Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 95 (2016) 451 – 458

Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2015, 14-16 October 2015, Riga, Latvia

# Decision support tool for implementation of remanufacturing in an enterprise

Lasma Slotina*, Elina Dace

*Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia*

**Abstract**

Several global challenges exist that force manufacturing organizations to reduce the environmental impact of their products. Nowadays, the most common practices of products' end-of-life stage are landfilling and recycling. However, there are several other practices for products' end-of-life management that support reduction of environmental impact. One such option is remanufacturing which is a product-recovery option that gives the opportunity to produce new products by using products that have already reached their end-of-life stage. In the process, all modules and components are disassembled, and the used parts – recovered. Depending on the product remanufactured, the process helps reducing energy consumption by 85 %, avoiding up to 60 % of emissions and saving up to 85 % of raw materials, thus reducing the environmental impact considerably. Still, many barriers exist that prevent manufacturing enterprises from implementing the remanufacturing process. To assist enterprises, a decision support tool based on system dynamics modeling has been developed. The paper presents the decision support tool, and shows how the decision of implementing the remanufacturing process in an enterprise changes its performance with respect to environmental and economic aspects.

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.

*Keywords:* decision support tool; product design; remanufacturing; reverse logistics; system dynamics

* Corresponding author. Tel.: +371-27-812-540
*E-mail address*: lasmaslotina@gmail.com


Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
doi:10.1016/j.egypro.2016.09.062

## 1. Introduction

Remanufacturing provides an approach for sustainable development in three dimensions – environmental, economic and social. It brings back used products, but in a quality equal to or better than a new product. Remanufacturing recovers used products and turns them back with the same quality and functionality as new product [1].

Before starting any system, the most important issue is evaluation of economic aspects, as well as assessment of environmental and social aspects. A manufacturer will apply remanufacturing only if there is a certain cost saving in remanufactured products as compared to new ones. Otherwise, the remanufacturing concept is not interesting for manufacturers. There are also several other aspects as productivity of remanufacturing system and demand for remanufactured products [2].

From an environmental point of view, remanufacturing provides an opportunity to use fewer resources, reuse materials, and reduce pollution and waste. With respect to social aspects, remanufacturing offers constant advancement in different technologies, employment opportunities and purchase of products with lower cost, same quality and warranty [3].

Remanufacturing provides benefits not only for companies and businesses, but also for customers and the environment. The remanufacturing concept provides product quality at a lower price than a product which is not remanufactured, reduction of raw materials used and waste generated, and financial savings. According to Snodgress [4] implementation of the remanufacturing process saves up to 85 % of raw materials, reduces consumption of thermal and electrical energy by 60–85 %, and uses up to 90 % less water. Also, avoidance of up to 60 % of greenhouse gas emissions has been reported [4, 5]. Material, energy and water savings are significant and provide financial savings for an enterprise, thus allowing reduction in the price of a product. Still, many barriers exist that prevent manufacturing enterprises from implementing the remanufacturing process. The main barriers are related to lack of knowledge in society about the remanufacturing concept, thus causing suspicion of the remanufactured product. Also, the risk that investments in reorganizing the production and logistics' processes might be greater than the potential financial benefit which prevents manufacturers from implementing the remanufacturing concept in their enterprise [6].

Often small and medium size enterprises do not have enough knowledge and capacity to assess whether the remanufacturing process would provide a sustainable solution for further business development. Therefore, in this study, a decision support tool based on system dynamics modeling was developed to assist an enterprise in considering implementation of the remanufacturing process by showing the effect of such decision on production performance with respect to environmental, economic and social aspects. In several studies [2, 7–12] decision making methodologies have been presented. Though, they have mainly focused on evaluation of economic viability of remanufacturing, e.g. determining cost effectiveness index of remanufacturing.

## 2. Methodology

### *2.1. Preliminary assessment and data collection*

Not all enterprises are suitable for implementing the remanufacturing concept. An enterprise's suitability can be determined by conducting a preliminary assessment and avoiding thorough data collection and analysis. In this study, an algorithm was developed based on questions on characteristics of a product and its production process (see Fig. 1). By applying the algorithm, an enterprise can avoid thorough data collection and analysis that is both time and resource consuming.

After the preliminary assessment deeper analysis of the manufacturing processes has to be conducted this requires collection and analysis of data. Data collection is based on a set of environmental, economic and social indicators. In this study, a data questionnaire was developed that consists of four parts (see Fig. 2). The first part introduces the aim of the data questionnaire and its main target group necessary to be investigated. The second includes general information about the enterprise – number of employees, location of the enterprise, etc. The purpose of the third part of the data questionnaire is to get as detailed information about the manufacturing and remanufacturing process indicators and parameters as possible. In the last part of the questionnaire, additional information characterizing manufacturing and remanufacturing processes is collected.

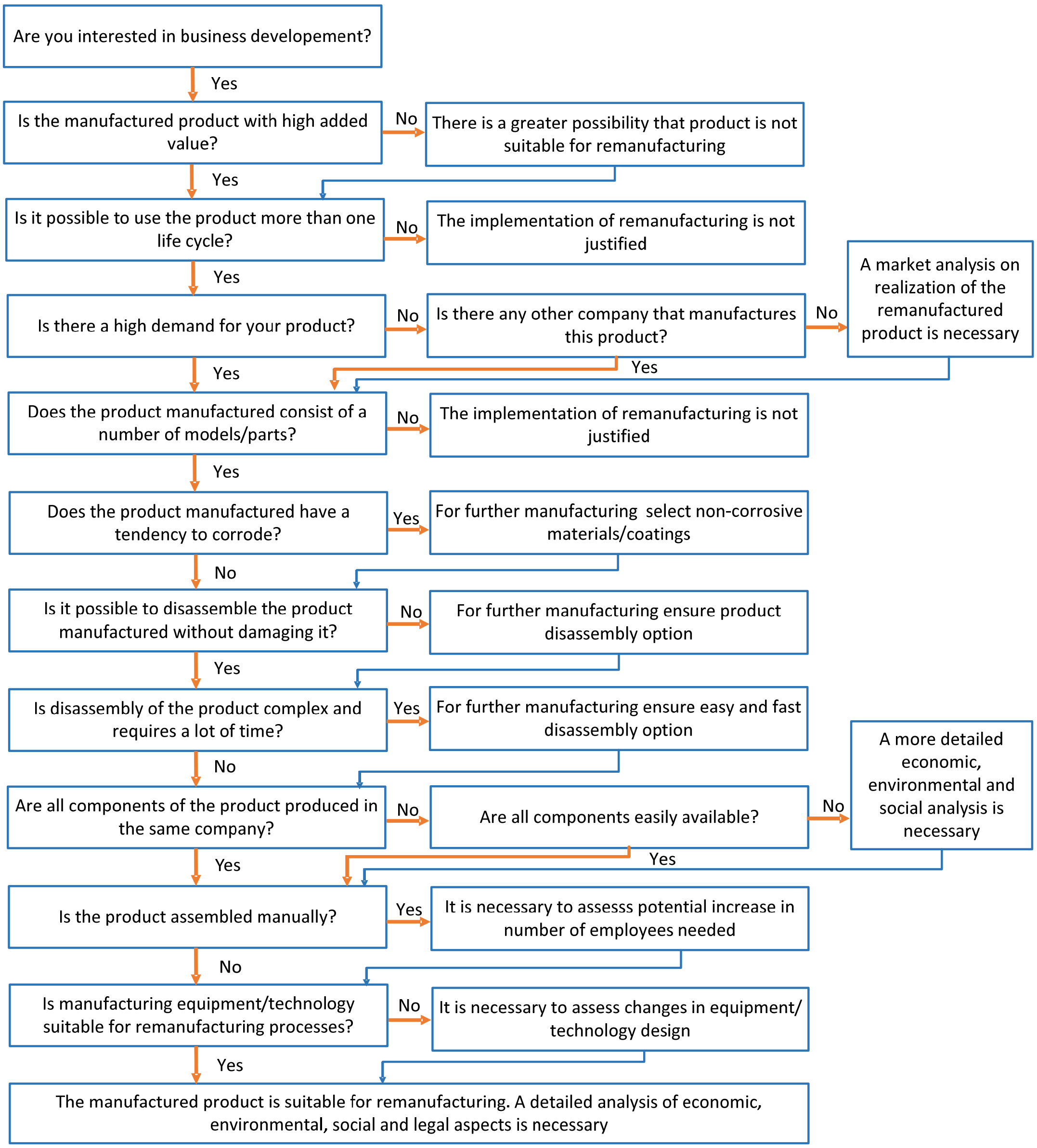


Fig. 1. Algorithm for preliminary assessment of a product's suitability for remanufacturing.

## *2.2. Decision support tool*

The overall aim of the decision support tool is to show how the decision of implementing the remanufacturing process in an enterprise would change its performance with respect to environmental, social and economic aspects. The decision support tool is applicable to any enterprise that considers introduction of the remanufacturing concept or that is interested in evaluation of the existing remanufacturing process. In this study, the decision support tool was developed by using system dynamics methodology. System dynamics is one of the methods of systems thinking. System dynamics was developed by Professor Jay W. Forrester in the middle of the 1950s [13]. Since then, system dynamics has been applied to a set of various complex systems (e.g. agriculture [14], forestry [15], transportation [16], energy [17, 18] and energy efficiency [19], waste management [20, 21], etc.). Although system dynamics was initially developed for analysis of industrial systems [13], it has rarely been applied for modeling remanufacturing processes, as usually Analytic Hierarchy Process (AHP) or Graph Theoretic Approach (GTA) has been used [22]. Previous system dynamics models on remanufacturing have been developed to evaluate a system's improvement strategies and to build a decision support tool for pricing models, thus they were mainly based on several economic and technical aspects, whereas social and environmental aspects were not assessed. System dynamics helps decision makers to analyze complex and dynamic behaviors within systems through modeling and simulation [22]. Although initially this method was developed to help companies to improve their understanding about manufacturing processes, nowadays it is mainly used for analysis and formulation of policies in public and private sectors [23].

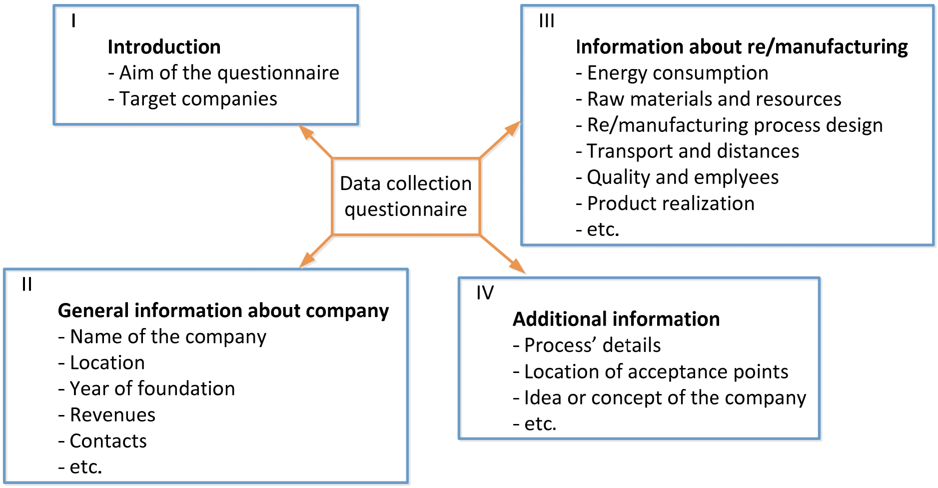


Fig. 2. General scheme of the data collection questionnaire.

A general structure of the model – decision support tool developed in this study is illustrated in Figure 3. The model consists of two main flows – manufacturing and remanufacturing flow. Flows are connected to each other as the remanufacturing flow partly depends on the manufacturing flow. The remanufacturing flow also depends on the overall demand for products. After the use stage, the manufactured products form inflow for the remanufacturing process. Overall, the model consists of 13 sub-models (see Fig. 3), each of them characterized with a set of equations.

In the model, the decision of whether to implement the remanufacturing process or not is based on the result of net income in case of manufacturing only and in case of remanufacturing. Comparison of the net income results allows to assess which of the concepts provides higher net income considering the number of products sold and various costs to produce them, such as transportation, energy consumption, materials, etc. Thus, net income accumulates the difference between revenue and costs (see Eq. (1)).

$$NI_i = \int (IPP_i \cdot SRP_j - \sum (VPC_i \cdot PR_i) + IM_i)(t) \cdot dt + NI_i^{init} \quad (1)$$

where

$NI_i$ the net income of $i$ ($i$ = manufacturing or remanufacturing), EUR;
$IPP_i$ income per product produced in process $i$, EUR/product;
$SRP_j$ sales rate of product $j$ ($j$ = manufactured or remanufactured products), products/year;
$VPC_i$ variable production costs of process $i$, EUR/product;
$PR_i$ production rate of process $i$, products/year;
$NI_i^{init}$ initial net income of process $i$, EUR.

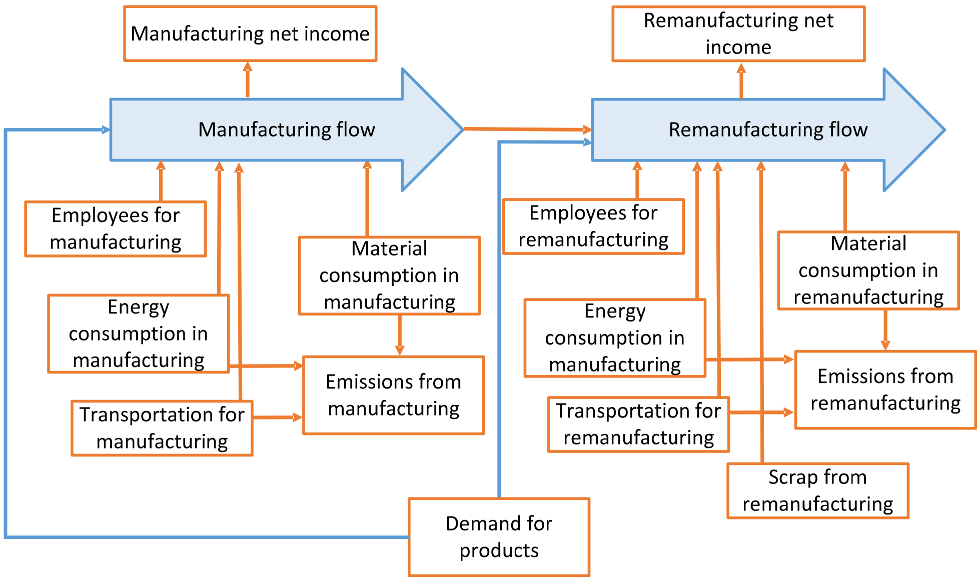


Fig. 3. Structure of the decision support tool.

Three scenarios were developed to test the model. The baseline scenario simulates the historical development of a manufacturing enterprise. This is the situation when the enterprise produces specific products and the concept of remanufacturing is not implemented. Scenario 1 simulates a situation when the enterprise decides to implement the remanufacturing concept – the products return after some specific time for remanufacturing Scenario 2 simulates the situation when the enterprise implements the remanufacturing concept and also makes some improvements in the design of the product and its production processes. It is assumed that improving the product design will make it possible to reduce the time consumed for a product's disassembly and assembly processes. It is also considered that the majority of customers are informed about the availability, quality and price of remanufactured products.

### *2.3. Case study*

Selection of an enterprise for the case study was made based on the developed algorithm for preliminary suitability analysis. The selected enterprise is located primarily in Latvia and provides manufacturing and remanufacturing of cardan shafts. Only electrical energy is used for manufacturing and remanufacturing processes as all equipment works with electricity. No water is consumed, and only dry cleaning is applied.

In Latvia, the enterprise has an established network of reverse logistics for receiving the used cardan shafts for remanufacturing. A partner in Germany ensures delivery of new spare parts.

## 3. Results

The results of the baseline scenario show what trends in the development of the system can be expected in the future if the enterprise applies only the manufacturing concept. Whereas, the results of Scenarios 1 and 2 show the development of the system in case of implementing the remanufacturing concept. It can be seen in Figure 4, that in ten years Scenario 1 provides an increase in the net income by about 30 % as compared to the base scenario. Scenario 2 provides a further increase in the net income and reaches 37 % above the base scenario level.

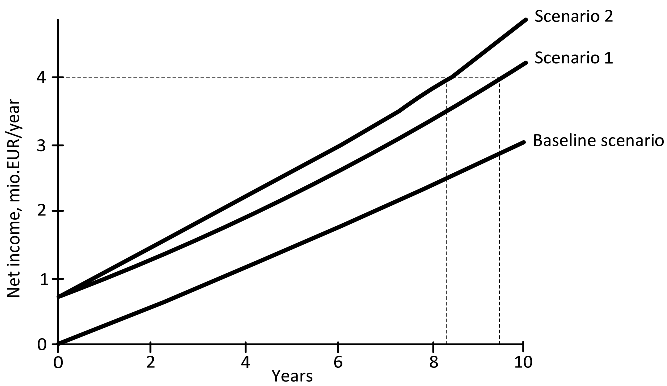


Fig. 4. Results of the net income.

The results clearly indicate that higher net income is achieved when remanufacturing is implemented. In addition, it can be seen that advancement in the product and process design (scenario 2) can provide higher net income – a 4 million EUR limit is reached in 8 years and 4 months as compared to 9 years and 4 months in case of scenario 1. To understand the advantages and disadvantages provided by each scenario, several indicators are expressed per product unit (see Table 1).

Table 1. Comparison of main indicators between scenarios.

| Indicator | Base scenario | Scenario 1 | Scenario 2 | Unit |
|---|---|---|---|---|
| Net income per product | 203.36 | 237.22 | 237.82 | EUR/product |
| **Social indicators** | | | | |
| Number of employees | 3 | 8 | 7 | employees |
| Time spent per product production | 100 | 206 | 199 | min/product |
| **Economic indicators** | | | | |
| Staff salaries per product | 8.00 | 16.48 | 13.48 | EUR/product |
| Transportation costs per product | 38.22 | 23.86 | 23.86 | EUR/product |
| Electricity costs per product | 0.42 | 0.44 | 0.44 | EUR/product |
| Average material costs per product | 250 | 147 | 147 | EUR/product |
| Total costs per product | 296.64 | 187.78 | 184.78 | EUR/product |
| **Environmental indicators** | | | | |
| Fuel consumption – reverse logistics of used products | 3.86 | 5.32 | 5.32 | litres/product |
| Fuel consumption – logistics of spare parts | 5.30 | 2.96 | 2.96 | litres/product |
| Total consumption per product | 9.16 | 8.28 | 8.28 | litres/product |
| Electricity consumption | 4.0 | 4.2 | 4.2 | kWh/product |
| Average consumption of new materials | 912 | 561 | 561 | kg/product |
| Emissions from transportation | 0.025 | 0.023 | 0.023 | $tCO_2$/product |
| Emissions from electricity production and transmission | 0.0016 | 0.0017 | 0.0017 | $tCO_2$/product |
| Emissions from materials' production | 1.64 | 1.01 | 1.01 | $tCO_2$/product |
| Generation of scrap metal | (1 353) | 528 | 528 | t/year |

Table 1 shows social, economic and environmental indicators. 'Number of employees' is selected as a social indicator. The results show that additional employees are necessary for the remanufacturing processes. It is explained by disassembly, cleaning and assembly processes involved in remanufacturing. In scenario 2, one less employee is necessary than in scenario 1, as improved product design allows faster disassembly and assembly realization. For the enterprise it allows producing more products per the same time unit.

Costs related to the production process are selected for economic aspects. Table 1 shows that staff salaries are twice as high in scenario 1 and by 70 % higher in scenario 2 than in the base scenario which is a considerable increase related to time spent per product unit produced. Electricity costs are slightly higher in scenarios 1 and 2 because of the specific processes necessary for remanufacturing. Whereas, transportation costs are by 60 % lower for remanufacturing scenarios, as less spare parts and materials are required for remanufactured products. Thus, transportation costs are composed mainly of reverse logistics costs within Latvia. In the base scenario, materials are transported more frequently and over larger distances. Thus, materials costs are also higher in case of manufacturing new products.

In Table 1, environmental aspects cover resource consumption and related greenhouse gas emissions (expressed in $CO_2$ equivalent). As described above, fuel and materials consumption is lower for remanufacturing processes, whereas electricity consumption is a bit higher. Similar results are obtained for $CO_2$ emissions. In addition, the amount of scrap metal generated was assessed. In the base scenario, used products do not return to the producer (enterprise), and are, most probably, sold as scrap metal to metal recyclers, although this does not provide any income for the enterprise. In case of remanufacturing, all parts that are in very bad condition and cannot be used in remanufactured products go to scrap metal, and the enterprise receives additional income.

To sum up all advantages and disadvantages provided by the scenarios, implementation of remanufacturing helps to produce about 46 % more product units and reduce materials' consumption by about 39 %. Also, almost 38 % of $CO_2$ emissions can be avoided and about 10 % of fuel consumption reduced. In the analyzed case, the implementation of remanufacturing process would reduce electricity consumption by about 5 %. Overall, for the enterprise selected as the case study, implementation of the remanufacturing process would provide clear advantages in all aspects considered.

## 4. Conclusion

A decision support tool based on system dynamics was developed in this study. An enterprise was selected for the case study to assess the potential impact of implementation of the remanufacturing concept. The obtained simulation results showed that the enterprise could achieve considerable reduction of fuel and materials consumption and the related emissions, thus significantly reducing the production costs. Moreover, net income of the enterprise would increase by 30 – 37 %. Advancement in the product and process design would provide further benefits. Finally, the obtained results confirm the applicability of the developed decision support tool for sustainability assessment of manufacturing and remanufacturing processes.

## Acknowledgements

The work has been supported by the National Research Program "Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)".

## References

[1] A description of the design for end-of-life process. United Kingdom: Centre of Remanufacturing and Reuse, Wax RDC; 2014.
[2] Sabharwal S, Garg S. Determining cost effectiveness index of remanufacturing: A graph theoretic approach. Int J Prod Econ 2012;144:521−532.
[3] Saavedra YMB, Barquet APB, Rozenfeld H, Forcellini FA, Ometto AR. Remanufacturing in Brazil: Case studies on the automotive sector. J Clean Prod 2013;53:267−276.
[4] Snodgress D. Remanufacturing – Sustainability for the 21st Century. Sustainable development. WTO Public Forum 2012 "Is Multilateralism in Crisis?" Geneva, Switzerland, 24-26 September, 2012.
[5] Gray C, Charter M. Remanufacturing and product design: Design for the 7th generation. UK: The Centre of Sustainable Design; 2007.

[6] Jin X. Modeling and analysis of remanufacturing systems with stochastic return and quality variation. PhD Dissertation, the University Of Michigan; 2012.
[7] Golinska P, Kosacka M, Mierzwiak R, Werner-Lewandowska K. Grey Decision Making as a tool for the classification of the sustainability level of remanufacturing companies. J Clean Prod 2014;105:28−40.
[8] Senthil S, Srirangacharyulu B, Ramesh A. A decision making methodology for the selection of reverse logistics operating channels. Pro Eng 2012;38:418−428.
[9] Kim E, Saghafian S, Oyen MPV. Joint control of production, remanufacturing, and disposal activities in a hybrid manufacturing remanufacturing system. Eur J Oper Res 2013;231:337−348.
[10] Xiang L, Li Y, Cai X. Remanufacturing and pricing decision with random yield and random demand. Comput Oper Res 2014;54:195-203.
[11] Abdulrahman MDA, Subramanian N, Liu C. Viability of remanufacturing practice: a strategic decision making framework for Chinese auto-parts companies. J Clean Prod 2014;105:311−323.
[12] Subramoniam R, Huisingh D, Chinnam RB, Subramoniam S. Remanufacturign Decision-Making Framework (RDMF): Research validation using the analytical hierarchical process. J Clean Prod 2013;40:212−220.
[13] Lane DC, Sterman JD. Jay Wright Forrester. Assad AA, Gass SI, editors. Profiles in Operations Research: Pioneers and Innovators. US: Springer; 2011.
[14] Dace E, Muizniece I, Blumberga A, Kaczala F. Searching for solutions to mitigate greenhouse gas emissions by agricultural policy decisions – Application of system dynamics modeling for the case of Latvia. Sci Total Environ 2015;527−528:80−90.
[15] Dace E, Muizniece I. Modeling Greenhouse Gas Emissions from the Forestry Sector – the Case of Latvia. Agron Res 2015;3(2):464−476.
[16] Barisa A, Romagnoli F, Blumberga A, Blumberga D. Future biodiesel policy designs and consumption patterns in Latvia: A system dynamics model. J Clean Prod 2015;88:71–82.
[17] Romagnoli F, Barisa A, Dzene I, Blumberga A, Blumberga D. Implementation of different policy strategies promoting the use of wood fuel in the Latvian district heating system: impact evaluation through a system dynamic model. Energy 2014;76:210–222.
[18] Kuplais G, Blumberga D, Dace E. System Analysis for Integration of Landfill Energy Production in Regional Energy Supply. Waste to Energy. Syngellakis S, editor. Southampton: WIT Press; 2015.
[19] Asere L, Blumberga A. Government and Municipality Owned Building Energy Efficiency System Dynamics Modelling. Energy Pro 2015;72:180−187.
[20] Dace E, Bazbauers G, Berzina A, Davidsen PI. System dynamics model for analysing effects of eco-design policy on packaging waste management system. Resour Conserv Recy 2014;87:175−190.
[21] Blumberga A, Timma L, Romagnoli F, Blumberga D. Dynamic modelling of a collection scheme of waste portable batteries for ecological and economic sustainability. J Clean Prod 2015;88:224–233.
[22] Tako AA, Robinson S. The application of discrete event simulation and system dynamics in the logistics and supply chain context. Decis Support Syst 2012;52:802–815.
[23] Subramoniam R, Huisingh D, Chinnam RB, Subramoniam S. Remanufacturing Decision-Making Framework (RDMF): research validation using the analytical hierarchical process. J Clean Prod 2013;40:212−220.