

The Transformation of Supply Chains in Closed-Loop Supply Chains

Roman Domański and Michał Adamczak

Abstract Within the framework of the concept of sustainable development, economic growth should be considered not only in economic, but also environmental and social terms. The economies of countries face new challenges intended to satisfy growing human needs while maintaining (or improving) the quality of the environment. Not all countries are on the same level as regards the implementation of this strategy. We found that the implementation of the concept of sustainable development would be possible but for the activities undertaken by individual enterprises being a part of the supply chain. Special importance is given to the implementation of closed-loop supply chains. The aim of the chapter is to present the need to implement closed-loop supply chains in the Polish economy. The chapter presents the selected aspects of the decision-making process aimed at closing the material flow in the supply chain. The description contains a full analysis of the current ratio analysis at macroeconomic level (pertaining to the economies of selected European countries) and the review of the methods and techniques for the optimization of supply chains which realize forward and backward material flows.

Keywords Re-use of materials • Closed-loop supply chain • Sustainable development • Lot sizing problem

1 Introduction

Contemporary economic growth should be considered not only in economic, but also environmental and social terms. This triad is jointly referred to as sustainable development. The idea behind sustainable development (SD) is to satisfy growing

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human needs while maintaining the quality of the environment (Zaman and Goschin 2010).

While monitoring the values of economic indicators which refer to the three pillars of sustainable development, it should be noted that the implementation of the idea is at various stages in various countries. Considerable disproportions are visible even after narrowing the search area to the European Union. Therefore, questions arise what should be done to make sustainable development an economic reality, and not merely a concept of thought implemented in selected economies.

A particularly important role in implementing the idea of sustainable development is played by the methods, tools and techniques which serve the rationalisation of material flow in supply chains and, in consequence, in entire economies. One of the methods that aim at reducing the consumption of raw materials is a closed-loop supply chain. It enables maintaining economic growth without exploiting new natural resources, which also considerably reduces the social costs of such growth.

The aim of the chapter is to present the need to implement closed-loop supply chains in the Polish economy. The proposed methodology is based on selected stages of the decision-making process directed towards the transformation of traditional supply chains into closed-loop supply chains are presented. These stages include: the analysis of current status developed based on the authors' own set of macroeconomic indicators at the level of economies of individual countries, as well as the selected models of implementation focusing on the analysis of the closed-loop supply chain model implementation method.

2 Material Flows

In order to achieve a harmonious economy growth, all possible environmental factors and environmental conditions that impact the broadly-understood human surroundings must be taken into account (Korzeń 2001). It is therefore essential to take interest in the subsequent phase of a product's life (after it has been used until full utilisation of its components)—in order to close the cycle fully. Today a full cycle starts with the acquisition of raw materials and ends with sending clean and harmless product remains back to the environment. This is the essence of the flow of physical goods in an economy (Szołtysek 2009).

The chief developmental trend in contemporary production systems and waste management subsystems which function as part of them, is presently aiming towards the selection of raw materials, semi-finished products and finished product manufacturing technologies (intended for exploitation) so that these products could be later used to the highest extent as raw material for future technologies. Thus, plans provide for the recirculation of products following their consumption i.e. the replacement of a part of the stream of raw materials feeding the manufacturing process with waste materials. It results in replacing open-type processes, where products are sent back to the environment in the form of waste, with closed-type processes providing for the recirculation of material resources (Fig. 1). This

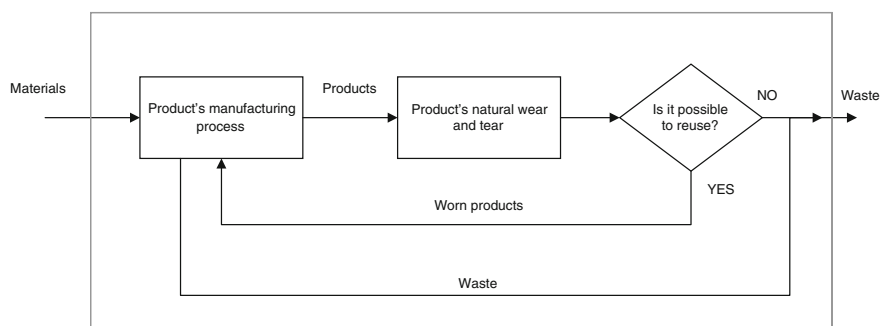


Fig. 1 Model showing the flow of material resources in economy, in a closed cycle (with recirculation), own study

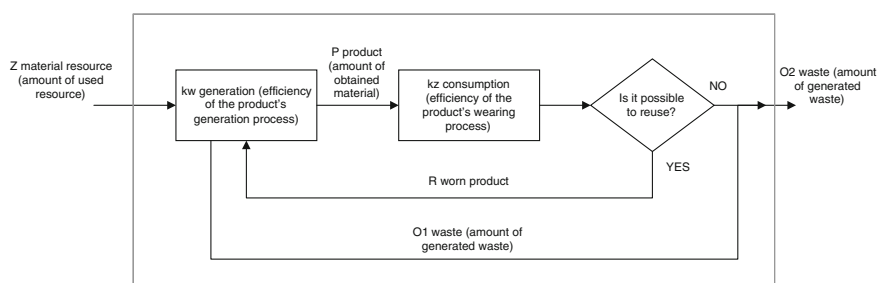


Fig. 2 Scheme of a model of the flow of material resources with recirculation own study

assumption provides a basis for developing analytical models of closed-loop material flows (Korzeń 2001).

The logistic model of material resource flow in a closed cycle presents a process which a single material resource is subject to, namely its processing into a product and, then, its wearing. In the closed model, a used product becomes a waste only partially, whereas its remaining part is directed back to the processing stage (Fig. 2).

Directing the stream of used products back to the processing stage brings down the level of used resources and reduces the amount of waste generated as a result of the flow process directed to the environment. The processes that maximise the flow effectiveness coefficient minimise the coefficient of relative amount of waste generated in the process. It means that the technology maximising the amount of product generated with the use of a single amount of material resource minimises the amount of waste generated in the process (Korzeń 2001).

The supply chains were originally created to support the flows from the production of raw materials up to final customers. But at present the return flows within these chains become more and more important as well (Sadowski 2010). The modern logistics has to be able to solve problems of remains of production batches,

goods returns, warranty and post-warranty service, production wastes, packaging and packaging wastes. All these issues are covered by so-called reverse logistics (Brdulak 2012).

The logistic chain of forward type (traditional forward chain) covers the processes related to the production and the distribution of goods, i.e. their flow from the place of origin of raw materials to the place of their final consumption (i.e. final customer). The logistic chain of backward type (return chain) covers the processes of the return and the collection of used products (Seitz and Wells 2006), as well as the processes connected with their recycling, i.e. their flow from the place of final consumer to the producer (from the point of view of a given chain). The returned product can be disassembled up to modules, parts or materials (Wikner and Tang 2008) during the backward processes. The aim of this process (e.g. during recycling) is to restore the original market value of the product (Gupta and Pochampally 2004).

The aim of undertaken operations could be the reuse of materials, return of the value of products taken from the market, the proper recycling or the optimization of after-sale services and reducing scarce material.

3 Macroeconomic Analysis

The re-use of materials as part of supply chains with closed material loop is a challenge not only for production and distribution companies, but also for regional, national and international authorities. Macroeconomic analysis refers to such aspects of company operations as the use of materials, the productivity of resources, the amount of generated waste, or the per cent share of recycled materials. It was carried out with the use of macroeconomic indicators. Due to Poland's location in Europe and its membership in the European Union, the authors decided to compare the situation of Polish companies to European enterprises. In order to unify the analyses and make them more transparent, data from selected European countries has been presented. Mean values for 28 EU member states and detailed data concerning the Visegrád Group (Poland, Czech Republic, Slovakia, and Hungary), the Weimar Triangle (Poland, Germany and France) and United Kingdom have been shown. Selection of the research perspective was influenced by different degree of development of European economies. Countries such as Germany, France or United Kingdom are considered to be states characterised by high economic culture. States comprising the Visegrád Group are the states which accessed the EU in 2004 and have been dynamically developing since then. They lead changes in Central and Eastern Europe. On the basis of available data, the 2012 situation has been presented.

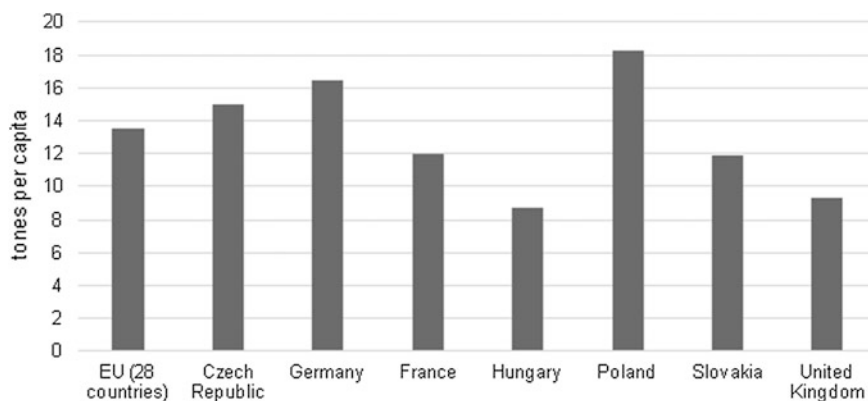
The first measure analysed is Domestic Material Consumption (DMC) per capita. It is defined as the total amount of material directly used in an economy per inhabitant. DMC equals Direct Material Input (DMI) minus exports. DMI measures

the direct input of materials for the use in the economy (Eurostat 2015). Results of the DMC per capita analysis for selected countries have been presented in Graph 1.

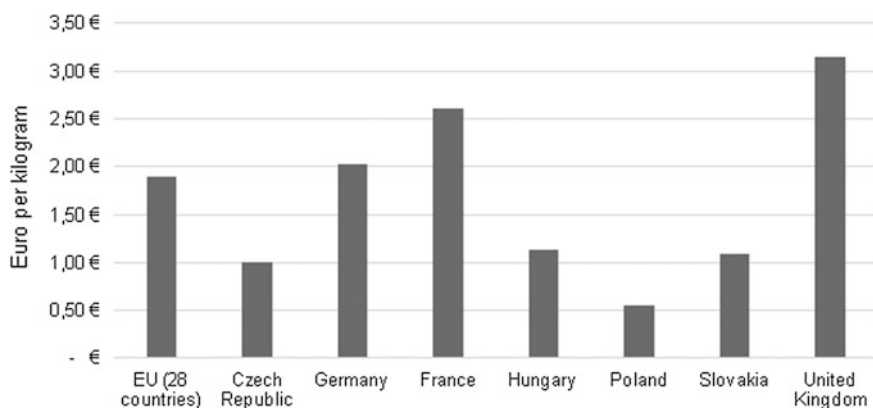
The consumption of materials in Polish economy is the highest in analysed countries. It could show that manufacturing sector in Poland is really well developed, or manufacturing in Poland is unproductive. The consumption of materials itself proves considerable demand for them and high scale of manufacturing activity. However, it does not show how effective the processing stages occurring within an economy are. This issue is synthetically presented by the resource productivity index. Resource productivity is gross domestic product (GDP) divided by DMC (Eurostat). Analysis results have been presented in Graph 2.

While comparing the analysis results presented in Graph 1 with resource productivity, it should be explicitly remarked that high consumption of materials in Polish economy is translated into a high added product value. Resource productivity of Polish economy is lowest among all analysed countries. Whereas it comes as no surprise in the context of comparison with the countries of the Weimar Triangle or United Kingdom, it is surprising in the case of comparison with the states forming the Visegrád Group. Mean resource productivity of these economies is 100 % higher than Poland's. It shows how low the added value of technological processes executed in Polish economy is.

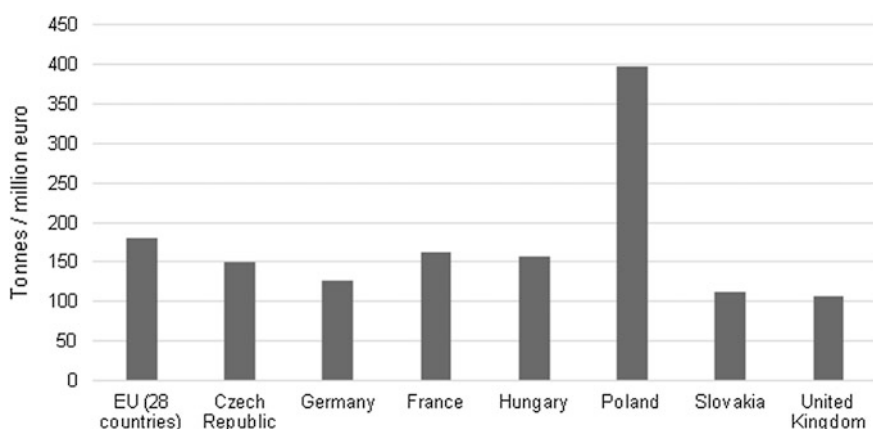
While analysing the results presented in Graphs 1 and 2, the question about the amount of waste generated by the economies of individual countries is of particular interest. The amount of waste itself does not fully reflect the issues tackled in the present chapter. It is therefore essential to present the amount of generated waste against a different macroeconomic indicator. A decision was taken that value of an indicator being the quotient of the total amount of waste and gross domestic product would be calculated. The value shows how many tonnes of waste are generated in a domestic economy to achieve GDP of one million EUR. Measures used in the quotient formula of the suggested indicator have been presented below.



Graph 1 Domestic material consumption per capita (Eurostat 2015)



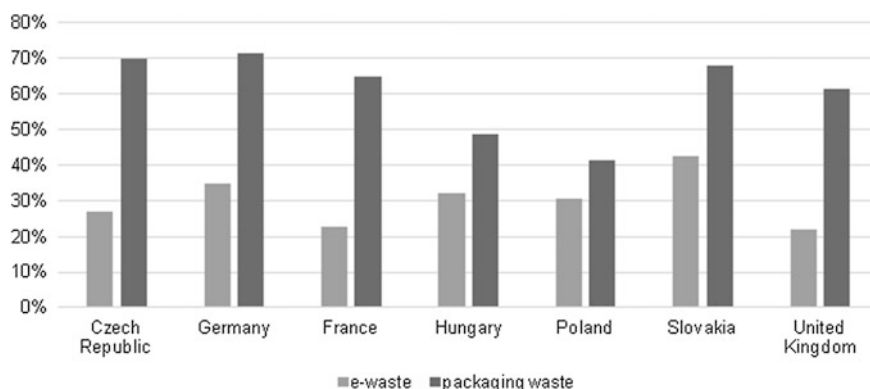
Graph 2 Resource productivity (Eurostat 2015)



Graph 3 Generation of waste by gross domestic product at market prices (Eurostat 2015)

Total amount of waste generated by households and businesses by economic activity. GDP is an indicator for a nation's economic situation. It reflects the total value of all goods and services produced less the value of goods and services used for intermediate consumption in their production. Expressing GDP in PPS (purchasing power standards) eliminates differences in price levels between countries, and calculations on a per head basis allows for the comparison of economies significantly different in absolute size (Eurostat). Results of the authors' analysis have been presented in Graph 3.

The results shown in Graph 3 bear out the hypothesis on low added value of Polish economy. Production in Poland is also characterised by generation of a large amount of waste per each million EUR GDP. The indicator showing the generation of waste by gross domestic product at market prices for Polish economy is more



Graph 4 Recycling rate (Eurostat 2015)

than twice higher than European average and over three times higher than German and Slovak economies. High value of the indicator proves that generation of a considerable amount of waste is required to obtain a million EUR GDP.

Apart from analyses showing the use of materials and the generation of waste, the amount of waste subject to recycling and re-use has been presented. The scope of available data has allowed the authors to focus only on two groups of waste: electronic waste and packaging waste. Electrical and electronic waste (e-waste) is a risk to environment because of its hazardous components. However, it also provides a high potential for recycling precious metals and other highly valuable materials. The indicator presents the effective recycling rate of e-waste which is the collection rate multiplied by the efficiency of treatment of waste electrical and electronic equipment (WEEE). Recycling rate for packaging waste means the total quantity of recycled packaging waste, divided by the total quantity of generated packaging waste (Eurostat 2015). Collective results of analyses have been presented in Graph 4.

Conclusions regarding the results presented in Graph 4 should be divided into two groups. Recycling waste for e-waste is, in the case of Poland, on average European level. In the case of packaging, the indicator for Polish economy is lowest among all analysed economies. It should be noted that the economies of the Czech Republic and Slovakia deal with the aspect particularly smoothly.

4 Selected Implementation Variants

Implementation of solutions increasing the share of recycled or remanufactured materials requires drawing up some new organisational solutions.

Cardoso et al. (2013) proposed the model of a supply chain, realizing two-direction flows. The aim of this model is to create a structural solution (choice of the structure of a supply chain) to maximize NPV indicator (net present value) in

the situation of the uncertainty of the demand. The elaborated model describes four levels. The final goods, in the described model, can be destined to the market through the distribution network, from the warehouse or directly from the production plant. The backward flow of used goods takes place from a client (market) to various points of the supply chain. The used goods (or their parts) go also outside the described structure and are identified with wastes (are not used within the analysed chain structure).

Jonrinaldi and Zhang (2013) presented the proposal of the model of the integration of products and stocks with regards to backward logistics in a finite time period. Total costs of functioning of the supply chain (of each part among mentioned below) are the aim function of this model. The model assumes the existence of a supply chain of 6-level structure. The described model was used by authors to inspect the influence of the coordination of the production process with stocks in conditions of the supply chain performing both forward (from producer to client) and backward (from client to producer) goods' flow on total costs of functioning of such supply chain.

The re-use of materials from goods used by consumers provides materials whose supply has not been precisely determined, which makes determination of optimum sizing of the lot of material flow on all stages of the supply chain more difficult. This issue has been discussed in the paper written by Zhendong et al. (2009). The authors have developed a supply chain model providing for a closed loop. A conceptual approach to a closed loop has been presented in Fig. 3.

Due to possible variants of performing the production process presented in Fig. 3, Zhendong et al. have presented four possible variants:

- capacitated dynamic lot sizing problem with only disposal,
- capacitated dynamic lot sizing problem with only remanufacturing,
- capacitated dynamic lot sizing problem with remanufacturing and disposal,
- dynamic lot sizing problem with capacitated production and uncapacitated remanufacturing, for optimising the flow of materials.



Fig. 3 The closed-loop supply chain with production, disposal and remanufacturing, own study based on (Zhendong et al. 2009)

4.1 Capacitated Dynamic Lot Sizing Problem with Only Disposal

In this variant, the general optimisation model assumes the following form (Zhendong et al. 2009):

$$\min \sum_{t=1}^T (f_t(x_t) + \theta_t(I_t^r))$$

where:

- T the length of the planning horizon
- t the index of the planning horizon, $t = 1, \dots, T$
- $f_t(x_t)$ the cost (or profit) of disposing x returned products in period t
- $\theta_t(I_t^r)$ the inventory cost of holding I of returned products held in inventory at the end of period t

4.2 Capacitated Dynamic Lot Sizing Problem with Only Remanufacturing

In this variant, the general optimisation model assumes the following form (Zhendong et al. 2009):

$$\min \sum_{t=1}^T (f_t(y_t) + \theta_t(I_t^r))$$

where:

- T the length of the planning horizon
- t the index of the planning horizon, $t = 1, \dots, T$
- $f_t(y_t)$ the cost (or profit) of returned products remanufactured in period t
- $\theta_t(I_t^r)$ the inventory cost of holding I of returned products held in inventory at the end of period t

4.3 Capacitated Dynamic Lot Sizing Problem with Remanufacturing and Disposal

In this variant, the general optimisation model assumes the following form (Zhendong et al. 2009):

$$\min \sum_{t=1}^T (f_t(x_t) + g_t(y_t) + \theta_t(I_t^r))$$

where:

- T the length of the planning horizon
- t the index of the planning horizon, $t = 1, \dots, T$
- $f_t(x_t)$ the cost (or profit) of disposing x returned products in period t
- $g_t(y_t)$ the cost of remanufacturing y returned products in period t
- $\theta_t(I_t^r)$ the inventory cost of holding I of returned products held in inventory at the end of period t

4.4 Dynamic Lot Sizing Problem with Capacitated Production and Uncapacitated Remanufacturing

In this variant, the general optimisation model assumes the following form (Zhendong et al. 2009):

$$\min \sum_{t=1}^T (g_t(y_t) + e_t(z_t) + \theta_t(I_t^r) + \emptyset_t(I_t^s))$$

where:

- T the length of the planning horizon
- t the index of the planning horizon, $t = 1, \dots, T$
- $g_t(y_t)$ the cost of remanufacturing y returned products in period t
- $e_t(z_t)$ the cost of producing z new products in period t
- $\theta_t(I_t^r)$ the inventory cost of holding I of returned products held in inventory at the end of period t
- $\emptyset_t(I_t^s)$ the inventory cost of holding I of serviceable products held in inventory at the end of period t

The variants described above may be broadened with conditions of limited capacities for each of the production activities (primary production, utilisation and re-use). For a situation in which the limitation of capacities changes in time, the issue of determining the size of material flow in a supply chain becomes a serious problem. Its practical solution is possible in a situation where various types of production processes coexist, but their capacities are definite (unchangeable) or indefinite (are not a limitation) (Zhendong et al. 2009).

5 Conclusion

Increasing the share of material from recycled used finished products is a long-lasting process involving both technological and organisational changes. In the chapter, the authors have focused on the organisational issues, particularly on the process of making decisions concerning the transformation of supply chains in favour of closed-loop supply chains. The most essential stages of this decisive process are the identification of the present situation and the implementation of changes. The stage related to the selection of the best solution has therefore been omitted. It has been stated that these solutions already exist and they form a set of best practices rooting from the issues relating to the closed-loop supply chain.

Making a diagnose on the situation on the macroeconomic level is the first stage of making decisions aiming at increasing the per cent share of recycled materials in materials used by production companies. The chapter presents a detailed macroeconomic analysis of Polish economy as opposed to other European economies in the context of the re-use of materials. The analysis shows that over 25 years after the transformation of its system, Polish economy has still much to catch up in the ecological context, not only as compared to the countries of the so-called “old Europe”, but also in comparison to the states of the Visegrád Group, which have similar histories. It makes one aware of how urgent the implementation of solutions increasing the re-use of materials should be.

As part of the stage of implementing solutions whose purpose is to increase the use of recycled materials, the authors suggest the use of a model for optimising the structure of these chains and the sizing of the lot of material flow in a closed-loop supply chain. The purpose of these activities is to eliminate negative impact of unstable stream of materials (in the form of processed used goods) on the costs of operational activity of the supply chain. The aim of its use is the minimisation of total costs of operational activities on an unstable supply market.

Acknowledgments This chapter has been the result of the study conducted within the grant by the Ministry of Science and Higher Education entitled “Modelling of economic order quantity in the supply chain” (project No. KSL 1/15) pursued at the Poznan School of Logistics in Poznań.

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Efficiency in Sustainable Supply Chain

Golinska, P.; Kolinski, A. (Eds.)

2017, VIII, 216 p. 72 illus., 34 illus. in color., Hardcover

ISBN: 978-3-319-46450-3