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MODEL FOR REGIONAL MANAGEMENT OF ELECTRICAL AND ELECTRONIC WASTE (WEEE) FLOWS

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Abstract

The tenacious technological development at latter decades has conditioned the growth of electrical and electronic equipment (EEE) amount and generation of their waste. That is a global heterogeneous problem including different stakeholders and various aspects: environmental, economic, social and technological. The regional electrical and electronic waste (WEEE) management systems (MS) are developed in order to solve this problem. The implementation of WEEE recycling and collection targets is not obtained in every region. The transdisciplinarity and differences of every country has shown the need for integrated evaluation of the regional WEEE systems in order to regulate EEE flows and WEEE collection, treatment activities in reasonable manner. The integrated model for evaluation and regulation of regional EEE and WEEE flows is described at this article. The model is based on life cycle thinking approach (LCThA), where all the stakeholders and other impact factors in particular region are integrated and evaluated in order to create cooperation based WEEE management system instead of current national WEEE treatment system. The verification of the model is based on the Lithuanian case study.

Keywords: material flow, region, waste of electrical and electronic equipment (WEEE), waste management

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1. Introduction

Waste of electrical and electronic equipment (WEEE) is one of the fastest growing waste fractions (annual increase by 3%) (Li et al., 2009; Robinson, 2009) and it has become a sustainability challenge that shadows the pervasive uses of electronic devices in contemporary society (Lawhon et al., 2010). It is an outcome of technological progress in electronic industry determining the exponential growth in the amount and variety of electrical and electronic equipment (EEE), the growth of economical welfare and unsustainable consumption. WEEE management systems (MS) implemented in the EU countries are not able to cope with the WEEE problem properly, especially in new EU member countries (joined EU since 2004). The best case scenarios of WEEE MSs from advanced countries could not be transposed directly to the countries behind the requirements of efficiency. The real WEEE collection rates differ a lot among the EU member countries (from 1 to 12 kg a person per year) (WEEE Forum, 2009, 2010). The data observed in WEEE MSs concern the inflow of obsolete EEE collected for recycling, discounting the contribution of illegal EEE supply and possible alternative WEEE disposal actions. Because of underestimating the alternative WEEE flows a great gap emerges between the amounts of WEEE generated and the share of WEEE that is collected separately for appropriate disposal or recycling (Bernstad et al., 2011; CECED, 2006; Magalini and Huisman, 2007). A specific problem when performing this estimation arises from the fact that consumers quite often store old appliances at home when they are no longer used (Gutiérrez et al., 2010). Therefore the need for analysis of EEE flows within the WEEE MS is essential trying to find out the reasons of inefficiency and providing solutions how

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to tackle the detected problems (Gurauskiene and Stasiskiene, 2011).

In the EU law the WEEE management being sustained according to the paradigm of extended producers' responsibility (EPR) and the waste hierarchy, however most of the WEEE MSs are concerned about the recycling (Betts, 2009; Chancerel and Rotter, 2009; Dalrymple et al., 2007; Ongondo and Williams, 2011; Zhiduan and Xiaobin, 2009), without or with the law consideration of preventive measures. Stakeholders of the system attempt to implement different preventive measures in their activities, such as eco-design (Gurauskiene, 2006, 2010; Unger, 2008; Varzinskas et al., 2007), cleaner production (Staniskis et al., 2010), greener marketing (Molina-Murillo and Smith, 2009), reverse logistics (Achillas et al., 2012), but unfortunately, it has no sense in decreasing EEE environmental impact from the life cycle approach (LCThA) (Lazarevic et al., 2012). WEEE is an intermediate stage of the life cycle or anthropogenic stock of materials (Korhonen, 2007), therefore efficient WEEE management, according to the (LCThA), is the underpinning to the sustainable resource management and vice versa.

Waste management systems incorporates environmental, economic and social aspects, therefore there is a need for research to analyze the complex WEEE management mechanism. Transdisciplinarity is accepted as a promising research approach to respond to complex real-world problems such as WEEE (Lawhon et al., 2010). The strategic management concept of WEEE or EEE flows in a regional context based on the character of the flows among the agents involved, making direct and indirect influence on them, could lead to the efficient improvement of WEEE MSs. Therefore the need for the model as a tool for evaluation of the interactions of different aspects of the WEEE system and possibility to model them is identified. The research presented at this article analyses the complexity and cross impact analysis of the EEE and WEEE flows mechanism. The aim of the research was to create theoretical and practical basis by developing a model for evaluation and improvement of existing WEEE MSs. The model is verified on the Lithuanian WEEE MS.

The academic importance and practical value of this article topic – management of regional flows of EEE and their waste are determined by the need to optimize WEEE MSs according to the specific features of a particular region and the efficiency level of the existing MS. Herein the region is defined as the geographical or administrative unit, where the flows of EEE and WEEE could be analyzed and the WEEE MS could be implemented. Ordinarily the WEEE MS is implemented at the national level, therefore the particular national WEEE MS is investigated at this paper (Fig. 2, where the national MS is equal to the WEEE treatment system), incorporating an extra flows and agents which are not involved in the existent system (illegal EEE and WEEE flows, reuse of obsolete EEE and etc.). There is the presumption that after the analysis of existent national WEEE MS it could be extended or narrowed on purpose to optimize the range of region for the efficient management of EEE and WEEE flows. The research object is broader than the existent WEEE management systems, which are usually narrowed down to waste collection and recycling activities of obsolete EEE. Therefore regional flows of EEE and WEEE are investigated. All EEE life cycle stages and stakeholders are integrated together with other relevant impact factors involved.

The model is based on the following thesis: EEE flows within the life cycle are influenced by relevant impact factors and their interactions of the regional EEE system. Therefore, identification of the mechanism – clarifying the ways the relevant impact factors operate and interact making regulatory mechanisms (RMs) – is the underpinning for development of an effective EEE and WEEE flows management system or for improvement of the existent one.

The research is novel because of the developed integrated model for evaluation and improvement of WEEE MS. It helps to evaluate and integrate all the relevant impact factors and their interactions into a mechanism of EEE and WEEE flow management. The model is designed for deeper analysis of regional EEE flows within an existent WEEE MS applying the life cycle thinking approach (LCThA). It helps to evaluate real efficiency of an WEEE MS and to identify relevant impact factors determining the current operation of the system and to find out the roots of current efficiency making a prompt for the system improvement potential. Regulatory mechanisms, generated on the basis of the evaluation stages in the model, are reasonable from the life cycle point of view.

2. Methodology and materials

The complexity and versatility of WEEE management area, where interacts various stakeholders and all of the sustainability aspects, need to be analyzed in explicitly. Research covers the analysis of a WEEE management system using a holistic (LCThA). Major benefits of LCT lies in its ability to change actors' problem perception (Lazarevic et al., 2012). In order to analyze thoroughly the WEEE problem in a particular region a broad range of methodologies are integrated in the model (Fig. 1). The proposed model combines quantitative and qualitative methodologies, for evaluation of the current situation and simulation of possible changes. The intention of this model – to regulate the EEE and WEEE flows more expediently, based on the comprehensive evaluation of the current situation and identification of the impact factors generating the current regulatory mechanisms of the system. Development of the model was based on the following questions which correspond to the order of the processes of the model:

1. What are the main characteristics of the defined system?
2. How efficient is the system?
3. Which factors does condition the characteristics of the system?
4. How does the impact factors do interacts and conditions the EEE flows? What kind of regulatory mechanism reflects the activity of impact factors?
5. What kind of measures could be proposed for improvement of current regulatory mechanism – increasing the efficiency of the explorative system?

The object of the model – regional EEE flows and different agents of the regional system. As the WEEE management system is being a complex issue, the model consists of the following layers representing different aspects of the system: stakeholders, physical flows, financial flows, responsibility/accountability, information flows. All the layers represent operation of the system therefore the analyses of these aspects are incorporated into the whole model.

The developed model incorporates evaluation and creation of different systems: 1) WEEE treatment system; 2) EEE flow system; 3) Relevant impact factors; 4) Operating mechanism of relevant impact factors; 5) Regulatory mechanism of relevant impact factors; 6) WEEE management system. In order to clarify the differences and interactions of those systems the Fig. 2 has been developed. The existent national WEEE management systems are entitled as the WEEE treatment system, because of their preference to WEEE treatment, despite the preventive measures. The analysis of those systems reveals the results about the operation of the system. The main object of those systems is the WEEE, ignoring the EEE flows and the stakeholders concerned with them, having the essential impact for the whole WEEE management system. EEE flow system incorporates all the mentioned stakeholders and flows, for the deeper analysis of the system. The identification of all the regional EEE flows using qualitative and quantitative methods, based on the defined indicators, the efficiency of the systems is evaluated. It is the basis for the identification of the relevant impact factors (RIF) and their interactions defined by the operation mechanism, describe the system in quantitative way and help to describe the operation principle of the evaluated system. The mentioned analysis of the situation enables to model possible changes developing regulatory mechanisms (RM) of relevant impact factors.

RIFs are the most relevant indicators, which The implementation of regulatory mechanism based on the broader evaluation of all relevant systems, enables to implement the WEEE management system, instead of WEEE treatment system, with the main objective to regulate the most relevant impact factors as the system in a whole for optimization of WEEE management efficiency in particular region.

The developing and implementation of the model is based on the integration of the essential methodologies. All the segments of the model complement one another with additional information and different approach to the system and efficiency evaluation. The model consists of the following stages:

1. Analysis of current WEEE MS for determining its efficiency state. The model is developed for creation of the new WEEE MSs, or for improvement of the existent ones. Therefore the analysis of the current WEEE management system is essential initial stage of the model. This analysis discloses the efficiency of the existent waste management system, with the guidelines for the further analysis.
2. Material flow analysis, using an LCThA for identification of problems and reasons of its inefficiency.

The second stage of the model – material flow analysis has been intended for the broader investigation of the EEE flows in the regional EEE flow system.

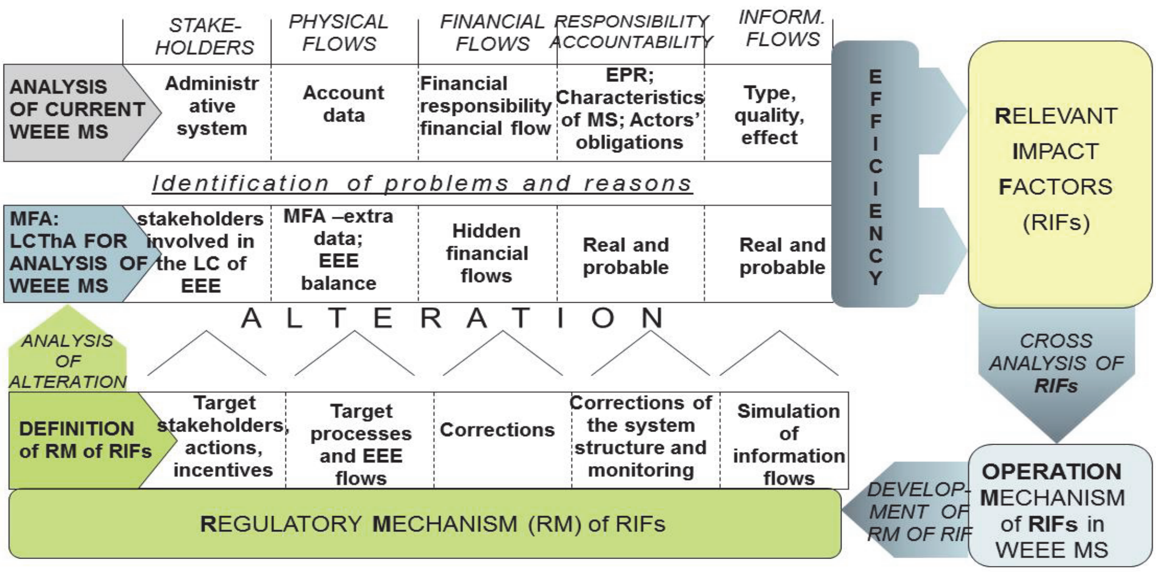

Fig. 1. Model for optimization of EEE and WEEE flow management system

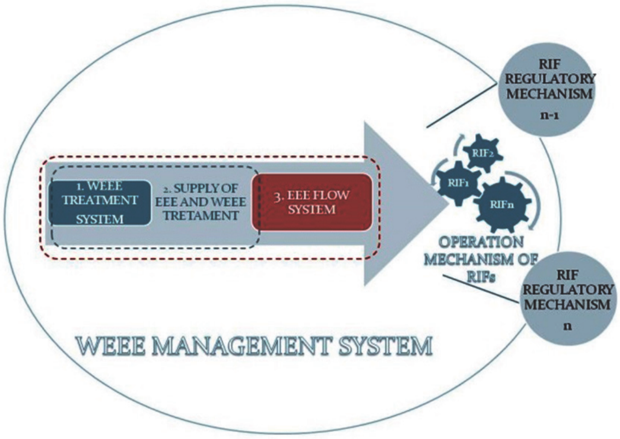

Fig. 2. Systems analyzed at the model

Material flow analysis (Binder, 2007; Brunner and Rechberger, 2004) is principal methodology of the research and it is a backbone of the developed model. Application of the MFA at a good level within the geographical boundary (Gurauskiene and Stasiskiene, 2011) has helped to model the WEEE MS as a structured agent based system (chain) connecting different life cycle stages of both EEE and associated stakeholders (Babbitt et al., 2009) with the physical, information and responsibility flows among them. The software STAN designed for substance flow analysis (Cencic and Rechberger, 2007; TU-Vienna, 2007), was used for data processing within an MFA and for representing the results. Additional methodologies are used to gain the following data: survey of the agents, modeling of the possible flows and paths by using available statistical data and empirical evaluations from literature reviews.

Activity of the agents in the MFA system is described as a different kind of processes influencing EEE flows: activity of EEE usage and accumulation of obsolete EEE are described as the process with the stock; the processes with multiple outcomes describe possible options for the agent defined by transfer coefficients. The flow indicator Tables are developed to indicate the overall distribution of the system flows systematically. Identification of RIFs is an outcome of the system efficiency evaluation, where the factors exerting the greatest influence on the operation of the system are distinguished.

The data collection has relied on different sources and methodologies. Primary data are the national department of statistics, the environmental protection agency, literature review, surveys and the interviews with various stakeholders of the system. The secondary data are the result of the primary data analysis and calculations revealing the previously underestimated data. Three types of questionnaires have been used agreeably to the groups of respondents: EEE producers/importers, EEE B2C users and EEE B2B users. Surveys and estimates of the statistical data have been conducted to evaluate the initial flow rate in/out of each process. Both types of the flow data: absolute (flow amount) and relative (flow rate) have been used because the data on some absolute flow amount is unavailable and the data on a flow rate covers it. The flow amount data was necessary to balance the input and output flows in the final chart of MFA. To collect the data on the whole EEE stock in the consumption process is quite difficult and time-inefficient; therefore 14 indicator-appliances were used. The potential amount of WEEE is an essential factor influencing the efficiency of WEEE MS. WEEE inventory and assumptions about the potential amount of WEEE have been made using an approved batch leaching method (Crowe et al., 2003; Kumar and Shrihari, 2007).

3. Evaluation of efficiency according to the defined indicators of efficiency is a parallel process to the stages mentioned before. Efficiency was evaluated using the qualitative system analysis and quantitative analysis based on the developed indicators of efficiency (Gurauskiene and Stasiskiene, 2011). The model evaluates the efficiency of the system from the different points of view, whereas different groups of indicators are generated: the agents of the system, EEE flows in the system, financial flows, responsibility, accountability within the system and information flows. This paper analyses the EEE flows in depth and the detail list of the efficiency indicators is in Table 2.

4. As an outcome of the efficiency analysis, relevant impact factors (RIF are identified determining the current operation of the system. Four categories of impact factors are distinguished in order to reflect the most important aspects in the systematic analysis of WEEE management system: 1) physical flow characteristics; 2) stakeholders; 3) driving factors; 4) limiting factors. The first IF category corresponds to MFA indicators and it represents the results EEE flow analysis. The second group of IF includes all the stakeholders influencing the EEE flows. Driving forces – includes aspects initiating or maintaining the operation of WEEE MS. Limiting factors define the technological, financial or behavior boundaries for the efficient operation of the system.

The analysis of impact factors is performed in order to identify the current operational mechanism of the system and to simulate the possible changes.

5. Cross impact analysis of RIFs helps to assess activity and passivity of each IF. The cross impact analysis of relevant impact factors, using the interview of experts and rating of the factors, has been employed within the model for identification of the EEE flows operational mechanism, disclosing the options of management and coordination of the mechanism, whereas surveys, analytical tools and simulation methodologies were also applied. Cross impact analysis of relevant IFs helps to assess activity and passivity of each IF (Table 1). Based on this analysis all the IFs are distinguished to the following four categories determined by the estimation of activity of each factor: active, ambivalent, passive and mitigating. The example of IF grid application is provided at the section of results.

Table 1. Cross impact analysis of relevant impact factors

	RIF 1	***RIF 2***	***RIF***	***RIF X***	***Sum of columns (RIF activity)***
RIF 1	x				
RIF 2		x			
RIF ...			x		
RIF X				x	
Sum of rows (RIF passivity)					

6. On the basis of the RIFs analysis, the operational mechanism of identified IFs can be depicted. It is used as the basis for the simulation of regulatory mechanisms. Alteration of the WEEE MS is analyzed evaluating the influence of the developed regulatory mechanisms.

7. Simulation of regulatory mechanisms is based on the existing RIF operation mechanism (OM) and on the analysis how they could be managed to regulate the whole system through the actions implemented in particular stages of the existing operation mechanism and in IFs. To manage the system various cyclic regulatory mechanisms could be modeled. Alteration of the WEEE MS is analyzed evaluating the influence of the developed regulatory mechanisms.

3. Results and discussion

Lithuanian WEEE MS has been chosen as the case study to represent the utility of MFA as a measure disclosing specific problems of a particular WEEE MS and contributing to its improvement according to WEEE MS model. Lithuania implemented WEEE MS in 2005 according to the requirements of the WEEE Directive. Lithuania is one of several new EU member countries encountering problems with efficient implementation of the EU requirements for waste treatment. The current system involves the following actors: producers/importers, retailers, consumers, WEEE collectors, WEEE recyclers and municipalities, and governmental organizations regulating the system.

Inefficiency of Lithuanian WEEE MS is proved by the Environmental Agency reports and national statistical data. The national collection rate determines unconformity to the national and European laws requirements; it has also detected inefficiency of a recently developed national WEEE MS. In Lithuania the WEEE MS is based on the principle of extended producers' responsibility (EPR) realized as individual or collective responsibility. The current system involves the following stakeholders: producers/importers, dealers, consumers, WEEE collectors, WEEE recyclers and municipalities, and governmental organizations regulating the system. Most of the producers/importers exercise individual responsibility (90%), the members of producers/importers entities (10%) represent the greatest share of the EEE market (70%).

Efficiency of an administrative WEEE MS based on the WEEE Directive is targeted to the achievement of the collection rate without any deeper analysis of the real situation and the potential for improvements. Expansion of WEEE MS in the national EEE flow system applying the MFA has allowed identifying and quantifying the system strengths and weaknesses disclosing their possible causes. The EEE flow chart has been defined incorporating the basic processes (Fig. 3). MFA has made it possible to detect RIFs of the system which are its core regulators. Therefore particular measures to improve WEEE MS should be directed to them.

Distribution of the EEE flow according to the law of mass conservation in the analyzed system is as follows (Eq. 1):

$$Input\ (100\%) = \Delta Stock\ (66\%) + Output\ (34\%) \qquad (1)$$

This distribution shows that each year two thirds of the input is accumulated in the system stock. The influence of each process on the system can be identified by representing the results graphically as the Sankey diagram representing distribution of the flows (Fig. 3) and summarizing the flow rates using the mass balance approach in Table 2. The analysis in depth describing the flows inside the processes (subsystems) is done for evaluating actors' behavior and the other possible EEE paths. The following subsystems were analyzed: "EEE supply", "Consumption" and "Obsolete EEE".

MFA has disclosed some very important features of current WEEE MS:

– A real amount of WEEE generated per year is 3 times higher than that collected for formal waste treatment (FWT), because of the alternatives of general WEEE disposal consumers are used to (storing, landfilling). It shows a great potential to the improvements in WEEE MS efficiency.

The formal reuse market does not exist in Lithuania. The informal market of reusable EEE could lead to the leaching of EEE to the informal waste treatment (IWT) sector (the data are collected from the surveys).

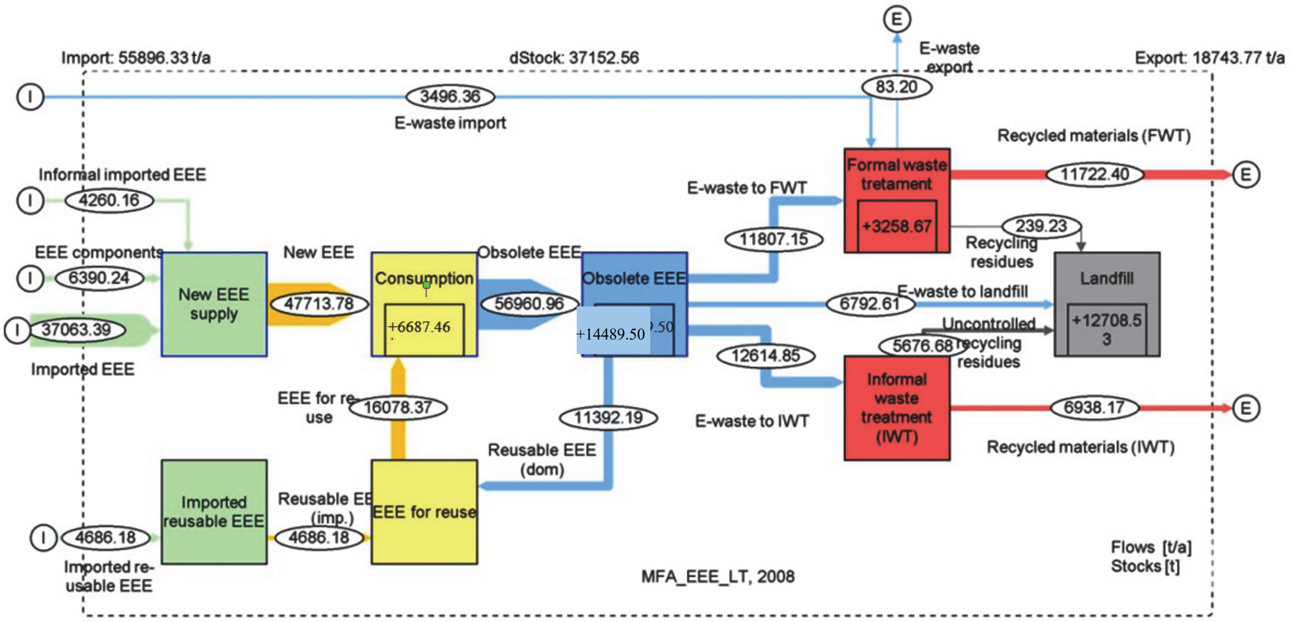

Fig. 3. EEE flows in Lithuania (Gurauskiene and Stasiskiene, 2011)

Table 2. MFA indicators of WEEE MS (Gurauskiene and Stasiskiene, 2011)

	Input	*ΔStock*		*Output*	
Process		*share of system Σ input*	*share of system Σ stock*	*share of system Σ input*	*share of system Σ output*
Total	100%	66%	100%	34%	100%
Supply of new EEE	85%				
Supply of re-usable EEE	8%				
Consumption		12%	18%		
Obsolete EEE		25%	39%		
FWM sector	6%	6%	9%	21%	63%
IWM sector				13%	37%
Landfill		23%	34%		

– The behavior of consumers to put a value to obsolete EEE, suspends one third of the obsolete EEE flow. That is conditioned by consumers' attitude and the lack of information about the possible WEEE treatment options.

– A great share of WEEE going to landfills indicates immaturity of a separate waste collection system in Lithuania (based on data from the national statistics and surveys of the users).

– An unaccountable share of the supplied EEE flow influences the amount of WEEE to be recycled. It is also difficult to quantify the second hand EEE supply; therefore there is a need for additional monitoring points. The data concerning the share of producers and importers were not clear; it was disclosed after a detailed analysis of the companies supplying EEE. These data are essential in evaluating the potential of environmental measures implementation at the manufacturing companies in the region, as a preventive tool to the WEEE problem.

– The amounts of EEE supplied and collected WEEE in Lithuanian WEEE MS has no reliance in the time period of 2005–2008. It shows inefficiency of MS, where the collection rate is a main driver and limit of collection.

– Neither reverse flows of recycled materials have been detected nor has EEE been dismantled inside the national EEE flow system for components reuse. All the WEEE collected at the FWT sector is recycled to the secondary materials for an export market. In Lithuania obsolete EEE is quite rarely collected and released to the poor personsas an alternative treatment of obsolete EEEt.

– Statistical analysis of current WEEE MS and its expansion by applying MFA have disclosed the relevant IFs determining the current operations and present efficiency, namely: the financing system of WEEE management; the uncontrolled EEE flows (including extra actors of the system); environmental awareness of consumers; motivation of producers/importers to collect and recycle greater amounts of WEEE; informal waste treatment (IWT) sector; reuse market of EEE and its components (absence of formal); data quality and monitoring points.

3.1. Identification of relevant impact factors (RIFs)

A list of RIFs based on the former analysis is defined: 4 categories of RIF and 26 RIFs within them

(Fig. 4). As the waste MSs are composed of interacting socio-economical, environmental and technological aspects, the following categories of IF are distinguished: 1) physical flow characteristics (IF with letter F: F1-F5), 2) stakeholders (V1- V9), 3) driving factors (S1-S6), 4) limiting factors (R1-R6).

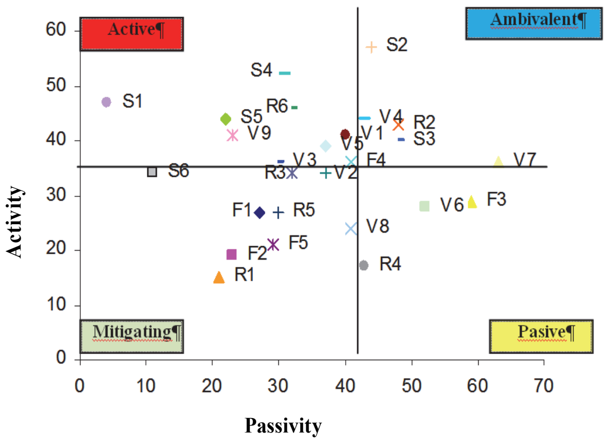

Fig. 4. Grid of the RIFs activity

Note: Abbreviations of relevant impact factors: F1 - Amount of EEE supplied to the market; F2 – Amount of EEE in use; F3 – amount of EEE waste collected; F4 – loss of EEE flows; F5 – Storage of obsolete EEE; V1 – Producers; V2 – Importers; V3 – distributors; V4 – B2C consumers; V5 - B2B consumers; V6 – WEEE collectors; V7 – WEEE recyclers; V8 – illegal recyclers; V9 – administrative institutions; S1 – legal requirements; S2 – Information; S3 – separate waste collection practice; S4 – consumption patterns; S5 – technological development; S6 – financial systems; R1 – potential of recycling; R2 – environmental awareness, R3 – waste disposal/collection options; R4 – data quality; R5 – preventive measures; R6 – cooperation.

Having defined and analyzed RIFs, the cross impact analysis is performed investigating activity and passivity of RIF in the EEE flow regulatory mechanism. 10 representatives (experts) from the different stakeholder groups evaluate the RIFs rating its influence on the other RIFs in a scale from 0 (no influence) to 3 (strong influence). Having summed up the results of evaluation, the RIF activity – passivity grid is combined (Fig. 4). It represents the distribution of RIFs according to the following features in the regulatory mechanism:

– active RIFs exert a strong influence on the other RIFs, but they are not affected by other factors;

– passive RIFs do vice versa to active RIFs;

– ambivalent RIFs act as catalysts, they are affected by other factors but have a strong influence on other factors as well,

– the mitigating RIFs have the miserable influence on the system, and they are influenced by the system faintly, these factors act as stabilizers of the system.

The tendency in distribution of different IF categories are as follows: physical flow characteristics are mostly described as mitigating factors describing activity and efficiency of the system. They are determinant indicators of the system activity.

An ambivalent characteristic is attributed to the most of the stakeholders. That is the main factors of the system which should be well managed on purpose to construct a preferred system mechanism. Most of the driving forces are active parameters, having a tremendous influence on the activity of most of the factors, but the limiting factors perform different roles, it depends on the latter. Comprehensive analysis of the regulatory impact factors enables designers to develop a scheme of the EEE flow operation mechanism (Fig. 5).

In Fig. 5 the following cycles of relevant IFs could be detected:

– OM of cooperation – is between the following IF: V1; V2; V3; V7 (incorporating V6 and V8); V4/V5 and V9 and the quality of the cooperation is determined expressed by the R4 and other quantitative IFs of the system;

– Financial OM – is based on the active IF – S6. It has a strong influence to the WEEE MS as a whole as it impact the motivation to participate at the WEEE MS;

– OM of preventive WEEE management – the objective of this cycle is R5 which is driven by the active IFs: V9; S1; S5; S4 and R3 and implemented by the ambivalent IFs: V1/V2; V4/V5 and V7 and determined by R2; S2 and S3 utilizing the mitigating IFs: F1 and F2. The efficiency of this cycle could not be expressed via the F3, as the collection rate is not in the highest priority of prevention;

– OM of information flow – information and its distribution is the core of every MS, therefore the OM of information flow incorporates all IFs. However the core IFs acting at this OM incorporates the following ones: S2; S4; R3; S3; F4; V8; F3; V1 and V3.

These operation mechanisms and IFs they involve make it possible to generate corresponding regulatory mechanisms (RM) for managing the adequate IFs to regulate the mechanism reliably.

3.2. Development of reliable RMs of relevant impact factors (RIFs).

The objective of this stage of the model is to develop and evaluate the options to obtain the goals of the WEEE management. The present operation mechanism of RIFs is used as a background for developing RMs. The actions of different actors are considered to be regulators influencing the operation of the system in a kind of chain reaction. Most of the actors have few options of the actions which could influence the kind of EEE flows in both directions of the chain: up and down. Other IFs, according to the related factors, could mitigate or stimulate the activity of related factors. The main idea of generated RMs is to manage the activity of IFs in the way that IFs (actors) would be stimulated to act to such a degree that could improve the efficiency of WEEE MS, the other factors support the measures taken to achieve the objective.

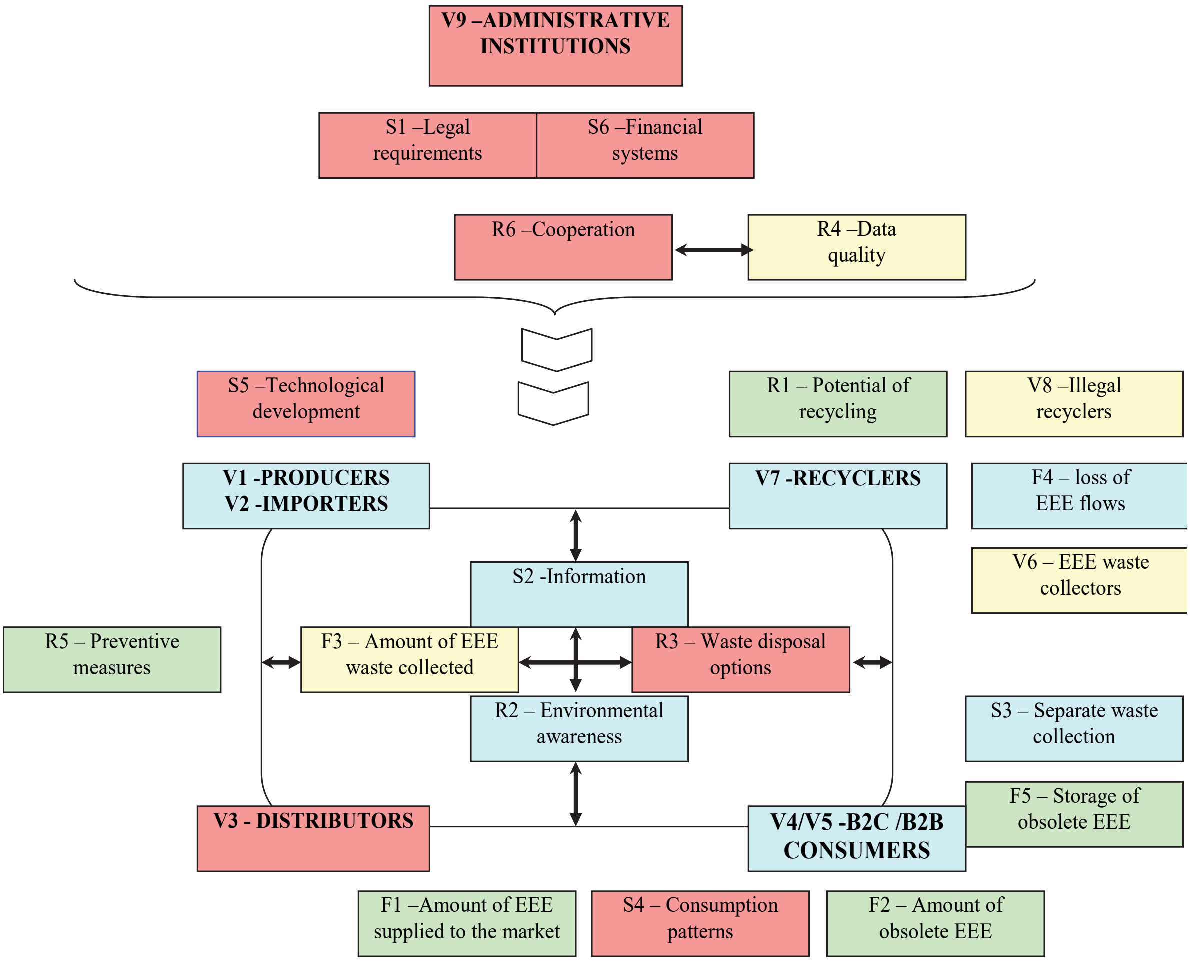

Fig. 5. Operation mechanism (OM) of regional EEE flows

Note: the colors of the IFs represents the activity determined in the Fig. 4, respectively: red color – IFs identified as active ones, yellow – passive IFs, blue – ambivalent IFs and green – mitigating IFs. The same style of colors, regarding the IFs, is used in the further schemes of this paper.

Interpretation and integration of the analysis results obtained in the previous sections are used to identify interferences and driving factors of the system for predicting the system operation activity insomuch that they could be managed to coordinate the mentioned factors.

RMs are developed mainly on the basis of regulation of active and ambivalent factors which have been identified to be the most relevant to the operation of the system.

The following regulatory mechanisms have been developed:

1. Development and improvement of WEEE collection system based on the improved financial flows system. It has been identified in the research that a financial aspect and infrastructure of a collection system is one of the most important factors of WEEE MS Therefore RM has been developed improving the WEEE collection rate in the following way:
2. the amount of WEEE collected (initiator of the system) → recyclers (concerned about increase in collected WEEE) → producers/importers (concerned about implementation of WEEE recycling targets) → suppliers (EEE shops) (mediator between producers and consumers) → coordinator of WEEE MS (organization based on the principle of coordination) → types and distribution of WEEE collection (measures to reach the goal) → collectors → financial aspect (driving factor) → sorting of waste (formation of the attitude and habit) → illegal recyclers (natural decrease in their activity, because of increase in environmental awareness and new motives to use the official waste recycling system) → loss of WEEE flows (decrease) –amount of WEEE collected (increase)
3. RM for coordination of stakeholders based on the information interchange. The information is one of the strongest ambivalent factors in RMs. Therefore the regulatory system based on regulation of the information flow is dedicated for both coordinating all actors within the system and assisting in implementation of other strategies. Even limitations of the collection infrastructure could be compensated by appropriate information flows. Big data gaps in the system and great possibilities to implement the interchange of information could significantly contribute to the improvement of WEEE management system. The information based RM offers the following operations: dissemination of

information and information interchange among actors. The MFA data and scheme can also be a useful tool for dissemination of the information as a measure to present the problem from an approach of the whole system and from a point of each actor separately.

4. Preventive WEEE MS is an alternative to the RM mentioned before. The main goal of this RM is to organize a close loop of EEE flows before the WEEE stage. 3 layers of prevention implementation could be distinguished: producers – integration of environmental aspects in the construction process (cleaner production, eco-design, environmental labeling); users – sustainable consumption; legal requirements and incentives – the laws or other legal requirements encouraging prevention of WEEE instead of stimulating increase in collected WEEE for recycling.

The need for independent coordinating institution playing an important role in each RM has been also identified. The idea of development of effective coordinating institution is the field of future research.

Effectiveness of developed RMs has been analyzed on the basis of qualitative methods describing the influence of each RM on different actors and EEE flow. This analysis has resulted in development of the scheme of RM actions (Fig. 6) and impact based on that of MFA. It describes and presents relevant points of the system, different influence of IF. It presents strategic management directions for improving the management system. Comprehensive measures and particular details should be analyzed either in future research, or in implementation stage at the real case.

Implementation of the model has proved that it is effective for identification of hot spots in the system and generation of efficient RMs. Some difficulties in quantitative evaluation of the RMs impact on the system have been determined. The qualitative evaluation and verification of the model has proved that the objective of this research has been fulfilled.

The developed model incorporates the analysis of a particular WEEE MS, which is essential for evaluating its complexity and peculiarity; modeling its improvement options, evaluating its influence on future EEE flows.

The research proposes to handle WEEE management as material flow management. WEEE – intermediate stage of the life cycle of raw materials, or it could be defined as anthropogenic stock of materials.

Most of the WEEE management systems based on the EPR principle do not fulfill its conception substantially, because WEEE MSs are intended for organizing recycling systems for fulfillment of WEEE recycling tasks. For this reason this research proposes to use EPR, incorporating specific responsibility of every stakeholder within the life cycle of EEE.

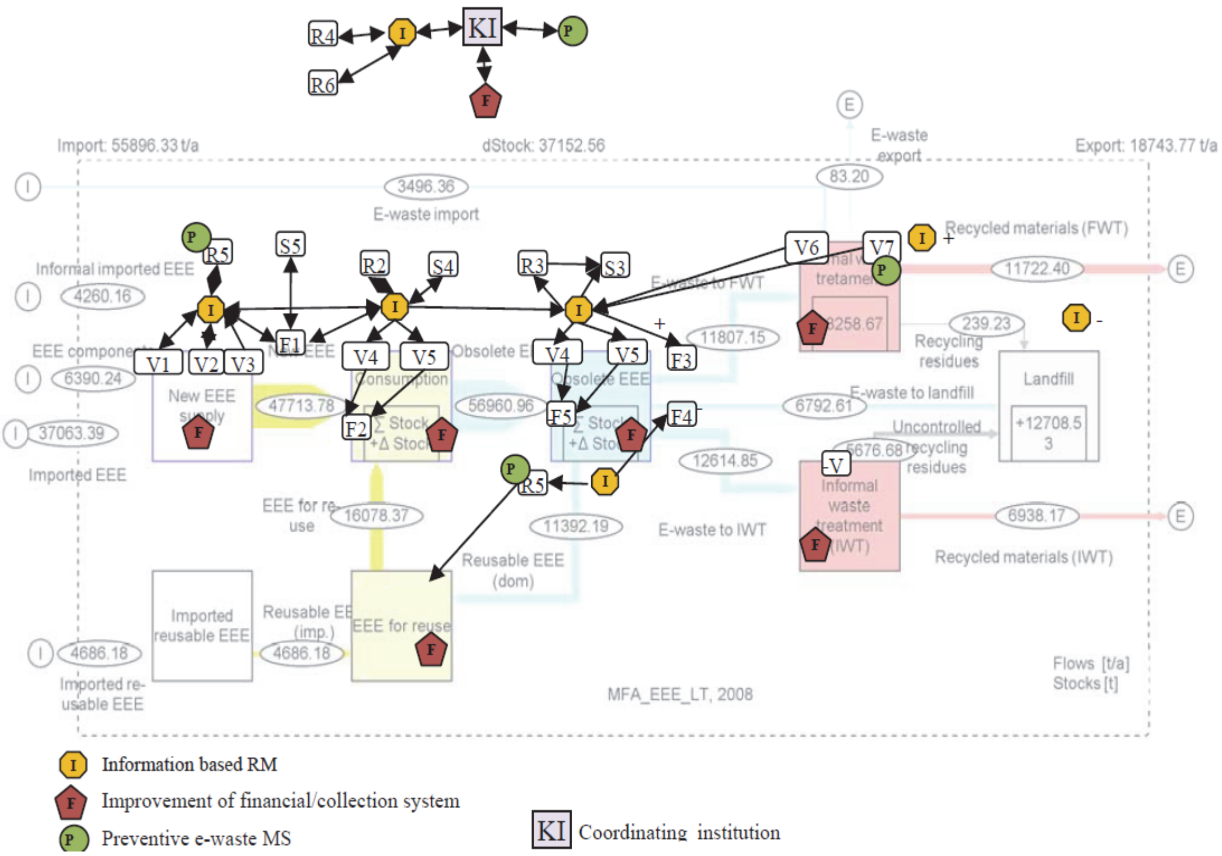

Fig. 6. Scheme of regulatory mechanisms. Improvement of WEEE MS by implementing EEE flow regulatory mechanisms. RMs are implemented through the specific impact factors and their interactions (see arrows)

This paradigm could lead to coordination of the actions of separate stakeholders, finding impulsive factors in the WEEE system mechanism for an adequate operation way of the actors. Practical value of the research is obvious because the integration of this model into the WEEE MS makes it possible to evaluate real efficiency of the system and its potential for improvement. The material flow database could be continuously used for its periodical evaluation and improvement. The MFA analysis helps to identify the data gaps and possible monitoring points for covering them. The integration of this model enables specialists to make timely and adequate decisions to improve the WEEE MS.

Verification of the model on the national WEEE management system has proved the relevance of the model for applying it to the regional systems. The application of the model has disclosed the following problems of the current system: inefficient collection system, meaningful influence of the human behavior on the whole system, negligible environmental awareness of the most stakeholders because of the lack of knowledge and information dispersion, great influence of an informal waste treatment sector on the WEEE management system. The mentioned factors determine low efficiency of the system: only 21% of the obsolete EEE goes to a formal waste treatment sector, the rest part of the EEE flow is distributed as follows: 22% for illegal treatment, 12% - into the landfills, 45% are stored at the users' houses or companies.

The model could be implemented in the countries where EEE flow monitoring is insufficient. Methodologies for identification and evaluation of the data gaps are as an integral part of the model.

Cross impact analysis of relevant impact factors of the investigated system helped to identify the active and ambivalent factors as the most important factors of the system. Therefore the three developed RMs are based on the management of those factors. The first two RMs are based on the improvement of the current system – for increasing the collection rate and the balance of the EEE flow within the system.

The experts' survey has shown the different potential of separate RMs: by implementing the financial RM, the collection of WEEE to the FWT could be increased by 80% in the analyzed MS. The information RM has potential to increase the collection rate by 50%. The third RM is a preventive one intended for developing closed cycles in the system before the EEE becomes waste. The RM based on prevention could increase collection of WEEE by 50% and the flow of reusable EEE by 35%. The analysis of the possibilities to implement those RMs has shown that there is no competition between them. They could be implemented complementary in the long period of time for continuous improvement of the system.

A direct impact of the model implementation - optimization of the WEEE management system is additionally supplemented by an indirect impact. It helps decision makers to make important and validated decisions continuously and on-time. It works as a background of monitoring system for continuous analysis and improvements.

4. Conclusions

Analysis of the research on EEE, WEEE, and the global WEEE management has disclosed a versatility of EEE problem. The evidence of the problem lies in the whole life cycle of EEE, whereas WEEE is an outcome of the earlier stages of LC and behavior of related actors. The WEEE management is identified as one of the most important sectors of sustainable resources management. Therefore there were stated at this research that WEEE management systems should be based on the material flow management, wherein the WEEE is not a kind of waste but the anthropogenic stock of materials.

The model and the case study presented at this paper represents the need for coordination of the stakeholders' activities within the EEE flow system, and the environmental measures they implement has been identified. The coordination is based on the regulation of the identified relevant impact factors within the WEEE MS.

The case study of Lithuania demonstrated the availability to employ the existent operational mechanism of relevant impact factors for the simulation of the regulatory mechanisms. The expert based analysis of the regulatory mechanisms indicated the potential to increase the WEEE MS efficiency from 50% to 80%. The real increase of efficiency could be evaluated after the implementation of the regulatory mechanism in the analysed WEEE MS and evaluation of the MFA.

References

Achillas C., Aidonis D., Vlachokostas C., Moussiopoulos N., Banias G., Triantafillou D., (2012), A multi-objective decision-making model to select waste electrical and electronic equipment transportation media, *Resources, Conservation and Recycling*, **66**, 76-84.

Babbitt C.W., Kahhat R., Williams E., Barbit Gr. A., (2009), Evolution of product lifespan and implications for environmental assessment and management: A case study of personal computers in higher education, *Environmental Science and Technology*, **43**, 5106-5112.

Bernstad A., la Cour Jansen J., Aspegren H., (2011), Property-close source separation of hazardous waste and waste electrical and electronic equipment – A Swedish case study, *Waste Management*, **31**, 536-543.

Betts K.S., (2009), E-waste reuse may be more pervasive than previously thought, *Environmental Science and Technology*, **43**, 6900-6901.

Binder C.R., (2007), From material flow analysis to material flow management Part I: social sciences modeling approaches coupled to MFA, *Journal of Cleaner Production*, **15**, 1596-1604.

Brunner P.H., Rechberger H., (2004), *Practical Handbook of Material Flow Analysis*, In: *Advanced Methods in Resource & Waste Management*, Lewis Publishers.

CECED, (2006), *Review of Directive 2002/96/EC WEEE collection targets in Slovakia and other Central European countries*, The View of Household Appliance Makers in Europe, 6-11.

Cencic O., Rechberger H., (2007), *Modelling Substance Flows and Stocks with STAN Software*, 1st International Seminar on Society and Materials SAM1, Seville, Spain, arcelor MITTAL, CD, 1-8.

Chancerel P., Rotter S., (2009), Recycling-oriented characterization of small waste electrical and electronic equipment, *Waste Management*, **29**, 2336-2352.

Crowe M., Elser A., Gopfert B., Mertins L., Meyer Th., Schmid J., Spillner A., Strobel R., (2003), *Waste from Eelectrical and Electronic Equipment (WEEE) – Quantities, Dangerous Substances and Treatment Methods*, Dimitrios Tsotsos (Ed.), European Environmental Agency (EEA), Copenhagen, Denmark, On line at: http://scp.eionet.europa.eu/publications/wp2003_1/wp/WEEE_2003.

Dalrymple I., Wright N., Kellner R., Bains N., Geraghty K., Goosey M., Lightfoot L., (2007), An integrated approach to electronic waste (WEEE) recycling, *Circuit World*, **33**, 52-58.

Gurauskiene I., (2006), Eco-design methodology for electrical and electronic equipment industry, *Environmental Research, Engineering and Management*, **37**, 43-51.

Gurauskiene I., (2010), Implementation of legal requirements for energy using products (EuPs) in Lithuanian industry: problems and possibilities, *Environmental Research, Engineering and Management*, **52**, 48-59.

Gurauskiene I., Stasiskiene Z., (2011), Application of material flow analysis to estimate the efficiency of e-waste management systems: the case of Lithuania, *Waste Management & Research*, **29**, 763-777.

Gutiérrez E., Adenso-Díaz B., Lozano S., González-Torre P., (2010), A competing risks approach for time estimation of household WEEE disposal, *Waste Management*, **30**, 1643-1652.

Korhonen J., (2007), From material flow analysis to material flow management: strategic sustainability management on a principle level, *Journal of Cleaner Production*, **15**, 1585-1595.

Kumar P., Shrihari S., (2007), *Estimation and Material Flow Analysis of Waste Electrical and Electronic Equipment (WEEE) - A Case Study of Mangalore City, Karnataka, India*, Proc. of the International Conference on Sustainable Solid Waste Management, 5 - 7 September 2007, Chennai, India, 148-154.

Lawhon M., Manomaivibool P., Inagaki H., (2010), Solving/understanding/evaluating the e-waste challenge through transdisciplinarity?, *Futures*, **42**, 1212-1221.

Lazarevic D., Buclet N., Brandt N., (2012), The application of life cycle thinking in the context of European waste policy, *Journal of Cleaner Production*, **29-30**, 199-207.

Li J., Gao S., Duan H., Liu L., (2009), Recovery of valuable materials from waste liquid crystal display panel, *Waste Management*, **29**, 2033-2039.

Magalini F., Huisman J., (2007), *Management of WEEE & Cost Models across the EU Could the EPR principle lead US to a better Environmental Policy?*, Proc. of the 2007 IEEE International Symposium on Electronics & the Environment, Orlando, FL USA, 7-10 May, 143-148.

Molina-Murillo S., Smith T., (2009), Exploring the use and impact of LCA-based information in corporate communications, *The International Journal of Life Cycle Assessment*, **14**, 184-194.

Ongondo F.O., Williams I.D., (2011), Mobile phone collection, reuse and recycling in the UK, *Waste Management*, **31**, 1307-1315.

Robinson B.H., (2009), E-waste: An assessment of global production and environmental impacts, *Science of the Total Environment*, **408**, 183-191.

Staniskis J.K., Stasiskiene Z., Kliopova I., Varzinskas V., (2010), *Sustainable Innovations in Lithuanian Industry*, (in Lithuanian), Kaunas: Technologija.

TU-Vienna, (2007), *STAN - Software for Substance Flow Analysis*, On line at: http://www.iwa.tuwien.ac.at/iwa226_english/stan.html

Unger N., (2008), A review of ecodesign and environmental assessment tools and their appropriateness for electrical and electronic equipment, *Progress in Industrial Ecology – An International Journal*, **5**, 13-29.

Varzinskas V., Gurauskiene I., Pipinyte L., (2007), Improvement in enviromental performance of vapour compression refrigeration system by the model for environmental product development, *Environmental Research, Engineering and Management*, **40**, 59-69.

WEEE Forum, (2009), *Annual Report 2008*, Brussels, Belgium: European Association of Electrical and Electronic Waste take Back Systems.

WEEE Forum (2010), On line at: http://www.weee-forum.org.

Zhiduan X., Xiaobin X., (2009), *Three-Tiered E-Waste Recycling Supply Chains Based on Revenue Sharing*, Proc. of 2008 IEEE Symposium on Advanced Management of Information for Globalized Enterprises (AMIGE), Tianjin, China, September 2008, 176-180.