
	Significant Interaction	**Adjusted MS**	**F**	**P-Value**
	*Average_Import_Growth_Fraction * Scavenger_Collection_Capacity*	3,32E+17	8988.03	0.000
	*Average_Import_Growth_Fraction * Time_to_Normal_Layoff*	1,01E+17	2725.39	0.000
	*Scavenger_Collection_Capacity * Time_to_Normal_Layoff*	2,82E+17	7646.25	0.000

Subsequently, table 27 reveals four individual main effects and four main interactions, influencing the level of *Informal_Workers.* One should note the presence of *Time_without_Legislation* as a significant individual factor without any presence in the two factors-interaction. This phenomenon might suggest that *Time_without_Legislation* is able to single-handedly push the level of informal workforces. However, it is unlikely to be the case as table 27 reveals a low level of F and MS when this factor influences the response variables. It appears that the significance of *Time_without_Legislation* might still depend on another factor, forming a more complex interaction such as three-way ANOVA interaction. Such higher order interaction is beyond the scope of this research.

Table 28. ANOVA Results for Significant Individual Factors for *Untreated_Products* in the Developing Country Model

Response Variable	Significant Variable	Adjusted MS	F	P-Value
Untreated_ Products	*Time_without_Legislation*	4,16E+24	9129.44	0.000
	Time_to_Achieve_Collection_Target	9,85E+23	2160.46	0.000
	Recycling_Subsidy	9,58E+23	2100.51	0.000
	Average_Import_Growth _Fraction	5,17E+23	1134.66	0.000
	Scavenger_Collection_Capacity	3,95E+22	86.70	0.000
	Formal_Collection_Cost	9,51E+23	2086.93	0.000
	Formal_Recycling_Cost	2,97E+22	65.05	0.000
	Initial_Collection_Percentage	7,43E+21	16.30	0.000

The ANOVA results of *Untreated_Products* reveal eight significant factors (Table 28), forming 18 significant interactions (Table 29). These interactions include nine interactions between two variables within the formal sector, two interactions within the informal sector, and seven cross-sector interactions. This plethora of combinations suggests two things: the unstable nature of the illegal disposal activities and the influential position of the informal sector for such variable in the developing countries.

Table 29. ANOVA Results for Significant Interactions for Untreated_Products in the Developing Country Model

Response Variable	Significant Interaction	Adjusted MS	F	P-Value
Untreated_ Products	*Time_without_Legislation * Time_to_Achieve_Collection_Target*	3,94E+23	864.82	0.000
	*Time_without_Legislation * Recycling_Subsidy*	4,18E+23	917.57	0.000
	*Time_without_Legislation * Average_Import_Growth_Fraction*	7,59E+21	16.66	0.000
	*Time_without_Legislation * Scavenger_Collection_Capacity*	8,92E+21	19.57	0.000
	*Time_without_Legislation * Formal_Collection_Cost*	4,10E+23	898.72	0.000
	*Time_without_Legislation * Formal_Recycling_Cost*	3,30E+21	7.23	0.007
	*Time_without_Legislation * Time_to_Normal_Layoff*	1,30E+22	28.60	0.000
	*Time_to_Achieve_Collection_Target * Recycling_Subsidy*	1,34E+23	294.11	0.000
	*Time_to_Achieve_Collection_Target * Average_Import_Growth _Fraction*	6,35E+21	13.94	0.000
	*Time_to_Achieve_Collection_Target * Scavenger_Collection_Capacity*	4,18E+21	9.17	0.002
	*Time_to_Achieve_Collection_Target * Formal_Collection_Cost*	1,34E+23	293.24	0.000
	*Time_to_Achieve_Collection_Target * Formal_Recycling_Cost*	9,59E+21	21.03	0.000
	*Time_to_Achieve_Collection_Target * Initial_Collection_Percentage*	2,13E+21	4.68	0.031
	*Time_to_Achieve_Collection_Target * Time_to_Normal_Layoff*	1,42E+22	31.10	0.000
	*Recycling_Subsidy * Scavenger_Collection_Capacity*	1,80E+21	3.94	0.047
	*Recycling_Subsidy * Formal_Collection_Cost*	5,78E+23	1267.88	0.000
	*Average_Import_Growth _Fraction * Scavenger_Collection_Capacity*	2,26E+21	4.96	0.026
	*Scavenger_Collection_Capacity * Time_to_Normal_Layoff*	4,90E+21	10.74	0.001

5.1.3 Comparing the Presence of the Main Effects within the Developed and the Developing Country Model

This section aims to emphasize several differences of the presented influential factors within the developed and the developing country model. Table 30 depicts this comparison. Initially, this study points out the differences between the situations of the formal sector in the developed and the developing country. In the former country, the official systems gain a stability, characterized by the limited presence of influential factors. Of these factors, there exist limited main effects coming from the informal sector that would be significant, i.e. scavenger capacity and informal job durations, only if two conditions are met: (1) both of them have high values, or (2) the recycling systems require a long period to achieve the collection target. Also, it is noteworthy to emphasize the presence of the refurbishment acceptance percentage or in more general, the recovery process outside the recycling option. In reality, it somehow got less attention by the formal systems as the limited reuse rate persists in the developed systems (Khetriwal et al., 2009; Manomaivibool, 2009; Walther et al., 2009). Because the reuse appears at a higher level in the waste hierarchy, the option to increase the reuse / refurbishment / refurbishment rate should be assessed and then, if feasible, promoted by the policy makers.

On the contrary, this study witnesses the unstable nature of the formal sector in the developing country by having so many influential factors. Moreover, the situations in the formal sector really depend on its informal counterpart. These conditions include the illegal import of WEEE, scavenger capacity, and informal job duration. Therefore, focusing only on the official systems would not be adequate to solve the WEEE problems, unless the situations in the informal sector are addressed. Of course, in reality, the illegal import of WEEE could not be associated only with the informal sector, as the government bears the responsibility to control its customs.

Table 30. Comparison between the Significant Factors and Interactions in the Developed and the Developing Country Models

Response Variable	Notable Main Effect	
	in Developed Country Model	in Developing Country Model
Formal_Collection_Rate	the presence of a relatively limited number of main effects, two significances coming from a cross-sectors interaction, and one coming from an external interaction (*Scavenger_Collection_Capacity * Time_to_Layoff_Workers*)	the presence of a relatively high number of main effects, twelve interactions depend on one factor of the opposite sector, and three interactions rely on factors exclusively within the informal sector
Formal_Cash_Availability	the presence of a relatively high number of main effects formed by variables within the sector and one significance coming from a cross-sector interaction of two insignificant factors (*Refurbishment_Acceptance_Percentage * Time_to_Layoff_Workers*)	the presence of a relatively high number of main effects, twelve interactions depend on one factor of the opposite sector, and three interactions rely on factors exclusively within the informal sector
Informal_Collection_Rate	the presence of a relatively limited number of main effects and a significant interaction between *Scavenger_Collection_Capacity and Time_to_Layoff_Workers*, hinting a correlation between *Informal_Collection_Rate* and *Formal_Collection_Rate*	the presence of a relatively limited number of main effects formed exclusively by the factors within the sector, a notable significance of *Average_Import_Growth_Fraction*
Informal_Cash_Availability	the presence of a relatively limited number of main effects, one significance formed by two cross-sector factors, and one significance constructed by one significant factor within the sector and one insignificant factor outside the sector, and a notable significance of *Initial_Collection_Percentage* and *Fixed_ARF*	the presence of a relatively limited number of main effects formed exclusively by the factors within the sector
Informal_Workers	the presence of a relatively limited number of main effects, three significance formed by a cross-sector interaction between significant and insignificant factors, one significance constructed by an interaction of two significant factors outside the sector, and a notable significance of *Initial_Collection_Percentage* and *Fixed_ARF*	the presence of a relatively limited number of main effects formed exclusively by the factors within the sector, a notable presence of *Time_without_Legislation*
Untreated_Products	the presence of a relatively limited number of main effects, two significance formed by a cross-sector interaction between significant and insignificant factors, one significance formed by an interaction between two individual non-significant cross-sector factors	the presence of a relatively high number of main effects, nine significant interactions between two variables within the formal sector, two interactions within the informal sector, and seven cross-sectors interactions

Subsequently, the different situations concerning the informal sector should be pointed out. In the developed country, this sector could enjoy stability, albeit in a very limited level, if the growing secondary market exists. Here, there exist few influential factors coming from the formal sector. It implies the presence of two situations: the isolated nature of the informal systems and the possibility to apply indirect interventions to limit their operations. The interventions are suggested based on the presence of influential factors, including the level of initial collection prior to the legislation, ARF, and refurbishment acceptance. In the developing systems, the informal sector not only could maintain stability but also enjoy its dominance in the systems, as there is only one significant factor coming from the formal one, i.e. *Time_without_Legislation.* The influence of this variable, however, seems to require a more complex relationship, interacting with more other factors. This condition hints to the reality in which the policymakers could offer no easy, simple, or partial solution in solving WEEE problems of the informal sector in the developing countries. Otherwise, the promoted solutions would be insignificant or worse, create additional problems. Nevertheless, the significant presence of *Time_without_Legislation* in the results might encourage the government to fasten the development of WEEE-specific legislation.

The results here also suggest that the policy makers in the developing countries should pay more attention to the situations in the informal sector, especially for the appeared significant factors. Denying this sector is no longer an option and the promoted solutions should conform to the sustainability pillars. These solutions should be kept away from two extreme sides: on the one hand from cracking down the entire informal recycling sector without considering the side effects such as higher unemployment, and on the other hand, leaving this sector to run business-as-usual, thus, e.g. exposing the informal workers to the more acute health situation. Finally, the comparative approach here points out the contrast situation of the least favored disposal options in the developed and the developing country. The illegal disposal is stable in the former case while dynamic in the latter.

5.2 Policy Analysis on the Models under Study

This section provides the analysis for several policy options dealing with WEEE management systems. It aims to assess the influence of these options on the behavior of the systems in both the developed and the developing country model. Here, this study selects three kinds of policy, i.e. the selection of financial schemes, the integration of the informal sector into the systems, and the legislative factors. The incorporation of such policies requires modification in the structure as will be discussed in the following section. After modification took places, the models will be simulated for 40 years as the simulation horizon under the growing used market case. Notice here that most parts of this section are dedicated exclusively to the developing country model as the presence of WEEE-related problems are significant.

5.2.1. Assessment for Schemes to Finance the Systems

This study assesses the impact of the following financial schemes to the level of *Formal_Cash_Availability*. They are:

- For the developed country model: a fixed Advance Recycling Fee (ARF), a flexible ARF, and a Deposit-Refund Scheme.
- For the developing country model: a fixed Advance Recycling Fee (ARF), a flexible ARF, a Deposit-Refund Scheme, and a Recycling Subsidy from the government.

Here, it should be mentioned that, in this section, this study suffices with the basic assumption that the implementation of any funding scheme creates no additional influence on the customer behavior, e.g. a higher level of customer willingness to dispose of waste if a Deposit-Refund Scheme was implemented in the systems. In reality, this kind of influence might exist. Such influence requires a more complex relationship to be applied and analyzed.

5.2.1.1 The Model Structure under Different Financing Schemes

Initially, the default mode of the SD models under study has already included the calculation of the formal revenue based on a fixed ARF and a Recycling Subsidy for the developed and the developing country model, respectively (see chapter 4). Therefore, such calculations will not be presented again in this chapter. Subsequently, the models will incorporate a different type of ARF, i.e. flexible ARF. This scheme utilizes an ARF procedure whose value is changing in each period based on the condition of the current EEE sales in the forward channels and the flows of WEEE in the reverse streams. This calculation is based on the procedure taken by SWICO Recycling, as appeared in Streicher-Porte (2006):

$$ARF\_per\_Product = \frac{(r*O*R)}{S} \tag{35}$$

With r as the reimbursement which is a cumulative unit of all costs (recycling, transport, collection, and administration), O as the estimated amount of obsolete products, R as the amount of the reserves, and S as the number of sales.

Then, this study adopts and transforms equation 35 into a stock-flow structure in the SD modeling, as indicated in Figure 44. This structure includes the following calculations to determine the current level of flexible ARF per product (*Flexible_ARF*).

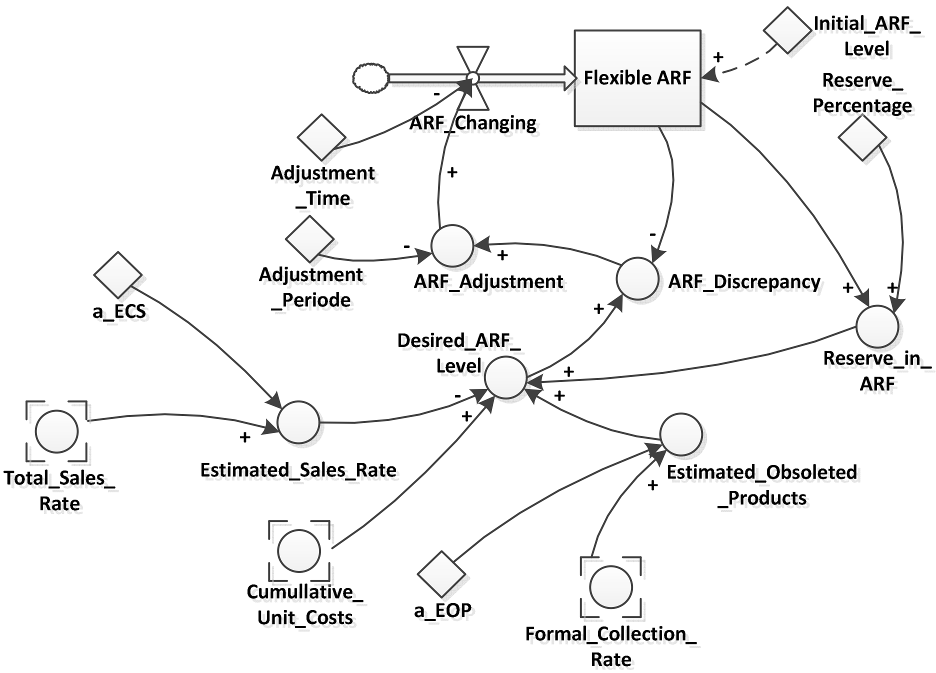

Figure 44. The Simplified Stock-Flow Diagram of the Calculation of Flexible ARF

$$Cumulative\_Unit\_Costs = Formal\_Recycling\_Cost + Formal\_Recycling\_Cost + Treatment\_Cost \quad (36)$$

$$Reserve\_in\_ARF = Reserve\_Percentage * ARF\_per\_Product \quad (37)$$

$$Desired\_ARF\_Level = ((Cumulative\_Unit\_Costs * Estimated\_Obsolete\_Products) + (Reserve\_in\_ARF * Estimated\_Sales\_Rate)) / Estimated\_Sales\_Rate \quad (38)$$

$$ARF\_Discrepancy = Desired\_ARF\_Level - ARF\_per\_Product \quad (39)$$

$$ARF\_Adjustment = PULSE(ARF\_Discrepancy, STARTTIME + Adjustment\_Period, Adjustment\_Period) \quad (40)$$

With 2% of *Reserve_Percentage* and 6 months of *Adjustment_Period* (Streicher-Porte, 2006).

The calculated flexible ARF per product will replace *Fixed_ARF* in the following equation of *Total_Recycling_Fee*. *Total_Recycling_Fee* latter will determine *Formal_Reverse_Revenue* in equation 10.

$$Total\_Recycling\_Fee = IF(TIMEIS(STARTTIME, Time\_without\_Legislation), 0 \ll USD/WK \gg, Total\_Sales\_Rate * Flexible\_ARF) \quad (41)$$

Finally, the deposit-refund scheme is captured simply by using the following calculations.

$$Total\_Recycling\_Fee = IF(TIMEIS(STARTTIME, Time\_without\_Legislation), 0 \ll USD/WK \gg, Total\_Sales\_Rate \ * Deposit\_per\_Product\ ) \quad (42)$$

$$Total\_Refund = IF(TIMEIS(STARTTIME, Time\_without\_Legislation), 0 \ll USD/WK \gg, Formal\_Collection\_Rate \ * Refund\_per\_Product\ ) \quad (43)$$

Here, this study supposes two assumptions: (1) the amount of deposit and refund fee will be at the same level of USD 6 per product, (2) the systems will be still burdened by the historical WEEE, i.e. the waste coming from EEE which was sold prior to the enactment of the legislation.

In the same way as with equation 41, equation 42 will be used to calculate *Formal_Reverse_Revenue* in equation 10. Also, the appearance of *Total_Refund* in equation 43 will be used to modify the calculation of *Formal_Reverse_Cost* in equation 11 as follows:

$$Formal\_Reverse\_Cost = Formal\_Collection\_Cost \ * Formal\_Collection\_Rate \ + Treatment\_Cost \ * \ Treatment\_Rate \ + Refurbishment\_Cost \ * Refurbishment\_Rate \ + Formal\_Recycling\_Cost \ * Formal\_Recycling\_Rate \ - Total\_Refund \quad (44)$$

5.2.1.2 The Results of Financial Schemes Assessment in the Developed Country Model

Figures 45, 46, and 47 illustrate the behavior of the systems in the developed country case under different financial schemes for 40 years of simulation horizon.

Initially, figure 45 depicts the annual level of ARF per product under the flexible ARF scheme. Here, it is assumed there is an absence of ad hoc intervention to intervene the ARF level during the simulation horizon, i.e. such level depends purely on the calculation. After the first six years of absence, the ARF level emerged and slowly increased, following the condition of the sales rate and the waste flow. Since the behavior of the sales trend usually follows the s-shaped growth curve from the beginning until saturation, eventually the behavior of the ARF level would produce the same shape. As clearly seen in figure 45, the ARF level almost stabilized in the value between five and six US dollar per product.

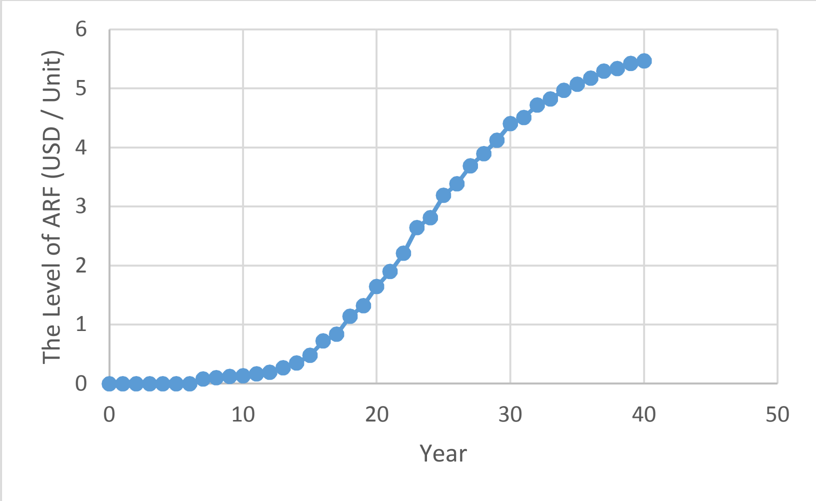

Figure 45. The Behavior of Annual ARF Level under Flexible Scheme in the Developed Country Model

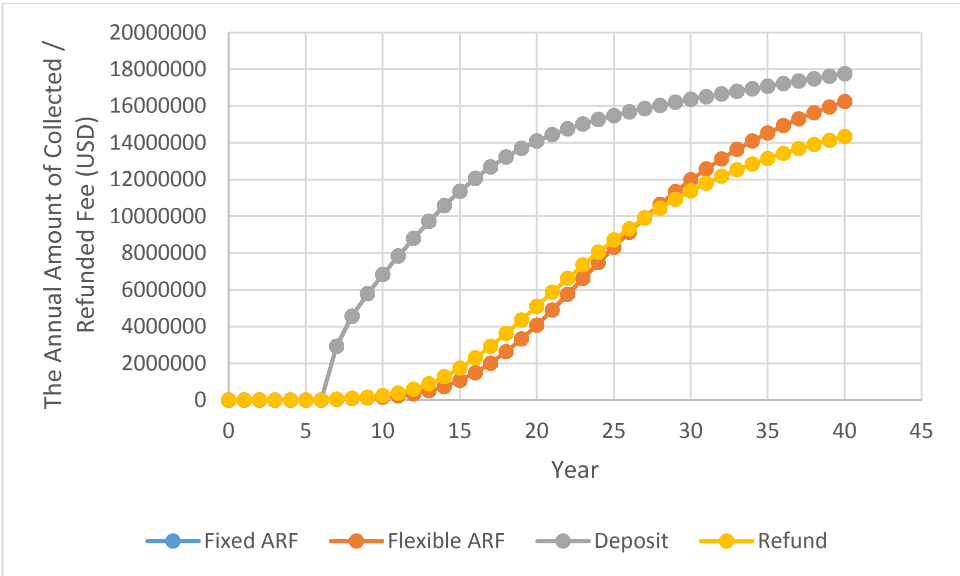

Figure 46. The Annual Amount of Collected Fund and Refunded Fee in the Developed Country Model

(in this graph, the blue line and dots overlap with the gray ones)

Figure 46 depicts the annual amount of collected ARF from the customers. After the first five years without regulation, the formal sector finally was allowed to gather additional income for the systems. During the first year of the implementation, this sector gathered approx. USD 2,925,688 and USD 48,259 under fixed and flexible ARF schemes, respectively. Then, the level of annual amount increases steadily with 7.75% of average annual growth rate for the former and 22.99% for the latter. Though figure 46 shows clearly that the gathered fee is higher under the former scheme rather than the latter, both of them eventually touch the final point with almost the same magnitude. In the final year, the former takes USD 17,765,414, while the latter receives USD 16,243,614. Figure 46 also exhibits the annual amount of collected deposits in the sales points and refund in the disposal channels. The level of deposit is still higher than the refund rates even up to the last year, thus ensuring the stability of the formal sector under such scheme.

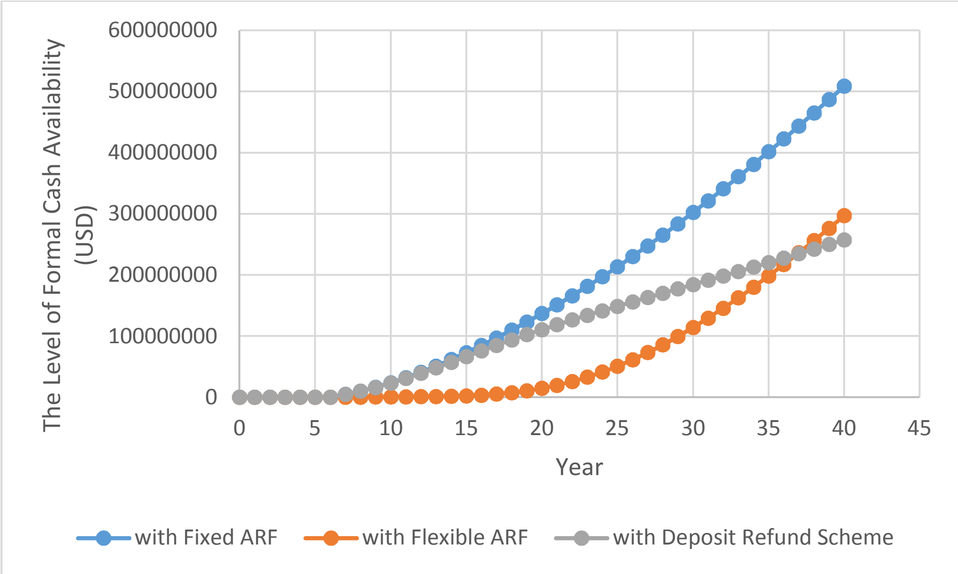

Figure 47. The Behavior of Formal_Cash_Availability under Different Financial Schemes in the Developed Country Model

Subsequently, figure 47 reveals the level of *Formal_Cash_Availability* during the entire simulation period. Here, it is clear that the formal sector could maintain their continuous lucrative state using each of the financial schemes. Among the schemes, the fixed recycling fee outperforms other schemes based on the magnitude of the formal cash. However, arguably, the flexible ARF, which is calculated based on the current market sales and waste stream, provides a fairer mechanism for the customers and the producers who participate in the scheme. Also, the Deposit-Refund Scheme might be more attractive to the customers to discard the waste in the formal channels, thus increasing the collection level. Therefore, it can be concluded that the concerns for appealing the stakeholders, especially the producers and the customers, would not be less attractive for the economic sustainability in the developed country case.

5.2.1.3 The Results of Financial Schemes Assessment in the Developing Country Model

Figure 48 to 52 depict the behavior of the recycling systems using different financial schemes during the simulation horizon.

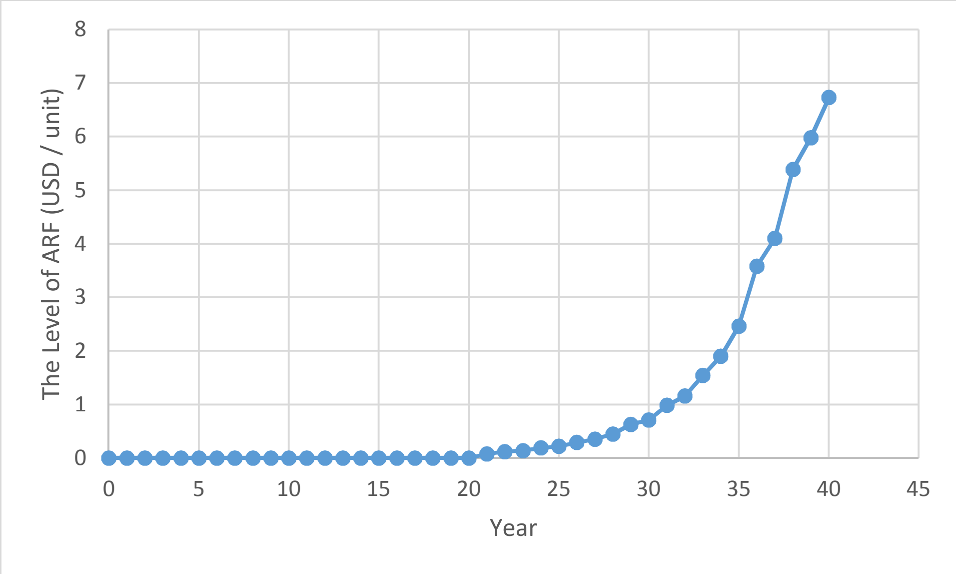

Figure 48. The Behavior of Annual ARF Level under Flexible Scheme in the Developing Country Model

Figure 48 shows the progress of ARF under the flexible scheme. It is introduced in the 21st year, marking the end of *Time_without_Legislation.* As clearly seen in the figure, the ARF level progresses so slowly, not reaching the level of USD 3 per product but after 15 years of its introduction. Afterwards, the level begins to rise significantly and touches the level over six US dollar per sold item. This ARF level might continue to increase in the foreseeable future because of the condition of EEE market that is yet to be saturated.

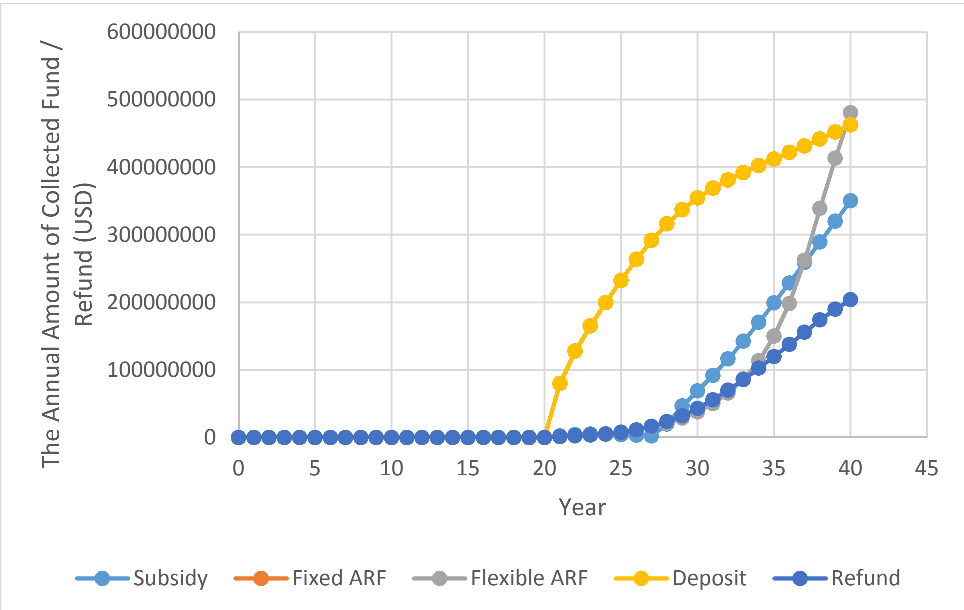

Figure 49. The Annual Amount of Collected Fund, Refund, and Subsidy in the Developing Country Model

(in this graph, the orange line and dots overlap with the yellow ones)

Furthermore, figure 49 exhibits the annual amount of collected fund, refund, and subsidy spent by the government. Here, it is clear that the fixed ARF scheme is much beneficial to the recycling systems. While the other schemes require few more years to finally climb up, fixed ARF provides a fast arrival of the fund. However, the behavior of the collected fund under this scheme (though remains high during the entire simulation horizon) seems to follow the logarithmic curve. Hence, it would be not too exaggerated to point out the stagnancy of the collected fee in the near future.

Moreover, figure 49 also points out another behavior. During the first year of initiation, the formal sector was able to gather USD 2,405,243 and USD 1,047,512 under subsidy and flexible ARF scheme, subsequently. Afterwards, the subsidy amount increases significantly with 29.96% of compound annual growth rate for the former and 38.07% for the latter. It is noteworthy that the collected fee under flexible ARF scheme reaches the highest point, among others, at the end of the simulation horizon. This condition happens because of the emergence of higher ARF level under the presence of high disposal. For the last note here, figure 49 also illustrates the amount of collected and refunded fee under the deposit-refund scheme. It shows that the level of deposit is still much higher than the refunded fee until the last year of the simulation horizon.

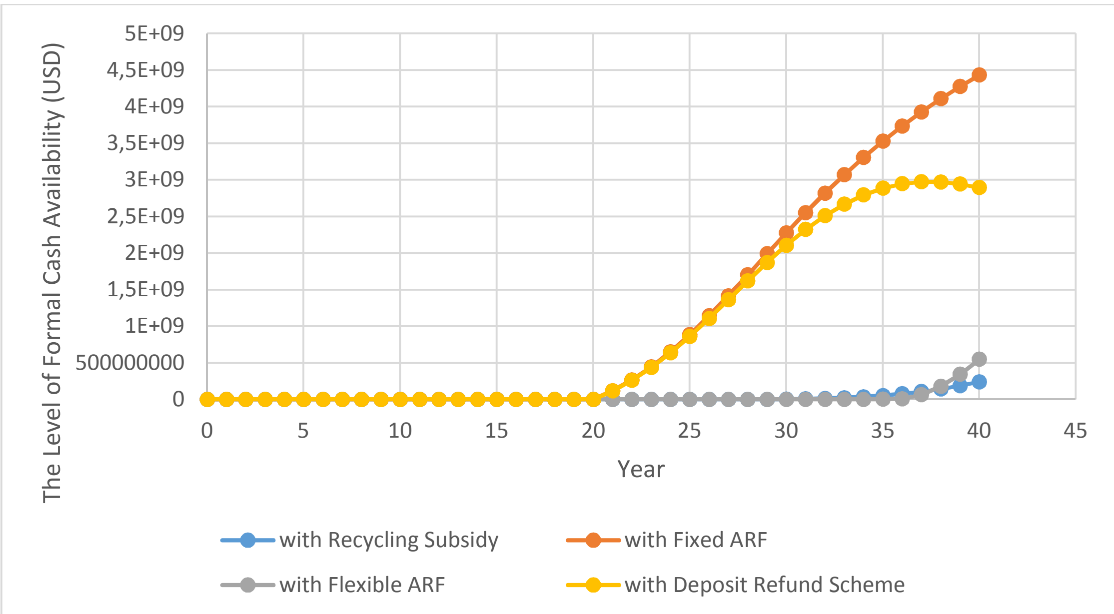

Figure 50. The Behavior of *Formal_Cash_Availability* under Different Financial Schemes in the Developing Country Model

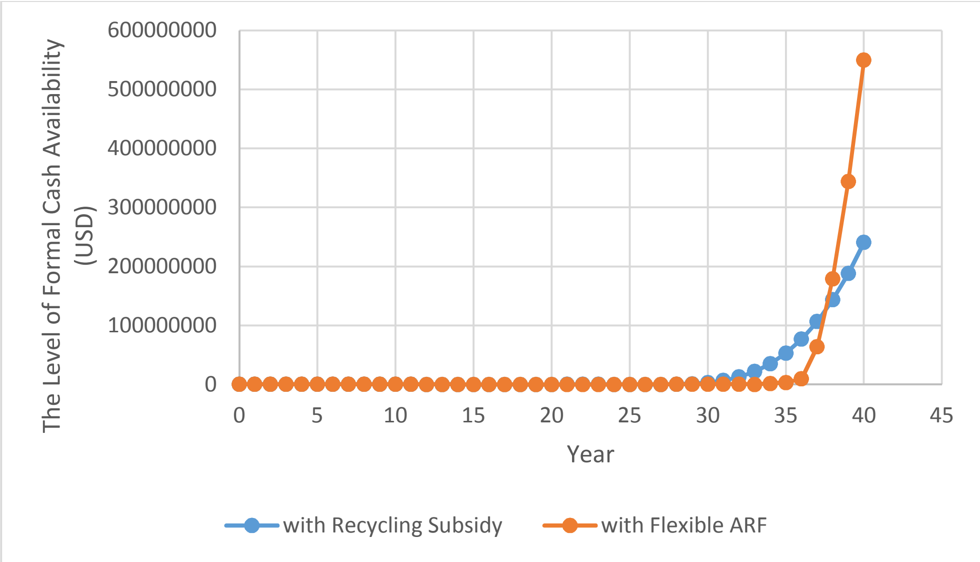

Figure 51. The Behavior of *Formal_Cash_Availability* under Recycling Subsidy and Flexible ARF Scheme in the Developing Country Model

Figure 50 illustrates the behavior of *Formal_Cash_Availability* under different financing schemes. Here, it is obvious that the formal sector would face the best financial condition under the fixed ARF scheme. This fixed ARF and deposit-refund scheme provide earlier fresh money for the systems. During the first decade of the initiation, the formal sector boosts its cash with 38.86% average annual growth rate under the former scheme and 37.94% under the latter. However, while it is still in the growing state under the former, the rise of the formal cash reaches its limit at the 37th year under the latter. This year marks the start of a declining state under the deposit-refund scheme. Moreover, to clarify the graphical illustration for the systems' behaviors, this study zooms in the level of *Formal_Cash_Availability* under flexible ARF and recycling subsidy scheme in figure 51. Here, it is clear that the formal sector requires a long time to finally establish its profitability under flexible ARF, as compared to the recycling subsidy. After a decade of stagnancy under the former, finally, the formal cash started to increase exponentially at the 34th year, lapses 14 years after the enactment of WEEE-specific regulation.

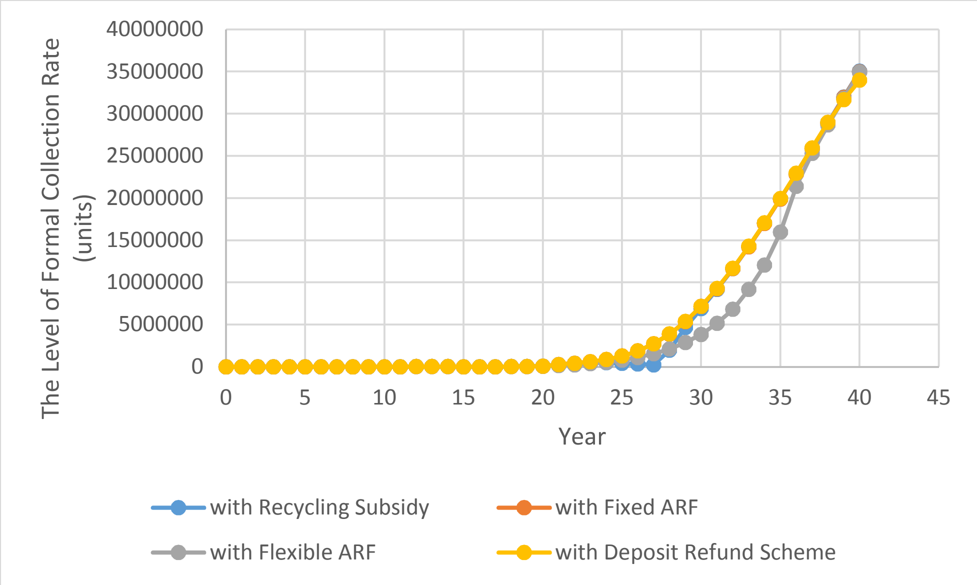

Figure 52. The Level of Formal Collection under Different Financing Schemes in the Developing Country Model

(in this graph, the orange and blue lines overlap with the yellow ones)

To conclude, the utilization of the fixed ARF and deposit-refund scheme provides a higher level of economic sustainability for the formal sector in the developing country case. The magnitude of the cash in the former cases are many times higher as compared to the recycling subsidy and flexible ARF. Since the level of *Formal_Collection_Rate* under all schemes (figure 52) illustrates a similar nature of behavior, the aforementioned conclusion is plausible. One should remain cautious, however, in transferring this conclusion into the real-world situation in the developing countries. There exist other additional influences associated with the selected financing schemes, especially the related transaction costs and the extra burden to administrate the record. These influential factors were omitted in this study to simplify the structures of the model.

5.2.2 Assessing the Impact of Regulation Absence and Recycling Subsidy on the Formal Sector in the Developing Country Model

This section is dedicated to assessing exclusively the impact of two factors of policy instruments on the operational and economic sustainability of the formal sector in the developing country case. These factors are *Time_without_Legislation,* and *Recycling_Subsidy* and – based on ANOVA – significantly influence the level of *Formal_Collection_Rate* and *Formal_Cash_Availability.* The former influential factor represents the quickness of a particular country to finally introduce a WEEE regulation. The latter factor clearly characterizes the level of the government subsidy for the certified recyclers to ensure the continuity of its recovery operation.

To accomplish the objective here, this study conducts more experiments using a different level of the influential factors, i.e. 0 – 30 years for *Time_without_Legislation* and USD 0 – 15 per product for *Recycling_Subsidy* and then simulates the model for 40 years as the simulation horizon. Figures 53 and 55 show a surface plot representing the impact of this two-way interaction on the behaviors of the formal sector.

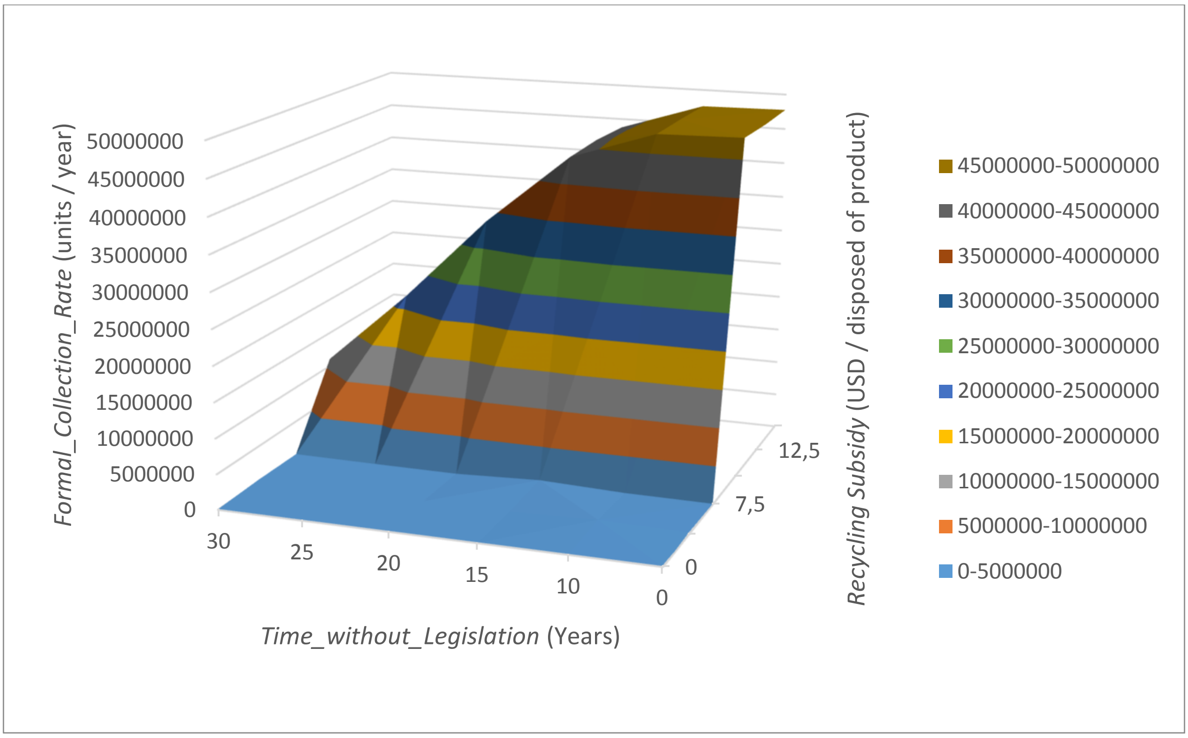

Figure 53. A Surface Plot Representing the Level of *Formal_Collection_Rate* based on the Influence of *Time_without_Legislation* and *Recycling_Subsidy*

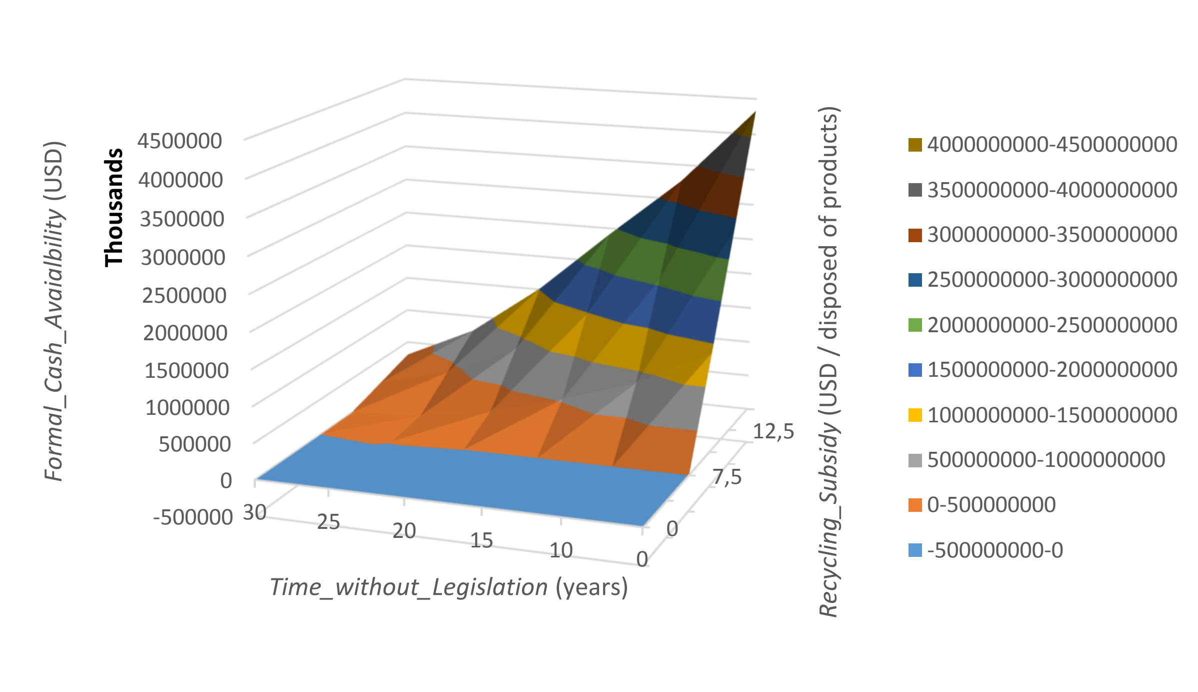

Figure 54. A Surface Plot Representing the Level of *Formal_Cash_Availability* based on the Influence of *Time_without_Legislation* and *Recycling_Subsidy*

Figures 53 and 54 reveal a higher significance of *Recycling_Subsidy* as compared to *Time_without_Legislation.* As clearly seen in the figures, the formal systems could not operate normally and become profitable, unless they are subsidized by the government with more than USD 7.5 per product. Only after this point, *Time_without_Legislation* might significantly influence *Formal_Collection_Rate* and *Formal_Cash_Availability.* The operations and the profit of the formal sector will then increase, as the level of *Recycling_Subsidy* rises and *Time_without_Legislation* declines. The results here, hence, suggest the following implications:

- The developing countries need to set up an effective WEEE-specific legislation as soon as possible, especially for a country with an already growing trend of WEEE generation and the huge presence of the informal sector and the secondary market. Otherwise, such countries would be caught up in a complicated and problematic situation where no single solution may solve the WEEE problems.
- The government in the developing countries are required to support the funding for the recycling systems, ensuring a sufficient amount of money for the formal systems. Otherwise, the formal sector might never be able to achieve the profitable state. Here, at least a certain limit of subsidy should be provided as a leverage for the systems. However, as has been noted by Chi et al. (2014), a particular government should

subsidize the formal sector only for a temporary period and needs to find other funding sources which may sustain the systems. If the government want to ensure the sufficient funding accordingly, the alternative funding should cover at least the secure level of the utilized recycling subsidy.

5.2.3 Assessing the Integration of the Informal Workers to the Formal Collection in the Developing Country Model

This section is devoted to assessing one of the suggested ways to solve the problems of the informal sector in the developing countries, i.e. integrating this sector into the whole nation's WEEE management systems. Based on several studies, such option, conceptually, provides a better sustainability for the systems and practically have produced some promising results (Besiou et al., 2012; GIZ, 2011). Therefore, the policy analysis here attempts to propose and conceptualize, in a more detailed structure, the required process of such integration. Then, this study will observe the impact of this policy option on several selected indicators.

5.2.3.1 The Model Structure under the Integration of the Informal Sector

This study constructs the following stock-flow diagram in Figure 55 to execute the integration of the informal sector in the model under study.

Figure 55 represents the financial structure of the formal sector in which the integration of the formal sector would appear. This formal sector requires the following two conditions to be fulfilled before the integration takes place. It includes:

- The government should already introduce the WEEE-specific legislation, i.e. when *Time_without_Legislation* have ceased to exist within the model.
- The level of *Formal_Cash_Availability* should exceed a certain amount of secure financial level.

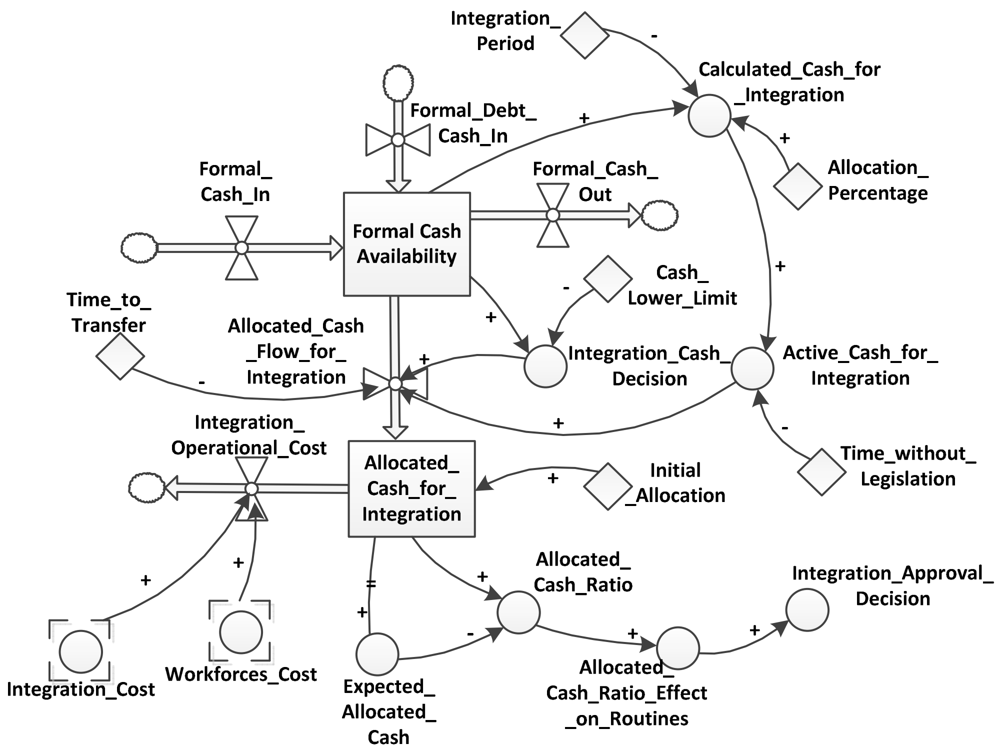

Figure 55. The Simplified Stock-Flow Diagram of the Financial Mechanism to Integrate the Informal Sector

If the above conditions were satisfied, an *Allocated_Cash_Flow_for_Integration* would arise in the systems, flowing into the stock of *Allocated_Cash_for_Integration.* Consequently, to fulfill the first requirement, this study uses the following equations.

$$Calculated\_Cash\_for\_Integration = PULSE((Allocation\_Percentage * Formal\_Cash\_Availability), STARTTIME + Integration\_Period, Integration\_Period) \quad (45)$$

$$Active\_Cash\_for\_Integration = IF(TIMEIS(STARTTIME, Time\_without\_Legislation, 0 \ll USD \gg, Calculated\_Cash\_for\_Integration) \quad (46)$$

For the second condition, it is simply determined by this equation:

$$Integration\_Cash\_Decision = IF(Formal\_Cash\_Availability \geq Cash\_Lower\_Limit, 1, 0) \quad (47)$$

Altogether, the aforementioned equations determine *Allocated_Cash_Flow_for_ Integration* as follows:

$$Allocated\_Cash\_Flow\_for\_Integration = Active\_Cash\_for\_Integration * Integration\_Cash\_Decision \quad (48)$$

The integration process also utilizes a calculation to determine the operational cost for the integration:

$$Integration\_Operational\_Cost = Formalization\_Cost + Workforces\_Cost \quad (49)$$

$$Formalization\_Cost = Formalization\_Cost\_per\_Worker * Integration\_Rate \quad (50)$$

$$Workforces\_Cost = Integrated\_Workers * Integrated\_Worker\_Wage \quad (51)$$

The formal sector provides a higher level of wages to the integrated workers, as compared with the informal sector.

$$Integrated\_Worker\_Wage = Weight\_for\_Wage * Informal\_Wage \quad (52)$$

This study uses the structure in figure 56 to determine the informal wage. One should notice that the utilized structure here is an enhanced one, different from the constant value of the base case and scenario analysis.

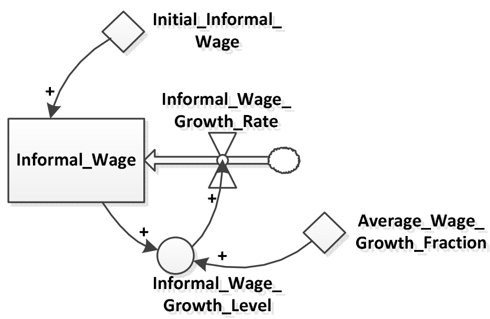

Figure 56. The Structure of the Calculation of *Informal_Wage*

Subsequently, figure 57 shows the structure of the integration process and the impact of such process to the collection activities of the formal sector.

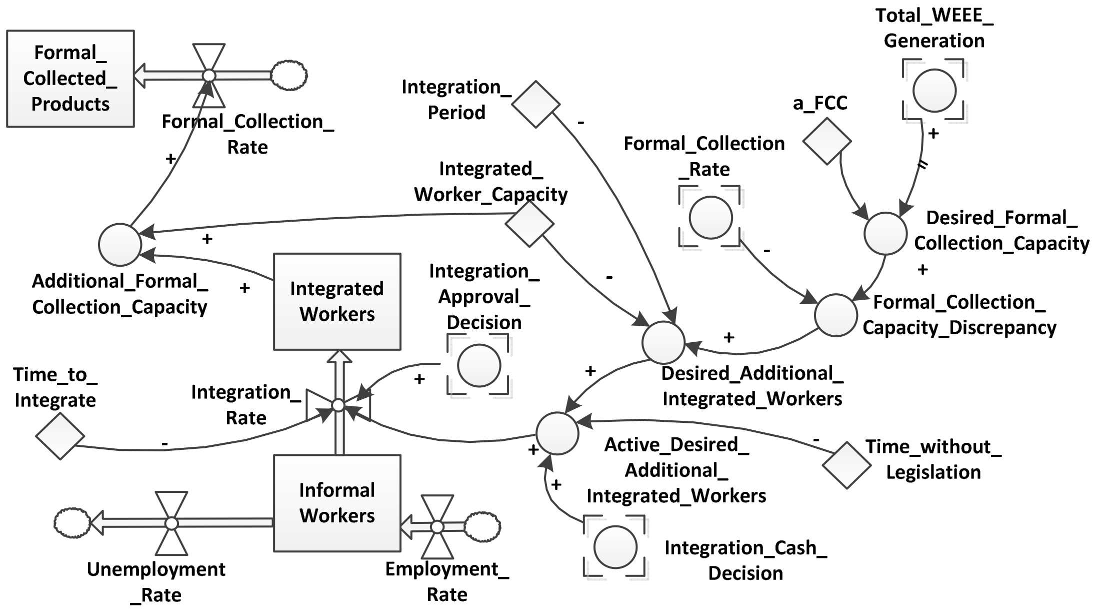

Figure 57. The Simplified Stock-Flow Diagram of the Operational Mechanism to Integrate the Informal Sector

In this figure, the level of *Informal_Workers* is diminished by *Integration_Rate,* rising the number of *Integrated_Workers.* The latter stock variable then influences an additional capacity for the formal sector. The equations of this relationship are as follows:

$$Desired\_Additional\_Integrated\_Workers = PULSE((Formal\_Collection\_Capacity\_Discrepancy / Integrated\_Worker\_Capacity), STARTTIME + Integration\_Period, Integration\_Period) \quad (53)$$

$$Active\_Desired\_Additional\_Integrated\_Worker = (IF(TIMEIS(STARTTIME, Time\_without\_Legislation), 0 << people >>, Desired\_Integrated\_Workers)\ ) * Integration\_Cash\_Decision \quad (54)$$

$$Integration\_Rate = (MAX\ ((MIN\ (Informal\_Workers, Active\_Desired\_Integrated\_Workers) / Time\_to\_Integrate), 0)) * Integration\_Approval\_Decision \quad (55)$$

$$Additional\_Formal\_Capacity = Integrated\_Workers * Integrated\_Worker\_Capacity \quad (56)$$

The presence of *Integration_Approval_Decision* in equation 55 means that the integration process will be affected by the condition of the allocated cash, using the same decision structures as for the *Formal_Cash_Availability*. Finally, to execute the policy analysis into the models, this study uses the additional selected assumptions for the parameter values which appear in table 31. One should notice that this section intentionally puts two levels of *Time_without_Legislation* in table 31 because the previous analysis has revealed its significances. Through this intervention, the following analysis may observe the emerging behavior under different nature of the legislation absence.

Table 31. Additional Parameter Values of the Analysis for Integrating the Informal Sector

Variable	Description	Value
Integration_Period (year)	The period when the integration process appears	0.5
Allocation_Percentage (%)	Percentage of the formal cash dedicated to integrating the informal sector	5
Initial_Allocation (USD)	The initial level of allocation at the beginning of simulation period	1,000,000
Cash_Lower_Limit (USD)	A lower limit to secure the formal cash when integration takes place.	5,000,000
Time_without_Legislation (year)	The gap time between the start of simulation and the time when the WEEE legislation finally comes into force	10 and 20
Formalization_Cost_per_Worker (USD / people)	Cost required integrating a single informal worker	20
Weight_for_Wage (dimensionless)	A constant representing a higher magnitude of the integrated worker's wage as compared with the informal one	1.5
Initial_Informal_Wage (USD / month / people)	Wage for a single informal worker at the beginning of the simulation	15
Average_Wage_Growth_Fraction (%)	A growth rate of the informal wage	5
Integrated_Worker_Capacity (unit/week/people)	Capacity of a single integrated worker to collect WEEE	6
Time_to_Integrate (year)	The length of a single integration period	0.5

5.2.3.2 The Result of Policy Assessment when Integrating the Informal Sector

This section provides several selected indicators under the integration policy. Also, it shows the comparison between the behavior of the systems with and without such policy. Figures 58 to 64 depict the specific indicators for the integration process.

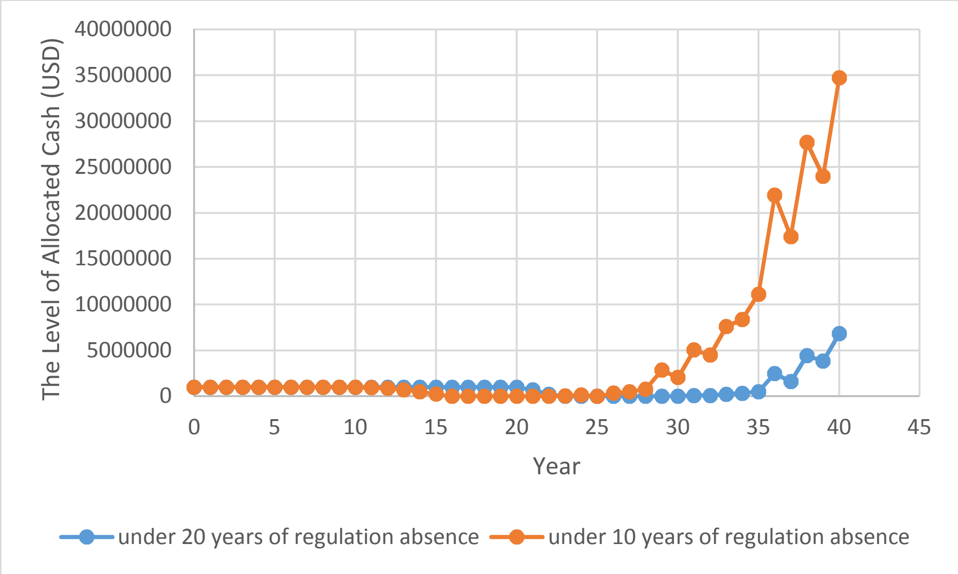

Figure 58. The Level of *Allocated_Cash_for_Integration* under the Integration Policy

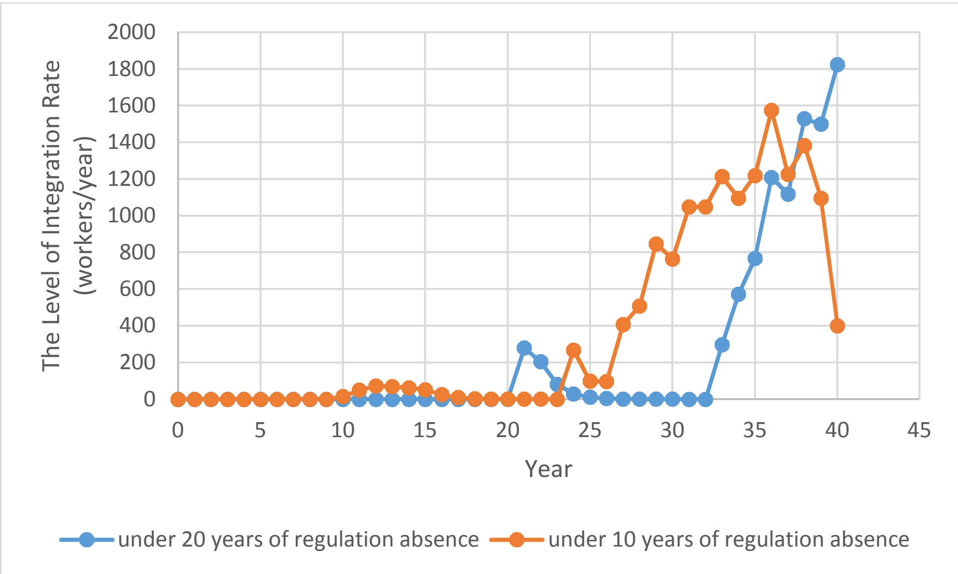

Figure 59. The Level of *Integration_Rate* under the Integration Policy

In figures 58 and 59, the systems start to behave dynamically as the integration process takes place after the cease of *Time_without_Legislation,* 10 years of absence for the former and 20 years for the latter. In the case of the former, the integration process progresses at a relatively small rate during the first decade, depleting *Allocated_Cash_for_Integration.* Since this cash level also covers the wage for the integrated workers, *Allocated_Cash_for_Integration* diminishes significantly and reaches a zero level between the 16th and 22nd year of the horizon, pushing the formal sector to hold the integration process. Finally, the *Allocated_Cash_for_Integration* starts to flourish from the 26th year onwards, securing the future cash for this policy. Nevertheless, this case observes a fall of *Integration_Rate* at the very end of the horizon. This phenomenon happens, not because of the failure of the integration process *per se*, rather because the presence of a collapse in the informal sector as will be discussed in the following sections. For the latter case, the integration process has a quick start during the first two years, only to face a zero level of allocated cash in the remaining years of a decade. Therefore, *Integration_Rate* has to be limited from the 23rd year until the beginning of the third decade. Not until the 33rd year finally, *Integration_Rate* climbs up significantly, surpassing the same variable of the former at the 38th year. It should be noted here, that these higher numbers of the latter at the very last years are not the signal of a better condition as the integration process under the former is limited by the fall of the informal sector.

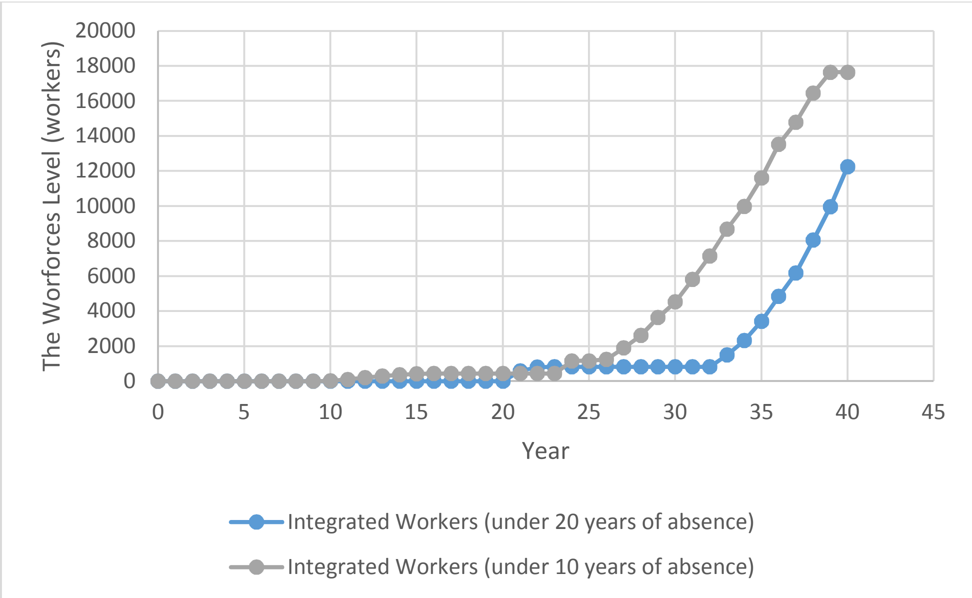

Figure 60. The Level of *Integrated_Workers* under the Integration Policy

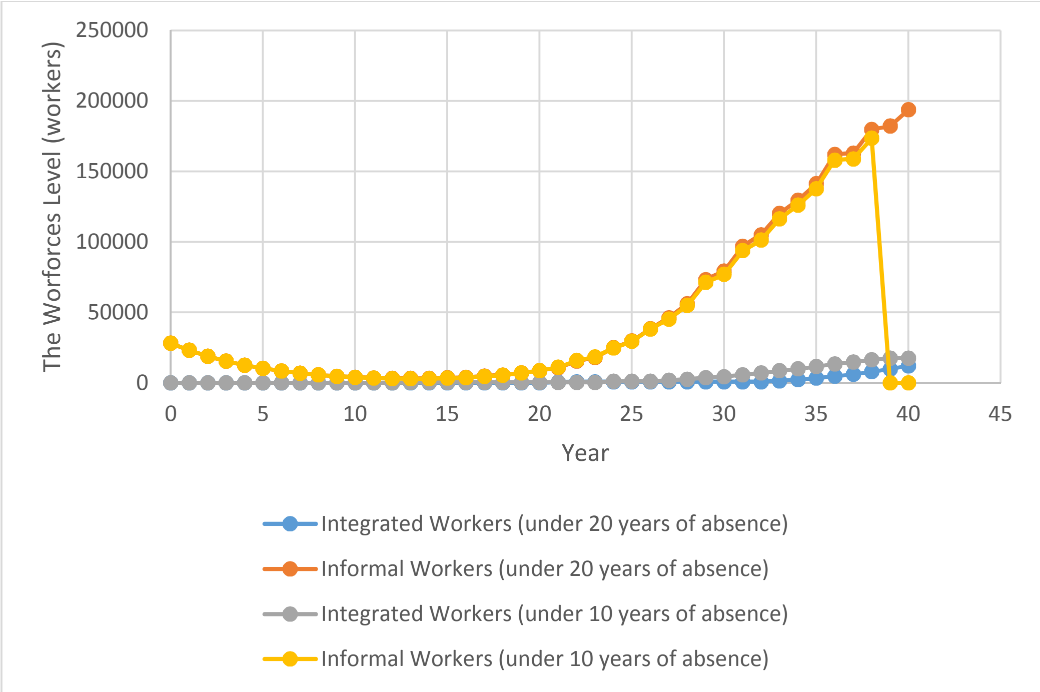

Figure 61. The Level of *Integrated_Workers*, as compared with *Informal_Workers* under the Integration Policy

Figures 60 and 61 exhibit the level of *Integrated_Worker* during the entire simulation period. Initially, it reveals a higher achievement of the integration process under a less long time of absence. Under the 10 years of absence, the size of *Integrated_Workers* has averagely tripled as compared to the longer absence. Subsequently, figure 61 illustrates the behavior of this stock variable in the perspective of *Informal_Workers.* As clearly seen, the size of *Integrated_Workers* in both cases is obviously insignificant as compared to *Informal_Workers.* Also, this study observes a collapse of *Informal_Workers* at the 39th year. This phenomenon, however, was not caused mainly by the presence of the integration policy. This notion will be elaborated in the remaining parts of this section. The following figures show a comparative perspective of the systems' behavior with and without the integration policy.

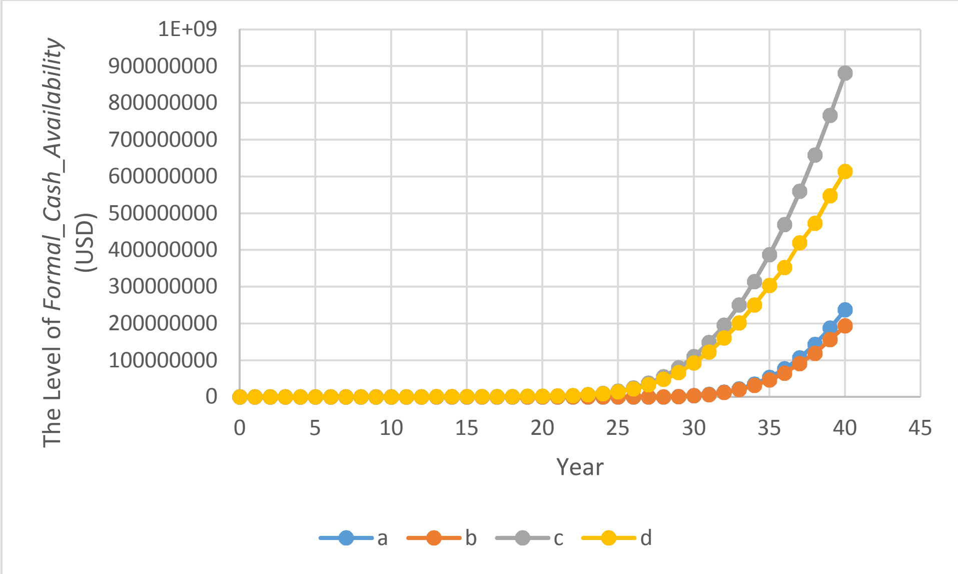

Figure 62. The Level of *Formal_Cash_Availability* with and without the Integration of Informal Sector

(a = 20 years of absence without integration, b = 20 years of absence with integration, c = 10 years of absence without integration, d = 10 years of absence with integration)

Figure 62 exhibits the behavior of *Formal_Cash_Availability* under the influence of the policy and different values of *Time_without_Legislation*. Initially, this figure reveals the impact of the integration process on the level of formal cash, i.e. a lower level of cash under the activeness of the integration policy. At the end of the 40th year, the cash levels are approx. 18% and 30% lower for the 20 and 10 years of absence, respectively. These lower levels indicate the presence of outflow cash to support the operations. Though existing, the impact is still marginal, as curves "a" and "b" or "c" and "d" illustrate similar behaviors. It is, however, *Time_without_Legislation* which actually causes significant differences in the systems' behavior. The presence of a lower value for this influential factor significantly increases the magnitude of *Formal_Cash_Availability,* i.e. up to ten times higher in the last decade of the 10 years of absence.

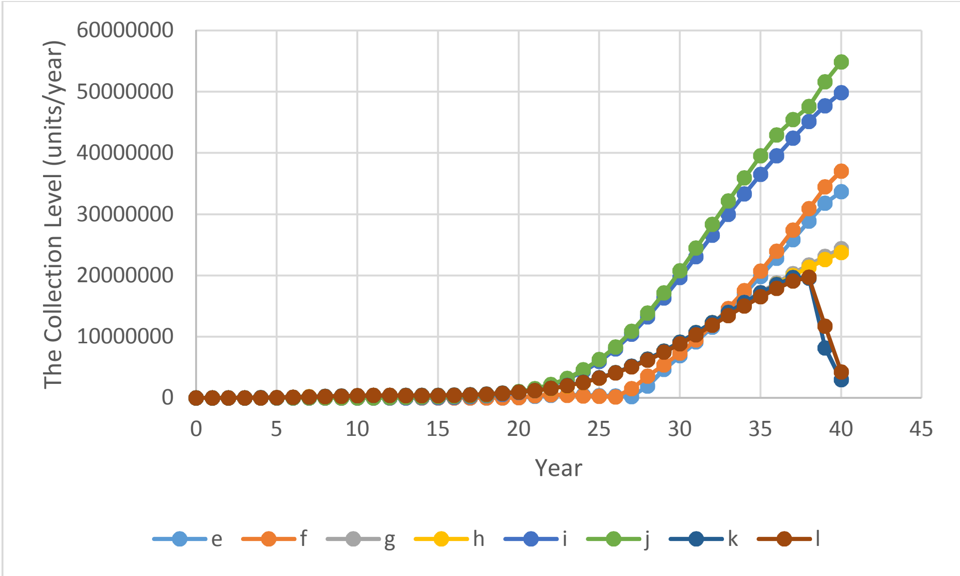

Figure 63. The Collection Level with and without the Integration of Informal Sector

(e = Formal Collection * without Integration * 20 years of absence, f = Formal Collection * with Integration * 20 years of absence, g = Informal Collection * without Integration * 20 years of absence, h = Informal Collection * with Integration * 20 years of absence, i = Formal Collection * without Integration * 10 years of absence, j = Formal Collection * with Integration * 10 years of absence, k = Informal Collection * without Integration * 10 years of absence, l = Informal Collection * with Integration * 10 years of absence)

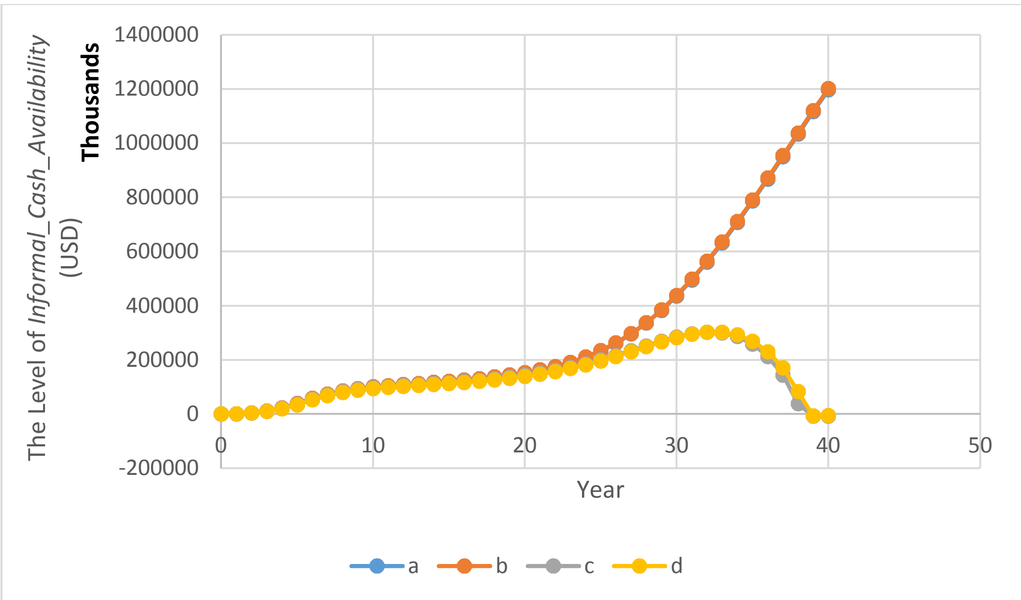

Figure 64. The Level of *Informal_Cash_Availability* with and without the Integration of Informal Sector

(a = 20 years of absence without integration, b = 20 years of absence with integration, c = 10 years of absence without integration, d = 10 years of absence with integration; in this graph, the blue lines and dots overlap with the orange ones and gray lines and dots overlap with the yellow ones)

Figure 63 shows the behavior of collection activities, formal and informal, under the influence of integration policy and *Time_without_Legislation.* First of all, figure 63 confirms the influence of integration policy to increase the formal collection and holds the informal one, albeit limited. Here, it is more convincing to state that *Time_without_Legislation* plays a more important role in the models, as the collapse of informal collection happens under a shorter absence of WEEE-specific regulation. This fall appears because the informal cash seems to bear too much burden of the informal operation. A further examination is required to answer why such fall happen, even though the growing used market has been applied for the policy analysis. This effort then reveals the presence of a significant interaction, causing the failure of the informal sector. This interaction is formed by three decisive factors: (1) a shorter absence of *Time_without_Legislation,* (2) growing used market, and (3) growing wage structure within the informal sector. The growing market drives the expansion of the informal operation, whereas the increasing wage causes the increase of informal operation cost. These two factors, if combined with the fast arrival of the legislation, increases the burden of informal cash significantly, causing a presence of diminishing state at the 34^{th} year of simulation period (in figure 64). Soon, the informal sector faces an out-of-cash, influencing a collapse of its informal workforces and inevitably ceasing the recovery operation to exist.

To conclude, the enactment of integration policy decreases the number of informal workers and thus the level of informal collection. It also increases the level of formal collection and decreases the formal cash availability, proportionally. Though the behaviors of the systems with and without integration policy do not differ significantly, these results are promising for the real-world implementation. In practical terms, the results suggest that it is possible to produce several notable outcomes in the same time using the integration policy: giving a formal job with a relatively higher salary to marginalized persons, saving them from the crude operation of the informal sector, and increasing the collection level of the formal sector. Hence, this study suggests the early consideration for integrating the informal sector in the proposal of a new WEEE-specific regulation or an amendment for such regulatory approach.

Chapter 6 Conclusion

This chapter aims to summarize the results and findings from the previous sections. It also promotes some practical insights for the policy makers for the improvement on how to deal with the issues discussed. Lastly, the limitations of this study are discussed and the outlook for the future research is remarked.

6.1 Main Findings

This study intends to become a valuable part of the global initiatives, solving the emerging WEEE problems. It deals with the comparative efforts to assess the WEEE management systems of the developed and the developing countries and to extract the lessons learned for the future development of the systems, especially in the developing ones. As the recent research stream lacks the presence of the proper framework for a comparative work, this thesis attempts to propose a *systematic* – incorporating system thinking perspective – and *integrative* – combining the qualitative and the quantitative approaches – framework to deal with the issue. Particularly, there are several important questions raised by this thesis, namely:

“What are the WEEE issues existing within the developed and developing countries?”

To answer the first question, the qualitative approach in this study found the presence of the main issues in the developing region, i.e. the increasing WEEE generation from the domestic user, the high quantity of illegal WEEE import, the dominant presence of the informal sector, the long-term absence of WEEE-specific legislation, the lack of consumer awareness, and the failures of several take-back initiatives and pilot projects, on the one hand. On the other hand, it figured out a similar increasing trend of WEEE generation, the issue of illegal export from the source countries, an increasing attention – albeit limited – for the presence of the informal waste sector, the attempts to achieve a higher collection and recycling target, and the concern of the waste streams outside of official collection and recycling in the developed systems.

“What are the determinants of the WEEE issues the within developed and developing countries?”

From the qualitative approach, this study found the main determinants of the WEEE systems in the developing countries, i.e. uneven regional development within a country for the most defining exogenous factor and the high number of illegal WEEE import and the long-term absence of the WEEE specific legislation. For the developed region, this study found a long socio-historical basis for giving a higher priority to the waste issues and the significant presence of the legislation and take-back initiatives as the main driving forces.

From the base case and the sensitivity analysis from the SD approach, this study revealed that the secondary market plays an important role for the presence of the informal sector. Because the informal sector is so dominant in the developing countries, consequently, the status of the secondary market is elevated as one the main determinants in this region.

The ANOVA analysis revealed several additional main determinants for the systems. In the developed country, there appear several main interactions within the systems, including the combination between either the scavenger capacity or the level of refurbishment percentage with the informal job duration and the interaction between the advance recycling fee with several other factors. For the developing systems, there are a plethora of main interactions which means almost every selected factor might become dominant when they interact with another factor. Nevertheless, the significant presence of illegal import is again witnessed here. Also, it is noteworthy to mark the importance of the absence of legislation in the developing countries. The policy analysis further confirmed the status of this absence and also revealed a more important role of the recycling subsidy in this region.

"How is the dynamics of WEEE management systems within the developed and developing countries?"

In general, this study found the stable nature and dominant position of the formal systems with its growth in the developed region. Whereas this official sector suffers from instability within the developing countries. Remarkably, the informal sector in the developed country might also enjoy a stability, albeit limited and isolated in nature, if the growing secondary market exists. The influential and dominant position of the informal sector in the developing countries should again be noted as it enjoys its growth for a long-term period, even continuously for decades in the case of a growing used market.

"Are the answers to the previous questions mutually exclusive between both of the countries' categories?"

No, they are not completely different. This study found similarities of the issues between the two types of regions. There is an increasing trend of WEEE generations, the lack of consumer awareness, just to name a few. But most importantly, the matter of illegal movement of WEEE cannot be seen as a partial issue. This issue presents the gap between the developed and the developing regions and interconnects, historically and until recently, the WEEE management systems in the two regions.

6.2 Policy Recommendations and Suggestions

This part of the thesis highlights the answer to the last question:
"Which policy options are suitable to tackle the WEEE issues for both country's categories?"

Since the presence of the WEEE legislation has been so significant in the developed regions, this study suffices the recommendations for the developed country with only promoting the reuse and the refurbishment sectors as the means to divert the waste from the landfilling. As the presence of the reuse consideration by the official systems is somehow limited in this region, the academia may take the initiative by assessing the current situation and the magnitude of these two sectors within the developing regions. The policy makers may also start to consider the presence of these sectors in the future legislation and the collection schemes. Also, a clear definition, distinction, and classification of the UEEE and WEEE should be set-up and then harmonized in the international community to ensure that this effort does not translate to a higher rate of illegal waste movement (Milovantseva and Fitzpatrick, 2015). This notion leads to the issue of the transboundary movement. A proper and efficient mechanism should be set up to control the borders. The present gaps between the approaches and the legislation between the two systems also should be addressed and then minimized in a concrete manner.

The plethora of the main interactions within the developing countries suggests that an easy, simple, and partial solution would be infeasible, if not impossible, to solve the problems of WEEE. Hence, a holistic and multi-perspective approach should be developed. Initially, the issue of the informal sector in this region should be addressed properly. The solutions for this issue should be kept away from the two extreme sides: on the one hand from cracking down the entire informal recycling sector without considering the side effects such as higher unemployment, and on the other hand, leaving this sector to run business-as-usual, thus, e.g. exposing the informal workers to the more acute health situation. The solutions that conform to sustainability pillars may be encouraged. The way to enhance the informal sector should be developed because it is conceptually better for the sustainability (Besiou et al., 2012) and practically achievable (GIZ, 2011). It may be accomplished through the integration of the informal sector into the formal one and building its capacity and environmental awareness in recovering the WEEE. This integration and capacity building processes should already be considered and included in the proposal of a new WEEE-specific regulation or an amendment for such regulatory approach. It is also suggested that the implementation of this integration should be conducted in a series of pilot projects rather than a direct complete nationwide implementation. As the experiences increase, the ways to improve the integration process might be developed adequately and then a nationwide program can be implemented.

Also, this study suggests that the informal sector in the developing world did not arise in a vacuum. The promoted solutions need to explore a cross-sector collaboration, including the fields of economics, education, agriculture, and urban planning. Hence, the upstream sides of the problems, providing the informal sector with the adequate number of the migrant workers from the rural to the urban areas, also might be solved. It is also vital to understand the real nature of the secondary market of EEE, the downstream side of the informal systems in the developing region. The economic size of this sector should be assessed in a more comprehensive manner. Then, instead of forcing a rigid standardization for this lucrative sector, the policy makers may perform a joint collaboration with academia to empower this sector, e.g. by giving a workshop on how to adequately refurbish and repair the EEE and how to conduct a simple accounting or marketing.

Furthermore, this study supports the initiation of the drafting process for any country with the absence of the WEEE-specific legislation. This regulation should comprehensively consider the presence of relevant stakeholders, including the informal recycling sector and the refurbishment sector. This regulation should also progress the involvement of the producers, instead of enforcing a direct responsibility. Initially, the government may offer an incentive mechanism for the producers to set-up their own take-back systems. Afterwards, the full EPR-based regulation may take place either by setting up PROs or running the individual collection systems. For the financing within the regulation, the initial recycling subsidy may be provided. After several years of sustainable operations, the regulation may create a transition period to decrease the subsidy and then set up the ARF or deposit-refund mechanism.

6.3 Limitation and Outlook

This study acknowledges several limitations, which offer directions for the future research. To simplify the qualitative analysis for the developing countries, this study focuses on the assessment of three countries: China, India, and Nigeria. It is useful to include more developing countries from other continents, e.g. Romania from Europe and Brazil from South America. This study has also a limitation with the generalization of the situations within the developed countries. In fact, apart from having similar landscapes, each developed country might have a unique set of characteristics which will influence the behavior of the systems. Hence, it is also important to include a country-specific analysis from the developed countries.

The SD models (i.e. the developed and the developing country model) in this study are limited to the isolation of the analysis for each model. This kind of treatment is selected to simplify the simulation process. In reality, WEEE management systems in the developed and developing countries have been interacting simultaneously in an interconnected world. Therefore, it would be so beneficial if the future studies could develop a global stock-flow model of WEEE systems. Such huge model may help to understand the dynamics of the illegal transboundary movement and the impact of a standardization of the global WEEE treatments on the sustainability of the systems.

Lastly, the results of this study are also subjected to the synthesized parameters, with its limitation. Hence, the issue of replicability of the model may rise. Therefore, additional empirical studies accompanied by data enhancement are necessary to give a deeper understanding, especially for the realities of the informal sector and the secondary market in the developed and developing countries.

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Appendix

Generic Mathematical Formulation behind the System Dynamics Model

1. Bass Model

No	Variable Name	Type of Variable	Unit	Equation
1.	Total_Population	Stock	[customer]	*Total_Population* (0) = *Initial_ Population* *Total_Population* (*t*+d*t*) = *Total_Population* (*t*) + d*t* * *Growth_Fraction*
2.	Primary_Products_ Adopters	Stock	[customer]	*Primary_Products_Adopters* (0) = 0 *Primary_Products_Adopters* (*t*+d*t*) = *Primary_Products_Adopters* (*t*) + d*t* * *Adoption_Rate*
3.	Population_Increasing_ Rate	Flow	[customer / year]	*Population_Increasing_Rate* = *Growth_Fraction* * *Total_Population*
4.	Adoption_Rate	Flow	[customer / year]	*Adoption_Rate* = *Adoption_from_Advertising* + *Adoption_from_WOM*
5.	Adoption_from_Advertis ing	Auxiliary	[customer / year]	*Adoption_from_Advertising* = *Potential_Adopters* * *Innovation_Fraction*
6.	Adoption_from_WOM	Auxiliary	[customer / year]	*Adoption_from_WOM* = *Primary_Product_Adopters* * *Adoption_Fraction* * *Contact_Rate* * *Potential_Adopters / Total_Population*
7.	Potential_Adopters	Auxiliary	[customer]	*Potential_Adopters* = *MAX (Total_Population – Primary_Product_Adopters, 0)*
8.	Initial_Purchase_Rate	Auxiliary	[unit / year]	*Initial_Purchase_Rate* = *Adoption_Rate* * *Initial_Sales_per_Adopter*
9.	Repeat_Purchase_Rate	Auxiliary	[unit / year]	*Repeat_Purchase_Rate* = *Primary_Product_Adopters* * *Average_Consumption_per_Adopter*
10.	Total_Sales_Rate	Auxiliary	[unit / year]	*Total_Sales_Rate* = *Initial_Purchase_Rate* + *Repeat_Purchase_Rate*

2. Waste Generation

No	Variable Name	Type of Variable	Unit	Equation
1.	Total_WEEE_ Generation	Auxiliary	[unit / week]	*Total_WEEE_Generation = Obsolete_Product_on_First_Year + Obsolete_Product_on_Second_Year + Obsolete_Product_on_Third_Year + Obsolete_Product_on_Fourth _Year + Obsolete_Product_on_Fifth _Year + Obsolete_Product_on_Sixth_Year + Obsolete_Secondary_Products*
2.	Obsolete_Product_on_ First_Year	Auxiliary	[unit / week]	*Obsolete_Product_on_First_Year = DELAYMTR (Total_Sales_Rate * First_Year_Distribution, 1, 3, 0)*
3.	Obsolete_Product_on_ Second_Year	Auxiliary	[unit / week]	*Obsolete_Product_on_Second_Year = DELAYMTR (Total_Sales_Rate * Second_Year_Distribution, 2, 3, 0)*
4.	Obsolete_Product_on_ Third_Year	Auxiliary	[unit / week]	*Obsolete_Product_on_Third_Year = DELAYMTR (Total_Sales_Rate * Third_Year_Distribution, 3, 3, 0)*
5.	Obsolete_Product_on_ Fourth_Year	Auxiliary	[unit / week]	*Obsolete_Product_on_Fourth_Year = DELAYMTR (Total_Sales_Rate * Fourth_Year_Distribution, 4, 3, 0)*
6.	Obsolete_Product_on_ Fifth_Year	Auxiliary	[unit / week]	*Obsolete_Product_on_Fifth_Year = DELAYMTR (Total_Sales_Rate * Fifth_Year_Distribution, 5, 3, 0)*
7.	Obsolete_Product_on_ Sixth_Year	Auxiliary	[unit / week]	*Obsolete_Product_on_Sixth_Year = DELAYMTR (Total_Sales_Rate * Sixth_Year_Distribution, 6, 3, 0)*
8.	Obsolete_Secondary_ Products	Auxiliary	[unit / week]	*Obsolete_Secondary_ Products = DELAYMTR (Secondary_Sales_Rate, Secondary_Products_Residence_Time, 3, 0)*

3. Formal Reverse Logistics

No	Variable Name	Type of Variable	Unit	Equation
1.	Formal_Collected_Products	Stock	[unit]	*Formal_Collected_Products* (0) = 0 *Formal_Collected_Products* (*t*+d*t*) = *Formal_Collected_Products* (*t*) + d*t* * *Formal_Collection_Rate* – d*t* * *Refurbishment_Acceptance_Rate* – d*t* * *Refurbishment_Rejection_Rate*
2.	Refurbishable_Products	Stock	[unit]	*Refurbishable_Products* (0) = 0 *Refurbishable_Products* (*t*+d*t*) = *Refurbishable_Products* (*t*) + d*t* * *Refurbishment_Acceptance_Rate* - d*t* * *Refurbishment_Rate* - d*t* * *Refurbishment_Disposal_Rate*
3.	Rejected_Products	Stock	[unit]	*Rejected_Products* (0) = 0 *Rejected_Products* (*t*+d*t*) = *Rejected_Products* (*t*) + d*t* * *Refurbishment_Rejection_Rate* - d*t* * *Treatment_Rate*
4.	Treated_Products	Stock	[unit]	*Treated_Products* (0) = 0 *Treated_Products* (*t*+d*t*) = *Treated_Products* (*t*) + d*t* * *Treatment_Rate* + d*t* * *Refurbishment_Disposal_Rate* - d*t* * *Recycling_Acceptance_Rate* - d*t* * *Recycling_Rejection_Rate*
5.	Formal_Recyclable_Products	Stock	[unit]	*Formal_Recyclable_Products* (0) = 0 *Formal_Recyclable_Products* (*t*+d*t*) = *Formal_Recyclable_Products* (*t*) + d*t* * *Recycling_Acceptance_Rate* - d*t* * *Formal_Recycling_Rate* - d*t* * *Recycling_Disposal_Rate*
6.	Controllably_Disposed_Products	Stock	[unit]	*Controllably_Disposed_Products* (0) = 0 *Controllably_Disposed_Products* (*t*+d*t*) = *Controllably_Disposed_Products* (*t*) + d*t* * *Recycling_Rejection_Rate* + d*t* * *Recycling_Disposal_Rate*

7.	Formal_Collection_Rate	Flow	[unit / week]	*Formal_Collection_Rate = (MAX (MIN (Total_WEEE_Generation, Active_Collection_Capacity * Total_WEEE_Generation, 0) * Formal_Approval_Decision*
8.	Refurbishment_Acceptance_Rate	Flow	[units / week]	*Refurbishment_Acceptance_Rate = MAX ((Refurbishment_Acceptance_Percentage) * (Formal_Collected_Products / Refurbishment_Inspection_Time), 0)*
9.	Refurbishment_Rate	Flow	[units / week]	*Refurbishment_Rate = MAX (MIN (Refurbishable_Products / Refurbishment_Time, Refurbishment_Capacity), 0)*
10.	Refurbishment_Disposal_Rate	Flow	[units / week]	*Refurbishment_Disposal_Rate = MAX (Refurbishable_Products / Formal_Stock_Keeping_Time, 0)*
11.	Treatment_Rate	Flow	[units / week]	*Treatment_Rate = MAX (Rejected_Products / Treatment_Time, 0)*
12.	Recycling_Acceptance_Rate	Flow	[units / week]	*Recycling_Acceptance_Rate = MAX (Treated_Products / Recycling_Inspection_Time, 0)*
13.	Formal_Recycling_Rate	Flow	[units / week]	*Formal_Recycling_Rate = MAX (MIN (Activated_Recycling_Capacity * Formal_Collection_Rate, Recyclable_Products / Formal_Recycling_Time),)*
14.	Recycling_Rejection_Rate	Flow	[units / week]	*Recycling_Rejection_Rate = MAX (Treated_Products / Formal_Stock_Keeping_Time, 0)*
15.	Recycling_Disposal_Rate	Flow	[units / week]	*Recycling_Disposal_Rate = MAX (Recyclable_Products / Formal_Stock_Keeping_Time, 0)*
16.	Active_Collection_Capacity	Auxiliary	[units / week]	*Active_Collection_Capacity = IF (TIMEIS (STARTTIME, Time_without_Legislation), Initial_Collection_Percentage, Collection_Capacity_Percentage)*
17.	Collection_Capacity_Percentage	Auxiliary	[units / week]	*Collection_Capacity_Percentage = DELAYMTR (Max_Collection_Percentage, Time_to_Achieve_Collection_Target, 3, Initial_Collection_Percentage)*
18.	Max_Collection_Percentage	Auxiliary	[units / week]	*Max_Collection_Percentage = IF (TIMEIS (STARTTIME, Time_without_Legislation), Initial_Collection_Percentage, Legislative_Collection_Percentage)*

19.	Expected_Refurbishment_Rate	Auxiliary	[units / week]	Expected_Refurbishment_Rate = DELAYINF (Refurbishment_Rate, a_ERR, 1, Refurbishment_Rate)
20.	Active_Recycling_Capacity	Auxiliary	[units / week]	Active_Recycling_Capacity = IF (TIMEIS (STARTTIME, Time_without_Legislation), Initial_Recycling_Percentage, Recycling_Capacity_Percentage)
21.	Recycling_Capacity_Percentage	Auxiliary	[units / week]	Recycling_Capacity_Percentage = DELAYMTR (Max_Recycling_Percentage, Time_to_Achieve_Recycling_Target, 3, Initial_Recycling_Percentage)
22.	Max_Recycling_Percentage	Auxiliary	[units / week]	Max_Recycling_Percentage = IF (TIMEIS (STARTTIME, Time_without_ Legislation), Initial_Recycling_Percentage, Legislative_Recycling_Percentage)
23.	Expected_Recycling_Rate	Auxiliary	[units / week]	Expected_Recycling_Rate = DELAYINF (Formal_Recycling_Rate, a_ReR, 1, Recycling_Rate)
24.	Max_Collection_Percentage	Auxiliary	[%]	Max_Collection_Percentage = IF (TIMEIS (STARTTIME, Time_without_Legislation), Initial_Collection_Percentage, Targeted_Collection_Percentage)

4. Informal Reverse Logistics

No	Variable Name	Type of Variable	Unit	Equation
1.	Informal_Collected_Products	Stock	[unit]	Informal_Collected_Products (0) = 0 Informal_Collected_Products (t+dt) = Informal_Collected_Products (t) + dt * Informal_Collection_Rate + dt * WEEE_Import_Rate - dt * Informal_Acceptance_Rate - dt * Illegal_Disposal_a
2.	Informal_Accepted_Products	Stock	[unit]	Informal_Accepted_Products (0) = 0 Informal_Accepted_Products (t+dt) = Informal_Accepted_Products (t) + dt * Informal_Acceptance_Rate - dt * Informal_Reuse_ Rate - dt * Informal_Refurbishment_Acceptance_Rate - dt * Informal_Recycling_Acceptance_Rate

3.	Secondary_Products_ Inventory	Stock	[unit]	*Secondary_Products_Inventory* (0) = 0 *Secondary_Products_Inventory* (*t*+d*t*) = *Secondary_Products_Inventory* (*t*) + d*t* * *Informal_Reuse_Rate* + d*t* * *Informal_Refurbishment_Rate* - d*t* * *Secondary_Products_Sales_Rate*
4.	Informal_Refurbishable_ Products	Stock	[unit]	*Informal_Refurbishable_Products* (0) = 0 *Informal_Refurbishable_Products* (*t*+d*t*) = *Informal_Refurbishable_Products* (*t*) + d*t* * *Informal_Refurbishment_Acceptance_Rate* + d*t* * *Informal_Recycling_Rate* - d*t* * *Informal_Refurbishment_Rate* - d*t* * *Illegal_Disposal_Rate_c*
5.	Informal_Recyclable_ Products	Stock	[unit]	*Informal_Recyclable_Products* (0) = 0 *Informal_Recyclable_Products* (*t*+d*t*) = *Informal_Recyclable_Products* (*t*) + d*t* * *Informal_Recycling_Acceptance_Rate* - d*t* * *Informal_Recycling_Rate* - d*t* * *Illegal_Disposal_Rate_b*
6.	Untreated_Products	Stock	[unit]	*Untreated_Products* (0) = 0 *Untreated_Products* (*t*+d*t*) = *Untreated_Products* (*t*) + d*t* * *Illegal_Disposal_a* + d*t* * *Illegal_Disposal_b* + d*t* * *Illegal_Disposal_c* + d*t* * *Illegal_Disposal_d*
7.	Informal_Collection_ Rate	Flow	[unit / week]	*Informal_Collection_Rate = ((MAX (MIN ((Total_WEEE_Generation-Formal_Collection_Rate), Informal_Collection_Capacity), 0*1))) * Informal_Approval_Decision*
8.	WEEE_Import_Rate	Flow	[unit / week]	*WEEE_Import_Rate = Annual_WEEE_Import_Rate*
9.	Informal_Acceptance_ Rate	Flow	[unit / week]	*Informal_Acceptance_Rate = MAX ((Informal_Acceptance_Percentage * Informal_Collected_Products) / Informal_Inspection_Time, 0)*
10.	Informal_Reuse_Rate	Flow	[unit / week]	*Informal_Reuse_Rate = MAX ((Informal_Reuse_Percentage * Informal_Accepted_Products) / Informal_Delivery_Time, 0)*

11.	Informal_Refurbishment_Acceptance_Rate	Flow	[unit / week]	*Informal_Refurbishment_Acceptance_Rate = MAX ((Informal_Refurbishment_Percentage * Informal_Accepted_Products) / Informal_Delivery_Time, 0)*
12.	Informal_Recycling_Acceptance_Rate	Flow	[unit / week]	*Informal_Recycling_Acceptance_Rate = MAX (Informal_Recycling_Percentage * Informal_Accepted_Products / Informal_Delivery_Time, 0)*
13.	Secondary_Products_Sales_Rate	Flow	[unit / week]	*Secondary_Products_Sales_Rate = MAX (MIN (Secondary_Hand_Products_Demand, Secondary_Products_Inventory / Informal_Delivery_Time), 0)*
14.	Informal_Refurbishment_Rate	Flow	[unit / week]	*Informal_Refurbishment_Rate = MAX (MIN (Informal_Refurbishment_Capacity, Informal_Refurbishable_Products / Informal_Recovery_Time), 0)*
15.	Informal_Recycling_Rate	Flow	[unit / week]	*Informal_Recycling_Rate = MAX (MIN (Informal_Recycling_Capacity, Informal_Recyclable_Products / Informal_Recovery_Time), 0)*
16.	Illegal_Disposal_a	Flow	[unit / week]	*Illegal_Disposal_a = MAX ((Informal_Collected_Products / Informal_Stock_Keeping_Time), 0)*
17.	Illegal_Disposal_b	Flow	[unit / week]	*Illegal_Disposal_b = MAX ((Informal_Recyclable_Products / Informal_Stock_Keeping_Time), 0)*
18.	Illegal_Disposal_Rate_c	Flow	[unit / week]	*Illegal_Disposal_c = MAX ((Informal_Refurbishable_Products / Informal_Stock_Keeping_Time), 0)*
19.	Illegal_Disposal_Rate_d	Flow	[unit / week]	*Illegal_Disposal_d = MAX (Total_WEEE_Generation-Formal_Collection_Rate - Informal_Collection_Rate, 0)*
20.	Informal_Collection_Capacity	Auxiliary	[unit / week]	*Informal_Collection_Capacity = MAX (Informal_Collectors_Percentage * Informal_Workers * Scavenger_Collection_Capacity, 0)*
21.	Informal_Refurbishment_Capacity	Auxiliary	[unit / week]	*Informal_Refurbishment_Capacity = MAX (Informal_Refurbishers_Percentage * Informal_Workers * Refurbisher_Capacity, 0)*

22.	Informal_Recycling_ Capacity	Auxiliary	[unit / week]	Informal_Recycling_Capacity = MAX (Informal_Recyclers_Percentage * Informal_Workers * Recycler_Capacity, 0)

5. Secondary Market Demand

No	Variable Name	Type of Variable	Unit	Equation
1.	Second_Hand_Products_ Demand	Stock	[unit / year]	Second_Hand_Products_Demand (0) = Initial_Second_Hand_Demand Second_Hand_Products_Demand (t+dt) = Second_Hand_Products_Demand (t) + dt * Demand_Increasing_Rate
2.	Demand_Increasing_ Rate	Flow	[unit / year / year]	Demand_Increasing_Rate = Annual_Demand_Growth_Level
3.	Annual_Demand_ Growth_Level	Auxiliary	[unit / year / year]	Annual_Demand_Growth_Rate = (Average_Demand_Growth_Fraction + EXPRND (1 << %/year>>)) * Second_Hand_Products_Demand

6. Informal Workforces

No	Variable Name	Type of Variable	Unit	Equation
1.	Informal_Workers	Stock	[people]	Informal_Workers (0) = Initial_Informal_Workers Informal_Workers (t+dt) = Informal_Workers (t) + dt * Employment_Rate - dt * Unemployment_Rate
2.	Employment_Rate	Flow	[people / week]	Employment_Rate = Desired_Employment_Rate
3.	Unemployment_Rate	Flow	[people / week]	Unemployment_Rate = MAX (MIN ((Acute_Layoff_Rate + Normal_Layoff_Rate), Informal_Workers / Time_to_Layoff_Workers) 0)
4.	Normal_Layoff_Rate	Auxiliary	[people / wk]	Normal_Layoff_Rate = (MAX (Informal_Workers / Time_to_Layoff_Workers, 0)))
5.	Acute_Layoff_Rate	Auxiliary	[people / mo]	Acute_Layoff_Rate = (MAX ((Informal_Workers / Time_to_Acute_Layoff_Workers), 0)) * Acute_Layoff_Decision

6.	Desired_Employment_ Rate	Auxiliary	[people / week]	*Desired_Employment_Rate = (Desired_Employment_Rate / Time_to_Adjust) * Hiring_Appoval_Decision)*
7.	Desired_Additional_ Informal_Workers	Auxiliary	[people]	*Desired_Additional_Informal_Workers = PULSE ((Desired_Additional_Informal_Collectors + Desired_Additional_Informal_RecovWorkers), STARTTIME + Pc_A, Pc_A)*
8.	Desired_Additional_ Informal_ Collectors	Auxiliary	[people]	*Desired_Additional_Informal_Collectors = Informal_Collection_Capacity_Discrepancy/Scavenger_Collection_Capacity*
9.	Desired_Additional_ Informal_RecovWorkers	Auxiliary	[people]	*Desired_Additional_Informal_RecovWorkers = (Informal_Recycling_Capacity_Discrepancy + Informal_Refurbishment_Capacity_ Discrepancy) / Recovery_Workers_Average_Capacity*
10.	Informal_Collection_ Capacity_Discrepancy	Auxiliary	[units / week]	*Informal_Collection_Capacity_Discrepancy = MAX (Desired_Informal_Collection_Capacity - Informal_Collection_Capacity, 0)*
11.	Informal_Refurbishment _Capacity_Discrepancy	Auxiliary	[units / week]	*Informal_Refurbishment_Capacity_Discrepancy = MAX (Desired_Informal_Refurbishment_Capacity - Informal_Refurbishment_Capacity, 0)*
12.	Informal_Recycling_ Capacity_Discrepancy	Auxiliary	[units / week]	*Informal_Recycling_Capacity_Discrepancy = MAX (Desired_Informal_Recycling_Capacity - Informal_Recycling_Capacity, 0)*
13.	Desired_Informal_ Collection_Capacity	Auxiliary	[units / week]	*Desired_Informal_Collection_Capacity = DELAYINF (Total_WEEE_Generation, a_ECR, 1, Total_WEEE_Generation)*
14.	Desired_Informal_ Refurbishment_Capacity	Auxiliary	[units / week]	*Desired_Informal_Refurbishment_Capacity = DELAYINF (Informal_Refurbishment_Acceptance_Rate, a_IRR, 1, Informal_Refurbishment_Acceptance_Rate)*
15.	Desired_Informal_ Recycling_Capacity	Auxiliary	[units / week]	*Desired_Informal_Recycling_Rate = DELAYINF (Informal_Recycling_Acceptance_Rate, a_InRR, 1, Informal_Recycling_Acceptance_Rate)*

7. Formal Cash Availability

No	Variable Name	Type of Variable	Unit	Equation
1.	Formal_Cash_ Availability	Stock	[USD]	Formal_Cash_Availability (0) = Initial_Formal_Cash Formal_Cash_Availability (t+dt) = Formal_Cash_Availability (t) + dt * Formal_Cash_In - dt * Formal_Cash_Out
2.	Formal_Cash_In	Flow	[USD / week]	Formal_Cash_In = Reverse_Revenue
3.	Formal_Cash_Out	Flow	[USD / week]	Formal_Cash_Out = Formal_Reverse_Cost
4.	Formal_Reverse_ Revenue	Auxiliary	[USD / week]	Formal_Reverse_Revenue = Value_per_Refurbished_Products * Refurbishment_Rate + Value_per_Formal_Recycled_Product * Formal_Recycling_Rate + Total_Recycling_Fee
5.	Formal_Reverse_Cost	Auxiliary	[USD / week]	Formal_Reverse_Cost = Forma_Collection_Cost * Formal_Collection_Rate + Refurbishment_Cost * Refurbishment_Rate + Treatment_Cost * Treatment_Rate + Formal_Recycling_Cost * Formal_Recycling_Rate
6.	Total_Recycling_Fee	Auxiliary	[USD / week]	Total_Recycling_Fee = IF (TIMEIS (STARTTIME, Time_without_Legislation), 0 <<USD/week>>, Total_Sales_Rate * Fixed_ARF)
6.	Formal_Cash_Ratio_ Effects_on_Routines	Auxiliary	[dimensionless]	Formal_Cash_Ratio_Effects_on_Routines = IF (Formal_Cash_Ratio > 1, 100%, GRAPH (Formal_Cash_Ratio, 0, 0.1, {0, 0.011111, 0.025, 0.042857, 0.066667, 0.1, 0.15, 0.233333, 0.4, 0.65;1//Min:-1;Max:2//}))
7.	Formal_Cash_Ratio	Auxiliary	[dimensionless]	Formal_Cash_Ratio = IF (Formal_Cash_Availability <= 0<<USD>>, 0, Formal_Cash_Availability / Formal_Cash_Availability)

8. Informal Cash Availability

No	Variable Name	Type of Variable	Unit	Equation
1.	Informal_Cash_ Availability	Stock	[USD]	Informal_Cash_Availability (0) = Initial_Informal_Cash Informal_Cash_Availability (t+dt) = Informal_Cash_Availability (t) + dt * Informal_Cash_In - dt * Informal_Cash_Out
2.	Informal_Cash_In	Flow	[USD / week]	Informal_Cash_In = Informal_Revenue
3.	Informal_Cash_Out	Flow	[USD / week]	Informal_Cash_Out = Informal_Cost
4.	Informal_Revenue	Flow	[USD / week]	Informal_Revenue = (Secondary_Sales_Rate * Value_per_Informal_Refurbished_Product) + (Informal_Recycling_Rate * Value_per_Recycled_Product)
5.	Informal_Cost	Flow	[USD / week]	Informal_Operational_Cost = (Informal_Refurbishment_Rate * Informal_Refurbishment_Cost) + (Informal_Recycling_Rate * Informal_Recycling_Cost) + (Informal_Workers * Informal_Wage)
6.	Informal_Cash_Ratio_ Effects_on_Routines	Auxiliary	[dimensionless]	Informal_Cash_Ratio_Effects_on_Routines = IF (Cash_Ratio > 1, 100%, GRAPH ((Cash_Ratio, 0, 0.1, {0,0.35, 0.6, 0.766667, 0.85, 0.9, 0.933333, 0.957143, 0.975, 0.988889;1//Min:-1;Max:2//}))
7.	Informal_Cash_Ratio	Auxiliary	[dimensionless]	Informal_Cash_Ratio = IF (Informal_Cash_Availability <= 0<<USD>>, 0, Informal_Cash_Availability / Expected_Informal_Cash_Availability)