International Proceedings of Chemical, Biological and Environmental Engineering, V0l. 101 (2017)
DOI: 10.7763/IPCBEE. 2017. V101. 13

Application of Cost-Benefit Analysis for an Eco-Product Manufactured from Production Waste

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Abstract. Urban and regional development of municipalities and also industrial progress of the last decades lead to the generation of a high amount of household and production waste, with an important fraction of recyclable waste. Almost 40% from these are paper and cardboard waste. Paper and cardboard manufacturing is one of the most dynamic industrial sectors which addresses very seriously the concept of circular economy, by closing the production loop, since it is able to valorize the recovered paper at a high degree. However, there are production waste, generated during cardboard and corrugated packaging manufacturing, which can be further revaluated "in plant" for the production of various subassemblies or products. This way, the transport of production waste to the paper mill (for "off-site recycling") is avoided, production waste is turned into resource and the new products and/or subassemblies can be delivered on the market eco-efficiently, at reasonable price, with low impact in the environment, since they are entirely recyclable and biodegradable.

In this context, the present study developed an analysis of the efficiency, expressed in terms of costs and benefits and assessed by applying a method specific to Cost-Benefit Analysis (CBA), for an eco-product (**Eco-P**) manufactured from production waste, in the context of eco-innovation and eco-design principles.

The results showed that turning production waste into raw material by reusing it in the form of a marketable eco-product improves significantly process eco-efficiency by closing the loop, reduces eco-costs and increase the benefit/cost ratio.

Keywords: benefits, costs, eco-product, waste

1. Introduction

Currently, humanity makes efforts in the direction of economic development on a sustainable pathway for improving well-being, but also to protect the environment and preserve its resources [1]-[3]. The majority of products designed for consumption is the result of economic and industrial activities, which generate losses in the form of emissions and waste, with major consequences on economic and ecological performances [4], [5]. The production processes are in connection with the environment regarding resource consumption and waste generation [6]. It is obvious that generation of waste in manufacturing processes is the consequence of an inefficient and unsustainable use of natural resources, energy, capital [7]. From economists' perspective, both raw materials from natural resources and waste belong to the natural capital.

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Romania produced 281 tons/year.per capita of production waste with recoverable potential (waste from packaging, plastic glass, metal sectors) - in 2015 compared to the European Union (EU) average of 459 tons/year.per capita, according to the latest available Eurostat data [8]. However, in Romania only 50.5% of the total production wastes with recoverable potential are recycled or incinerated, compared with 89.3% for the European average [9]. If we focus on the amount of recyclable waste, at European level the statistics show that Finland followed by Belgium and Estonia generate a high amount of recyclable production waste in the EU (Fig. 1) [8]. Romania recycles a very small amount of production waste with recoverable potential (0.49 tonnes), while the EU average is 0.6 tons (Fig. 1), but we are still placed at the end of the European ranking do to the capacity of recycling.

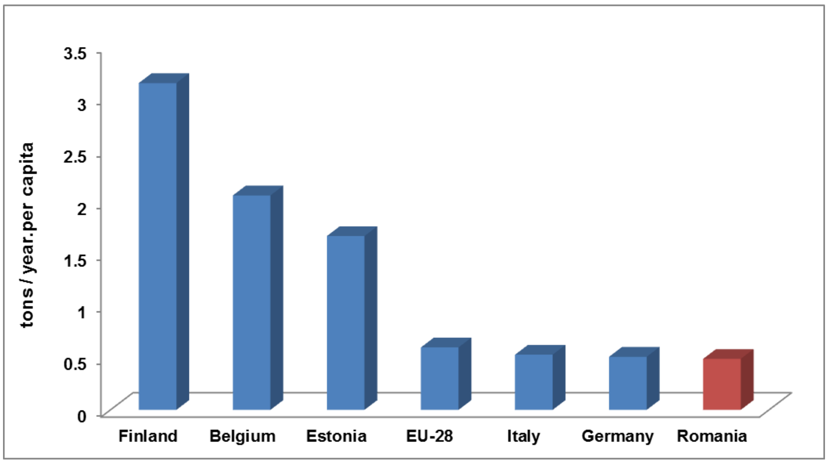

Fig. 1: Quantities of production recyclable waste generated worldwide in 2015

A specific category of waste comes from packaging, in particular cardboard packaging. Romania recovers only half of the used packaging (56.8 %), according Eurostat data [9], [10]. Because of the aggressive use of non-renewable resources, we must give up the linear economic models (the "cradle-to-grave" approach) and to adopt new models for a sustainable management of resources and energy, by replacing the raw materials with recoverable materials [10]. While Horizon2020 program established the strategy for a smart, sustainable and inclusive development of Europe 2020, the progress toward a circular economy is considered today in the centre of concerns for resource efficiency [11]. Prevention of waste generation, reuse and other related measures correlated with eco-innovation, eco-design could bring savings of 600 billion euro, or an increase of 8% in the annual turnover for companies in the EU-28, together with the reduction of the total greenhouse gas emissions with 2% -4% [12].

The circular economy would preserve as much as possible the benefit of a product, even when it reaches the end of its life cycle, such that to continue to be used productively and continue to generate benefits. Another way is to close the cycle "in plant" by revaluating the waste generated during manufacturing process due to incomplete processing of raw materials [13]. All these considerations emphasize the following potential advantages and benefits (Fig. 2) [13], [14]: *(i) sustainability*; *(ii) reducing the use of materials, difficult to recycle (replacement)*; *(iii) create markets for recycled materials (standards, public procurement)*; *(iv) creating products that are easier to recycle (eco-design)*; *(v) stimulation of separation and collection systems to minimize the costs of recycling and reuse*; (vi) *encourage consumption by hiring or leasing, instead of purchasing new products (new business models)*. Therefore, keeping the value of products and materials for as long as possible and generating less waste, the world economy may become more competitive and more resistant, but reducing the pressure on planet bio-capacity. Consequently, the manufacturing processes must reuse "in plant" the production waste as eco-reengineered and marketable products, based on knowledge transfer, eco-innovation, eco-design, switching from the classical "cradle-to-grave" approach to the more sustainable "cradle-to-gate" or "cradle-to-cradle", and extending the life cycle of materials and waste in the form of valuable products.

In this study, we developed an analysis of the efficiency of waste reuse in the form of an eco-product (**Eco-P**), by applying the Cost-Benefit Analysis. The industrial sector taken into analysis is cardboard and corrugated packaging manufacturing; more specifically the production waste generated during the fabrication of cardboard plates and corrugated boxes for packaging purposes. **Eco-P** was eco-innovated and eco-designed to rally the assortment of similar products, manufactured from cardboard plates, which the manufacturer is able to release successfully on the market. **Therefore, we applied a CBA methodology to demonstrate the economic feasibility of reusing and recycling this cardboard waste in the same process that generate it.** To achieve this goal we went through the CBA specific steps, establishing process boundaries, assessing of the benefits of eco-product, calculating benefit/cost ratio, finalized with sensitivity analysis.

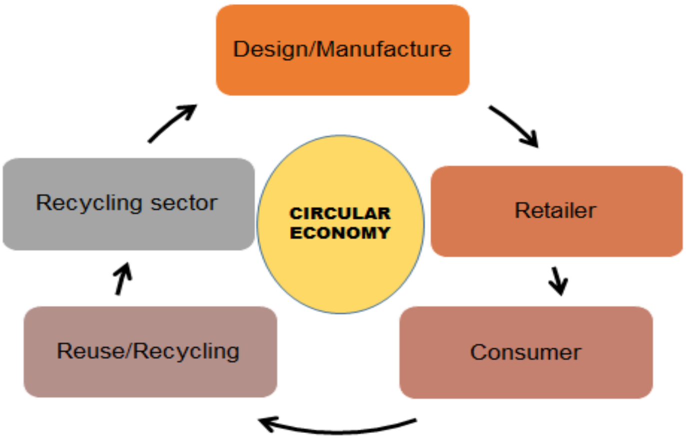

Fig. 2: The main steps in the circular economy.

2. Cost-Benefit Analysis of Production Waste

2.1. Production Waste Impact

Industrial progress has influenced the production waste not only regarding the quantity, but also the content (Fig. 3) [15]. Production wastes, in our work approach are those resulting during manufacturing process, having the same characteristics as the raw material used in product manufacturing, and which is a production lost if not re-used in the process [15], [16]. Defective management of production waste as that of energy and raw materials can lead to higher consumption and a more severe impact on the environment [17].

Cardboard consumption increased by 250% in the last 50 years and of course this has led to the intensive exploitation of forests, in many countries, the deforestation phenomenon appearing on large regions of the world [18].

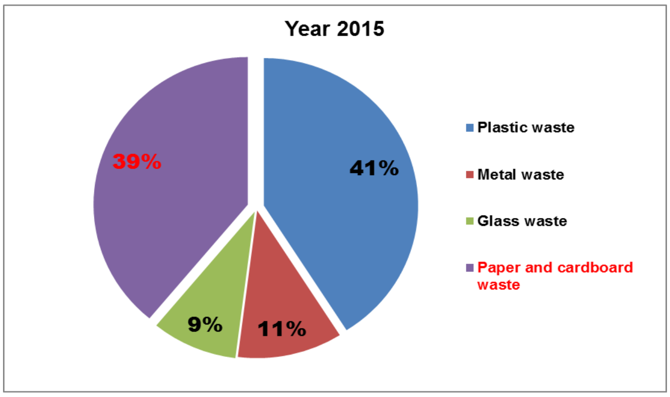

Fig. 3: Industrial waste production (year 2015).

Therefore, the extension of life cycle of any material of forest origin is extremely beneficial. It is estimated that about 25% of the cut trees all over the planet are used to produce paper and cardboard [19], [20]. It was estimated that a ton of recycled cardboard can save 3200 liters of water, 380 kWh electric energy, 22 trees older than 20 years, and avoids the release in the atmosphere of almost 850 grams of carbon dioxide [21]. Production of cardboard from wood consumes much more resources than the production of cardboard from recycled waste [22].

The materials manufactured from paper and cardboard are used in many areas, in particular for packaging [22]. These materials, at the end of their life are turned into waste [22]-[25]. Paper and cardboard can be recycled about 5 to 7 times. Moreover, cardboard waste can be reused for manufacturing of products, similar with others already manufactured from cardboard plate, but made from production waste, being completely recyclable and biodegradable, denoted here as **eco-products**.

2.2. Methodology

Cost-Benefit Analysis is a quantitative tool for financial estimation and evaluation, which allows processes to be evaluate based on a comparison between their costs and benefits [26]-[28]. In eco-efficiency evaluations, the purpose of the cost-benefit analysis is to assess whether the effects of the environmental impact are greater than the net benefit for society. Cost-Benefit Analysis is usually applied to evaluate many processes such as: (i) transport investment [29], (ii) pathology examination [30], (iii) waste electrical and electronic equipment reuse [31], (iv) watershed conservation [32], (v) energy conservation [32], etc. For an effective assessment of the economic impact of any project (including environmental investments) all stages of technical and economic analysis must be followed (Fig. 4).

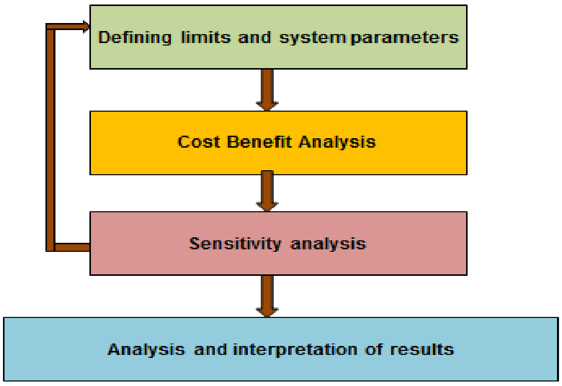

Fig. 4: Stages of cost-benefit analysis.

To achieve the **objective** of this study, all four phases of CBA were accomplish. **The evaluation of the economic performance and efficiency of an Eco-P using production waste generated during corrugated board and cardboard box manufacturing as raw material was first determined using cost-benefit analysis indicators: cost-benefit or benefit-cost ratio**.

The CBA methodology includes a *qualitative analysis* consisting in the *assessment of the benefits* of eco-product, and a *quantitative analysis* which compares different costs (land cost, construction cost, technology cost, operating costs etc.) to determine the lower costs.

Process boundaries for the Eco-P manufacturing, which underlie the cost-benefit analysis, are shown in Fig. 5.

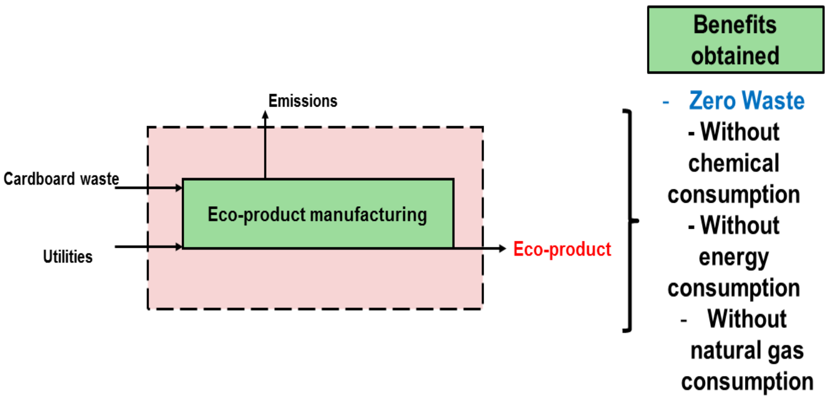

Fig. 5: Process boundaries

2.2.1. Inventory analysis

Costs identification was conducted by analyzing the nature of the project, types of siting, facilities and necessary infrastructure. In our CBA we considered the following cost categories: **direct costs** (project cost, land cost, construction cost, technology cost, operating costs etc.), **indirect costs**, for externalities.

2.2.2. Economic impact assessment

At this stage of the CBA, the information regarding the relevant costs and benefits was organized to determine the feasibility of our eco-product manufacturing. Benefits identification has been done considering the following three main issues: **economic, social and environmental** (Table 1).

Table 1.Benefits identified for Eco-P

Benefit type	***Benefits identified for Eco-P***
Economic benefits	5% of total costs
Social benefits	Creating jobs and material benefits Increased property value and comfort Benefits of human health
Environmental benefits	Reducing the volume of waste and emissions Energy conservation and consumption reduction of non-renewable resources Zero waste

2.2.3. Determining and analysing cost-benefit (RCB) and benefit-cost (RBC) ratios

The R_{CB} is the result of the ratio between the updated value of the total costs and the updated benefits (Eq. 1). The R_{BC} is the result of the ratio between the updated value of the total benefits and the updated costs (Eq. 2) (Fig. 6).

$$R_{CB} | = \frac{VT_c}{VT_B} \tag{1}$$

Where: R_{CB} represent cost-benefit report; VT_c represent value of updated costs; VT_B represent value of updated benefits

$$R_{CB} | = \frac{VT_B}{VT_C} \tag{2}$$

Where: R_{CB} represent benefit-cost report; VT_B represent value of updated benefits; VT_C represent value of updated costs

2.2.4. Sensitivity analysis

Sensitivity analysis sets minimum and maximum values for the variables included in the sensitivity analysis in order to determine the viability of the alternatives (production process), which can be influenced by the changes in input sizes. For each of the alternatives, the main parameters used in the cost and benefit analysis were analysed, such as: the costs involved in obtaining the Eco-P (e.g. investment costs, benefits from the sale of finite products and environmental benefits etc.).

3. Results and Discussion

The cost-benefit analysis of the product indicated that reusing production waste by manufacturing the **Eco-P** is a suitable alternative for implementation, because it brings significant benefits such as: energy consumption reduction, requires low consumption of raw materials, chemicals, natural gas, reduce the volume of waste and emissions released into environment (Fig 6.). For this study, we considered the update duration for 8 years. The economic benefits evaluated in this study take into account only the benefits resulted from reusing production waste as raw material for **Eco-P**. The net benefit of reusing production waste for obtaining the **Eco-P** is estimated at 2.7% from the total annual production of the targeted Romanian manufacturer. Our results show that, at the level of 2025, there will a significant reduction in the cost of manufacturing **Eco-P**. Thus, we can say that cardboard manufacturing industry brings a positive contribution to the economy by implementing the new product (Fig. 7). The CBA has shown that the cost reduction is influenced by the replacement of raw materials with the production waste.

The results have also highlighted the substantial reduction of raw material and energy costs, as well as the identification of a large number of benefits regarding the economic viability of the eco-innovated and eco-designed **Eco-P** obtained from production waste. It has also some additional benefits: saving landfill space, reduction of non-renewable resource consumption, improved company image and abatement of several environmental problems.

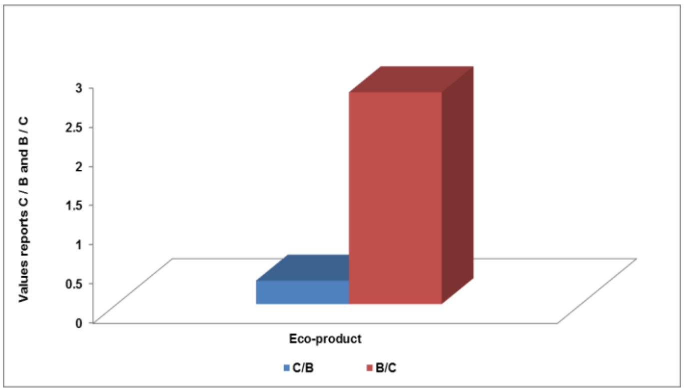

Fig. 6: Analysis of C/B and B/C reports.

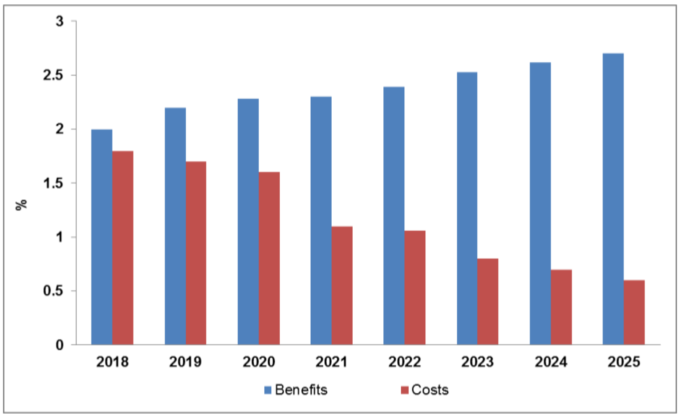

Fig. 7: Level of implementation

4. Conclusions

The first part of this study discussed a number of important aspects on certain issues and opportunities in industrial waste management, at European and national levels. It was highlighted that the production waste generated by the industrial sectors is a sustainable source as raw material, when it is reused “in plant”, by closing the loop, according to circular economy principles. We have identified the opportunity to revaluate the production waste from cardboard and corrugated board packaging manufacturing by making an eco-innovated and eco-designed eco-product (**Eco-P**).

In this context, we have applied Cost-Benefit Analysis methodology to assess the economic performance of **Eco-P**. The study only focused on the environmental and economic benefits.

In order to determine the economic viability of the process for **Eco-P** manufacturing and of product itself, the contribution of the main stages of the proposed process was analysed. The results showed that our approach offers a sustainable solution for valorisation of the cardboard waste, the manufacturing process tending toward "zero waste" by closing an almost complete loop. The assessment of socio-economic benefits in terms of costs and benefits ratio has proved that **Eco-**P is techno-economically sustainable.

The results of the study can help us in a better understanding the harmonization of circular economy with the priorities of sustainable development, and the measure the overall benefits of **Eco-P** manufacturing.

5. Acknowledgements

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS – UEFISCDI, project number PN-III-P2-2.1-BG-2016-0130, Contract 64BG/2016.

6. References

[1] M. E. Fortuna, I.M Simion, M. Gavrilescu. Sustainability in environmental remediation. *Environ. Eng. Manag. J.* 2011, **10** (12): 1987-1996.

[2] M. Gavrilescu. Cleaner production as a tool for sustainable development. *Environ. Eng. Manag. J.* 2004, **3** (1): 45-70.

[3] C. Ghinea, M. Petraru, I. M. Simion, D. Sobariu, H.Th.A Bressers, M. Gavrilescu. Life Cycle Assessment of waste management and recycled paper systems. *Environ. Eng. Manag. J.* 2014, 13 (8): 2073-2085.

[4] E. D. Comăniță, C. Ghinea, R. M. Hlihor, I. M. Simion, C. Smaranda, L. Favier, M. Rosca, I. Gostin, M. Gavrilescu. Challenges and opportunities in green plastics: An assessment using the ELECTRE decision-aid method. *Environ. Eng. Manag. J.* 2014, 14 (3): 689-702.

[5] M. Palmiotto, E. Fattore, V. Paiano, G. Celeste, A. Colombo, E. Davoli. Influence of a municipal solid waste landfill in the surrounding environment: Toxicological risk and odor nuisance effects. *Environ. Int.* 2014, 68: 16–24.

[6] C. D. Heaney, S. Wing, R. L. Campbell, D. Caldwell, B. Hopkins, D. Richardson. Relation between malodor, ambient hydrogen sulfide, and health in a community bordering a landfill. *Environ. Res.* 2011, 111: 847–852.

[7] G. De Feo, S. De Gisi, I.D. Williams. Public perception of odour and environmental pollution attributed to MSW treatment and disposal facilities: a case study. *Waste Manage.* 2013, 33: 974–987.

[8] Eurostat. Consumption of energy. On line at: http://ec.europa.eu/eurostat/statisticsexplained/index.php/ Consumption_of_energy, 2015.

[9] A. C. Puițel, T. Campean, F. Grad, D. Gavrilescu. Sustainable use of recovered paper in the Romanian paper industry. Part II - environmental impact. *Environ Eng Manag J.* 2014, **13** (8): 1909-1915.

[10] D. Căilean (Gavrilescu), C. Teodosiu. An assessment of the Romanian solid waste management system based on sustainable development indicators, *Sust. Prod. Cons.*, 2016, 8: 45–56.

[11] Y. Geng. J. Fu, J. Sarkis, B. Xue. Towards a national circular economy indicator system in China: an evaluation and critical analysis, *J. Clean. Prod.*, 2012, 23 (1): 216-224.

[12] D. Lavee. Is municipal solid waste recycling economically efficient? *Environ. Manag*, 2007, 40 (6): 926-943.

[13] I. Ordonez, U. Rahe. Collaboration between design and waste management: can it help close the material loop?. *Resour. Conserv. Recycl.* 2013, 72, 108-117.

[14] Z. Yuan, J. Bi, Y. Moriguichi. The circular economy: a new development strategy in China. *J. Ind. Ecol.* 2006, **10** (1-2): 4-8.

[15] A. Koolivand, H. Mazandaranizadeh, M.Binavapoor, A. Mohammadtaheri, R. Saeedi. Hazardous and industrial waste composition and associated management activities in Caspian industrial park, Iran. Environ. Nanotechnol. Monit. Manage. 2017, **7**: 9–14.

[16] P. Kappen, G. Ferrando-Miguel, S.M. Reichman, L. Innes, E. Welter, P.J. Pigram. Antimony leaching and chemical species analyses in an industrial solid waste: Surface and bulk speciation using ToF-SIMS and XANES. *J. Hazard. Mater*. 2017, 329: 131–140.

[17] S. Thambiraj, D. Ravi Shankaran. Preparation and physicochemical characterization of cellulose nanocrystals from industrial waste cotton. *Appl. Surf. Sci*. 2017, 412: 405–416.

[18] G. Capson-Tojo, E. Trably, M. Rouez, M. Crest, J.-P. Steyer, J.-P. Delgenès, R.Escudié. Dry anaerobic digestion of food waste and cardboard at different substrate loads, solid contents and co-digestion proportions. *Bioresour. Technol*. 2017, 233: 166–175.

[19] X. Fonoll, S. Astals, J. Dosta, J. Mata-Alvarez. Impact of paper and cardboard suppression on OFMSW anaerobic digestion. *Waste Manage*. 2016, 56:100–105.

[20] P. Jeetah, N. Golaup, K. Buddynauth. Production of cardboard from waste rice husk. Journal of Environmental Chemical Engineering. 2015, 3, Issue 1, March 2015, Pages 52–59

[21] S. Secchi, F. Asdrubali, G. Cellai, E Nannipieri, A. Rotili, I. Vannucchi. Experimental and environmental analysis of new sound-absorbing and insulating elements in recycled cardboard. *J. Build. Eng*. 2017, 5: 1–12.

[22] G. Leyssens, G. Trouvé, I. Caplain, C. Schönnenbeck, F. Cazier. Energetic performances and environmental impact of the combustion of cardboard/sawdust in a domestic boiler. *Fuel*. 2014, 122: 21–27.

[23] H. Diehla, F. Welle. How to determine functional barrier performance towards mineral oil contaminants from recycled cardboard. *Food Packag. Shelf Life*. 2015, 5: 41–49.

[24] F. Asdrubali, A.L. Pisello, F.D' Alessandro, F. Bianchi, M. Cornicchia, C. Fabiani. Innovative Cardboard Based Panels with Recycled Materials from the Packaging Industry: Thermal and Acoustic Performance Analysis, *Energy Procedia*. 2015, 78: 321-326.

[25] M. Gavrilescu, K. Demnerová, J. Aamand, S. Agathos, F. Fava. Emerging pollutants in the environment: present and future challenges in biomonitoring, ecological risks and bioremediation. *New Biotechnol*. 2015, 32: 147–156.

[26] C. Ghinea, M.Gavrilescu. Decision support models for solid waste management - an overview. *Environ. Eng. Manag. J.*, 2010, 9 (3): 869-880.

[27] E. D. Comăniță, R. M. Hlihor, C. Ghinea, M. Gavrilescu. Occurrence of plastic waste in the environment: ecological and health risks. *Environ. Eng. Manag. J.* 2016, 15 (3): 675-685.

[28] I. M. Simion, M.E. Fortuna, A. Bonoli, M. Gavrilescu. Comparing environmental impacts of natural inert and recycled construction and demolition waste processing using LCA". *Environ. Eng. Manag. J.*, 2013, 21 (9): 273-287.

[29] R. Vickerman. Beyond cost-benefit analysis; the search for a comprehensive evaluation of transport investment. *Research in Transportation Economics*, In Press.

[30] D. R. Howard, N. Kazemi, W. J. Rubenstein, M. J. Hartwell, J. Poeran, A. L. Chang, J. D. Podolnick. Cost-benefit analysis of routine pathology examination in primary shoulder arthroplasty. *J. Shoulder. Elb. Surg.* 2017, 26 (4): 674–678

[31] X. M. González, M. Rodriguez, Y. Pena-Boquete. The social benefits of WEEE re-use schemes. A cost benefit analysis for PCs in Spain. *Waste Manage*. 2017, https://doi.org/10.1016/j.wasman.2017.03.009.

[32] K. Burnett, Ch. Wada, A. Balderston. Benefit-cost analysis of watershed conservation on Hawai'i Island. *Ecol. Econ*. 2017, 131: 262–274.