Strategic Life Cycle Assessment in Individual Phase of Waste Production

Marcela Malindžáková [1], Dominik Puškaš [1], Katarína Čulková [2]

[1]*Technical University Košice, Institute of Logistics, Park Komenského 14, Košice, Slovakia*
[2]*Technical University Košice, Institute of Earth Sources, Park Komenského 19, Košice, Slovakia*

***Abstract* – Presently many firms have been forced to take into consideration decreasing material and energy consumption and minimizing waste production. Planning or evaluation of waste collection and recycling systems demands technical and economic performance for materials recovery. Here is the space for life cycle assessment using the individual phases of waste production by the way of diagram of material balance. The research considers specific conditions of waste processing company, orientated to the creation of integral system of waste processing. The results show creation and consequent evaluation of complex material flow.**

***Keywords* – Life cycle assessment, Waste production, Living environment, Waste flow, Logistics.**

1. Introduction

Method Life Cycle Assessment (LCA) is relatively new tool of evaluation, developed at the beginning in nineties in the 20th century. The tool enables to evaluate environmental aspects in the whole life cycle of the production, from obtaining of input sources till product liquidation, through specification of cumulative charge to the individual elements of living environment, with present providing of production reliability through reducing the number of failures [1]. In modern industrial companies that have available sources for innovation, such analysis is related also to projects with development of new or adapted products (LCA construction).

Presently many firms have been forced to take into consideration decreasing material and energy consumption and minimizing waste production in planning their network designs [2]. One way how to minimize manufacturing costs is using returnable material at the manufacturing process.

In practice, it might be necessary to simultaneously optimize more than one conflicting objective to obtain effective and realistic solutions, which reduce cost, improve product quality, and provide environmental benefits by minimizing waste production. Planning or evaluation of waste collection and recycling systems demands technical and economic performance for materials recovery [3], requesting calculation of processing costs and projections of revenues from material sales and sorting residues disposal costs. This could be considered as important factor explaining the relatively low overall recovery efficiencies in organizations. Waste management indicate several inter-country differences, when Berglund and Söderholm [4] studied data over 49 countries worldwide, concluded that relative waste recovery and use depend largely on long-standing economic factors, such as population intensity and competitiveness in the world market.

The use of LCA in area of waste had been followed by Fraj and Idir [5], studying the use of recycled concrete aggregates as an alternative source of coarse aggregates for the production of new concrete that can help to solve the problem of depleting natural resources and that of growing waste disposal crisis. However, their recycling could decrease the concrete performance, particularly for low grade recycled aggregates (RA). To compensate for this decrease, cement content can be adjusted and hence, the environmental interest of RA has to be assessed. This study aims at assessing the environmental footprint of recycled aggregate concrete (RAC), compared to natural aggregate one (NAC), considering the grade of used RA and the aggregates' delivery distance. Waste is studied from the view of LCA also by

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Corresponding author: Katarína Čulková,
Technical University Košice, Institute of Logistics, Košice, Slovakia
Email: katarina.culkova@tuke.sk

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Tucker et.al [6], when through an evaluation of life cycle impacts and system costs, the feasibility of a potential pozzolan market was evaluated in comparison to the two most common management strategies for recycled glass cullet. The relation between LCA and waste management can be followed up also by LCEA – life cycle energy analysis [7]. Hendrikcson et.al [8] utilized life-cycle assessment (LCA) to analyze the energy consumption and greenhouse gas (GHG) emissions of an operating Living Machine (LM) wetland treatment system that recycles wastewater in an office building. The results of this study can be applied to other case studies and scenarios to identify conditions under which decentralized water reuse can lower GHG emissions and energy use compared to centralized water reuse when selecting alternative approaches to meet growing water demands. Energy consumption considers also environmental impact through LCA approach [9]. The study follows parameters, such as life cycle energy use, and global warming potential, and water, air and land emissions. Results show the building with concrete frame is proved to have lower environmental impact compared to that with steel frame. The precast concrete building is found to be the most economical alternative due to the minimal environmental impact cost.

As for the construction sector, there are several studies of LCA use. For example Benveniste et.al [10] made illustration of LCA activities relative to the construction sector. Specifically, the study presents the results obtained from the life cycle analysis of the floor and wall tile sector, which served as the basis for drafting of the PCR required for the definition of Environmental Product Declarations (EPD). They made declarations based on LCA studies that permit the disclosure and dissemination of environmental information quantified over the life cycle of a product. Birgisdóttir, et.al [11] used LCA model for road construction and disposal of residues. According to the study, the LCA includes resource and energy consumption, and emissions associated with upgrading of bottom ash, transport, landfilling processes, incorporation of bottom ash in road, substitution of natural gravel as road construction material and leaching of heavy metals and salts from bottom ash in road as well as in landfill. The study presents results by showing the difference in environmental impacts between landfilling and utilization of bottom ash in road was marginal when these alternatives were assessed in a life cycle perspective.

LCA use in the area of ecological concepts, relying on an environmentally sound management of energy has been poorly characterized in literature and is ignored by public authorities. In order to provide practical data and information, filling this gap, Benetto et.al [12], made a comparative life cycle assessment of EcoSan system at an office building since standard conventional systems have very poor environmental performances. Results of the study speak about possible reducing of contribution to the ecosystem quality by more than 60%.

Albertí et.al [13] analyses whether the existing LCA and sustainability methods can be used in the assessment of a city or an urban region with the aim to check if the assessment tools can provide good results in the absence of LCA-based assessments for cities and urban regions. They concluded that current sustainability assessment tools do not consider various environmental impacts, Life Cycle (LC) perspective, and the possibility to compare the results among different areas. Based on the standards of life cycle assessment (LCA) of international standards for organization, LCA is considered also for vehicle biogas production. In this area Huang et.al [14] calculated the method for life cycle inventory (LCI). Results show that in the vehicle biogas production life cycle, improving the production process is the main way to reduce the energy consumption and reveal a sustainable developing way for the biogas produced by municipal waste. Lam et.al [15] evaluated the current and future life-cycle energy impacts of four alternative water supply strategies introduced during a decade-long drought, emphasizing the energy burden of alternative water supply strategies which added approximately 24% life-cycle energy use to the existing supply system (with surface water sources). This work shows that managing long-term water demand is also important, in addition to acknowledging the energy-intensive nature of some alternative water sources. Finally, the studies in the area of LCA use in industrial sphere are not equally distributed around the world.

2. Present state of problem solving

According to definition of the Act SR No 79/2015 waste present tangible material, in case researched industrial company records rising of the waste, its life cycle is prolonged due to the waste processing [16]. The company is obliged to get rid of the waste or to process it. According to the definition, the waste can be divided to the following categories:

- Dangerous waste – presenting direct risk to the living environment and finally it has negative impact to the health. It means mainly waste from the chemical industry, the radioactive waste and the waste of health care, etc.
- Other waste – all other waste that are not directly defined by the law.

Other structure of the waste can be made according to the waste origin. In this way, the waste can be structured as follows:

- Waste from vegetable and animal origin (for example fats, organic fibers, bones, skins, cellulose, etc.),
- Waste with mineral origin (for example scree with metal and non-metal elements from construction, spoil from mining and metallurgical industry, etc.),
- Radioactive waste (spoil from mining and processing of uranium, radioactive waste from atomic power plants, etc.),
- Waste with chemical origin (reducers, acids, coloring, not used fertilizers, waste from pharmaceutics industry, used oils, waste from transport – transport fumes, etc.),
- Communal waste (waste from offices, households, solid waste from cleaning works around the roads, water basins, etc.),

Ways how to remove the waste are several. Law determines concrete physical and chemical treatment, waste emission to the sea and ocean, or deep grouting.

Mostly used and the most known way of waste removing is stocking and burning. Stocking is the most simple and the oldest and commonly used method of waste disarming. During mining of coal, ores and other mineral raw material, volume of material that is not used, is rising, and it could be used as overlapping, stocking at the heaps, dumps and stacks. It means also certain type of stocking. Presently not managed spaces and quarries without special amendment for waste stocking exist. Presently we can meet stocks that are placed without overlapping or with overlapping. Result of such stocking is biologic or chemical contamination of underground or surface water, worsening of living environment, smoke and odor, and mainly threatening of the health and the living environment. Harmful substances, leached directly from the stock cause pollution of underground water.

Mainly communal waste creates input material for incinerator. It presents mainly:
a/ waste from households,
b/ separated waste from households with harmful substances content that has or could have dangerous characteristics,
c/ other waste, caused mainly due to the transport, recreation and sport, civil or technical equipment, etc.
d/ waste from greenery, mainly from parks, forests and gardens.

Generally we can state that utilization of waste in Slovakia is not on the demanded level in comparison with other developed countries, its rate is rather low. It is mainly due to several reasons, from which there is necessary to mention the most important ones, while some of them have general character, other are specific due to the possibility of their utilization:

- Mapping of waste is perceived as harmful substances, not as secondary raw materials, which means imperfectly used materials, therefore certain distrust to use secondary raw material is reflected,
- Interests of waste producer are closely departmental, orientated to company goals, perceived from the view of its economic efficiency and overreaching many times the interests of the whole society.

Industry produces considerable volume of industrial waste due to its technology using. Such semi products from the production pollute and under-evaluate living environment in close or distant surrounding. The term "dangerous waste" is not considered due to the number of reasons as totally correct and proper. Principally, it presents secondary raw material, used presently as useless material in the present knowledge of science, technique and technologies for finalization by new products.

By its legislation (decrees, prescriptions, laws and norms), the state provides recording of waste, waste processing, determination of waste categorization, and publishing catalogue of waste and claiming program of waste economy. In Slovakia there is applying Act SR No 79/2015 Coll., formulating waste economy as follows:

- To avoid waste rising,
- To evaluate possible material waste using (repeating using, recycling, etc.),
- To evaluate possible energetic use of waste (as a source of energy),
- To disarm the waste by the way not to threaten health and living environment.

In accord with the waste law, any producer of waste (physical or legal entity) is obliged to use waste as a source of secondary raw materials during its own activity. Waste that is not used can be offered to other producer.

The present Act SR No 79/2015 Coll., filling Act No 343/2012 Coll. about waste, puts great emphasize on avoiding the waste, minimizing of waste, repeated waste use for similar use, evaluation and also waste recycling.

In the past, not many organizations knew waste separation. We live in a period when more and more people realize the need and the necessity to process and the waste in the society [17]. During the process of material evaluation, the waste separation is very important since it has several advantages:

- Lower failure rate of equipment, resp. lower costs on maintenance,
- Better quality of living environment,
- Lower fees for inhabitants.

The biggest burning capacities for communal sphere in Slovakia present incinerator in Bratislava and Košice. In both cases the heat is used, rising by burning of communal waste after its previous separation, which presents energetic evaluation of the waste [18].

3. Methodology

During the research of strategic life cycle assessment in individual phases of waste production we used LCA method, presented by the way of diagram of material balance for individual processes (plant, process, operation). Due to sophistication of this way only simple version of the method had been used, for example the method input-output, when lists of aspects are prepared at the level of production process input and output for any area of activity in the company. Since the object of assessment is a company, processing the waste, the stocking aspects are recorded at the production system input. Gas emission, waste water, noise and other environmental aspects are recorded at the level of output. After registering of aspects stage of evaluation of influence to the living environment appears [19].

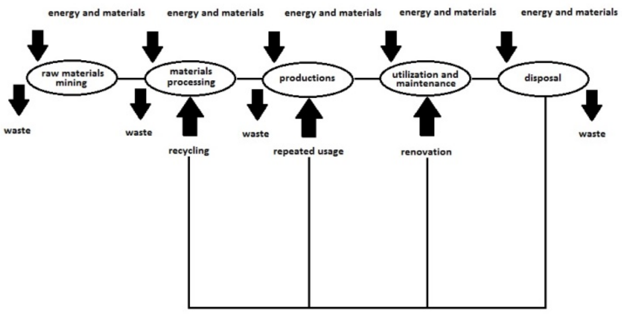

Figure 1. LCA analysis of material processing [20].

During the research, it was necessary to consider specific conditions of the waste processing company. Among the main criteria for evaluation of environmental aspects, belong the following conditions:

- Environmental conditions – measure of aspect is level of pollution, time of the acting, number of appearances and processes in which given aspect exists, the level of toxicity, damages caused by the aspect on the living environment, sensibility of the living environment to given aspect, etc.
- Economic and business conditions – costs of the tasks, connecting the living environment, the costs of ecologic investments and fees, the costs of waste utilization, internal recycling and waste transport, etc.
- Legal and organizational conditions – existence of applicable legal decrees, observing of legal demands, resp. voluntarily environmental system of management and strategy of clean production, etc. [21].
- Time conditions – prescriptions and plans of the processes, associated with ash using, limitation of carbon dioxide emissions in production process, obtaining of energy from renewable energy sources, diversification of production sources, etc.
- Social and marketing conditions – the social expectation connected with improving of life quality in relation to ecologic conditions, the level of social sensibility to given environmental aspects, expectations of the local administration, the ecological institution and other internal and external stakeholders in connection with ecologic strategy of the company and building of social awareness.

The algorithm of the LCA method is defined in accord with STN EN ISO 14044:2007 Environmental management. Requirements and guidelines consisting of 4 basic stages:

1. Defining of the goals and determination of the boundaries and the content of the system that should be evaluated in accord with the benchmarking principles. Defining of the stages in product´s life cycle regarding evaluation. Determination of unit parameters (m^3, m^2, kg), according to which individual environmental impacts will be calculated.
2. Inventory analysis.
3. Evaluation of the influences (impacts) of the product to the living environment.
4. Results interpretation, improving of the life cycle of the product [22].

Assumption of qualitative evaluation of environmental charge, influences, aspects, means detailed evaluation of material and energetic flows. Further important aspect of the LCA for products is the ability of several processes (participating on the creation and production) to influence positively the living environment. Such situation appears in industrial processes, for example during energetic using of the waste [18].

4. Results

Analyzed company KOSIT provides collection, separation, evaluation and disarming of communal waste, as well as summer and winter maintenance of road communications. Waste processing in the company is orientated to the creation of Integral system of waste processing. It means process of active influencing of waste flow in territorial unit with the use of effective logistics by the way the waste flows will be orientated to the equipment for separation, adaptation and evaluation of waste and consequent disarming of useless waste remains.

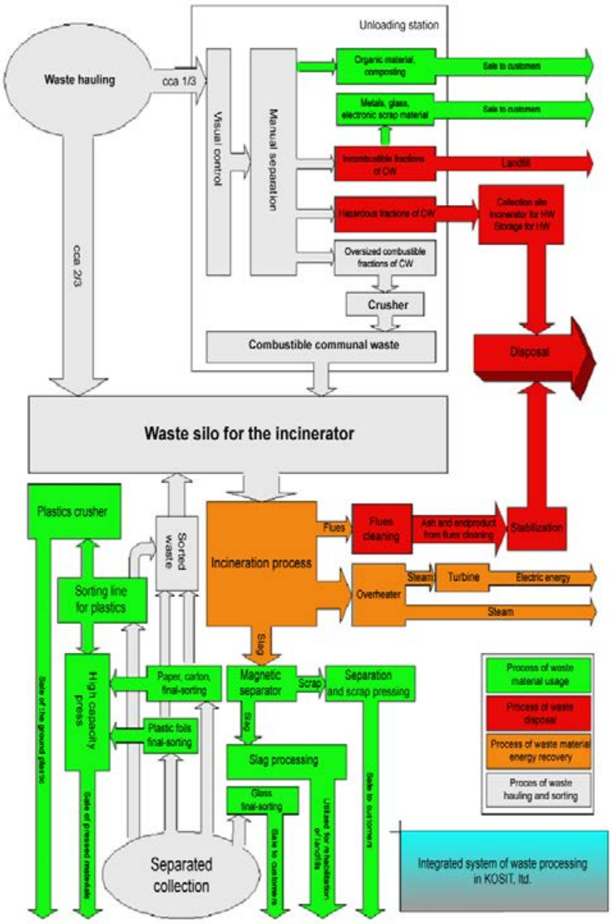

Figure 2. Integrated system of waste processing [16, 23].

The goal of the equipment management in direction of waste flow is to provide minimal remain of the waste stocked, and maximal evaluation of raw material from waste, mainly for energetic using. Preferences during waste evaluation are determined by the ecological, the economical and the technological possibilities of the system. The process map presents the structure of all the processes of the company in accord with demand QMS and EMS, mainly correspondent STN EN ISO norms.

Using of communal waste

The communal waste in containers contents still very precious raw materials, whose use could bring number of advantages, in comparison with their burning in furnaces or their stocking. One of the raw materials presents tetra – multilevel packages. Daily, several hundred tons of packages are sold on the market and other packages are produced directly in the production companies. According to the findings 30 empty, not damaged tetra packages for 1 liter are filling 1 container [24]. Such volume is consumed by one family, sometimes shorter than during 30 days. In the whole communal waste, on average 3% of such packages appear. Plastics and combined materials are very important in the industry and they are succeeded in number of other sectors. In this area ecologists are worried mainly due to the very heavily decomposable polyethylene. Packages also content soft and thin aluminum foil. Such packages content 21% of polyethylene, 5% aluminum foil and the remains belong to printing colors. Tetra packages cannot be optimally removed by burning. Considerably better solution is to adapt such packages and to produce from them tetra desks, which are possibly used in construction [25].

Analysis of material flow

Currently gaining on popularity are the best available techniques (BAT) under Act No 39/2013 Coll. on IPPC. It is an effective way to assess the practical suitability of particular techniques, particularly in terms of determining the emission limits in order to prevent and if not possible, at least to reduce the overall emissions amount and their negative impact on environment. The main priority in living environment protection is to use technologies and techniques that lead to waste minimizing influence on the living environment, limitation of emission rising or its decreasing [20].

Material evaluation of waste is orientated to the waste use as secondary raw material for production of useful products. Three types of material reevaluation can be specified:

a) By backward obtaining – separation of waste element, proper for further direct reuse,
b) Renovation of origin utility characteristics with the aim the waste could be used for former goal – regeneration,
c) Returning the waste to production cycle for production of socially demanded products with the goal to save primary raw material sources – recycling.

Due to the analysis of material flow of communal waste in KOSIT, there are available data during 2007-2012, mainly the total volume of imported waste, the total volume of burned waste, disposal / theoretical capacity of boiler, used / real capacity of boiler, hourly volume of burned waste, heat value of the waste at boiler efficiency 80% [26]. Considering the total volume of imported waste, there was necessary to create and consequently to evaluate complex material flow, presented by Sankey diagram in Figure 3.

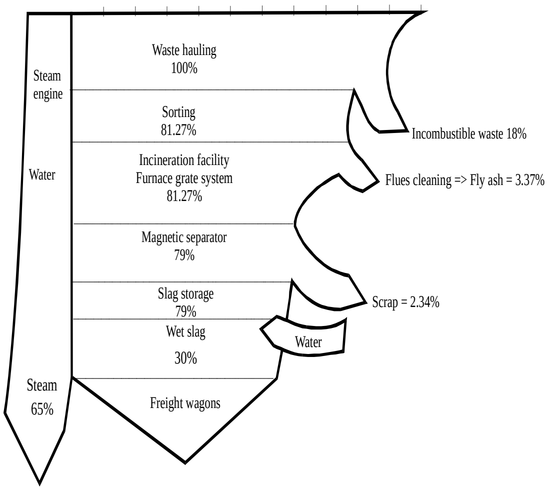

Figure 3. Sankey diagram – a material flow of the waste in waste processing company [27].

After waste separation, the unburned waste remains in volume 18%, structured as organic material, plastics, glass, electro waste. Solid waste can be burned without additional fuel. The process of waste burning runs in burning equipment (boilers, which are determined for heat adaptation of waste by burning). In boiler, 81% of waste is burning of total volume of imported waste, from which approximately 3%, which means 2300 $t.year^{-1}$ presents ash, approximately 2%, which means 1600 $t.year^{-1}$ presents metal scrap. Considering the material evaluation of the waste mass, the result of processing means slag production, which could be used during fillings of roads. Figure 4 illustrates that from total volume 81.72% of the waste, KOSIT produces annually 30% of wet slag [26].

Steam freely released can be used for production of heat and electric energy in steam or gas turbines. The development of technique and technology of equipment for slag use in Slovakia lags behind the possibilities of its correspondent use. Further real possibility for steam use is heating and supplementation of warm water to households and other objects, for heating glasshouses, swimming pools, etc. Therefore, heating plants do not have interest to use slag as a source of heating, 65% of the produced slag escapes to the air annually. Such waste of green energy is not understandable for specialists from the developed countries, dealing with the given issues.

The development of steam volume, freely released and sold to the companies is given in Figure 4, where we can see the volume of the sold steam does not reach even half of the steam produced and released to the air.

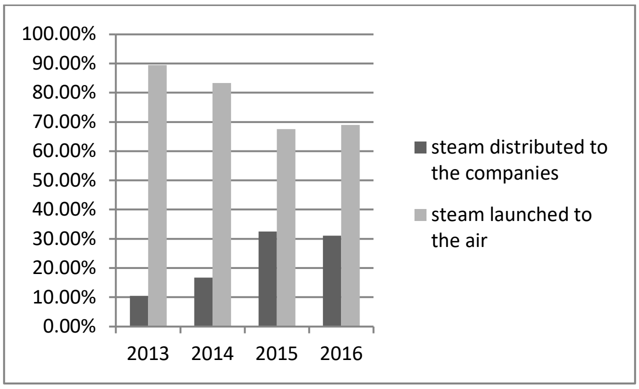

Figure 4. Comparison of steam volume, launched to the air and distributed to the companies

The company succeeded during last years to find out reliable and stable consumers, proven by gradual increase of slag collection during waste burning. Percentage of supplied steam volume for individual companies is illustrated in Figures 5-8.

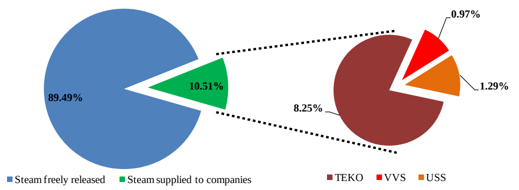

Figure 5. Comparison of steam volume, distributed to the companies in 2014

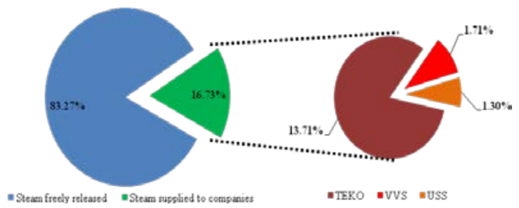

Figure 6. Comparison of steam volume, distributed to the companies in 2015

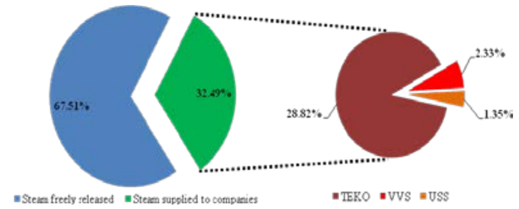

Figure 7. Comparison of steam volume, distributed to the companies in 2016

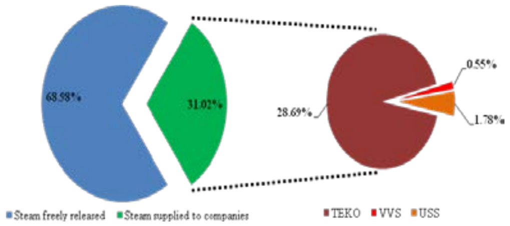

Figure 8. Comparison of steam volume, distributed to the companies in 2017 [16].

Unpopular waste from burning process presents ash creation. Due to the ash, the rising during waste burning, it is ranked according to the Decree of Ministry of Living Environment in Slovakia, No 129/2004 in category of waste among dangerous waste, and in the future it is necessary to deal with proper processing of the ash. The legislation of the European Union makes strict legislative measurements against its stocking and increases fees for such dangerous waste stocking. Organizations are forced to deal with and to apply technologies for treatment of the ash. Parts of new technologies installment are also the high investment costs that must be regarded and calculated in the organizations [28].

5. Discussion

The main interest of the companies should be increasing of effectiveness of material using with regard to environmental and social impact [29]. In particular, an ambitious utilization rate target may be very costly to enforce as it can conflict with the existing trade patterns of paper and board products as well as with other environmental goals. Additional policy targets may therefore be desirable, especially since paper recycling is motivated primarily by environmental concerns and seldom is a benign activity in itself.

Moreover, rich countries tend to recover relative more waste than it is the case in low-income countries. During municipal solid waste collection and disposal services it is necessary to estimate the cost functions. Waste and recycling costs must be also estimated as functions of factor costs. This was analyzed by Bohm et.al [30], suggesting that both marginal and average costs of recycling systems exceed those of waste collection and disposal systems. Moreover, the use of environmental friendly materials can further reduce the environmental emissions to a significant extent. The risk of a worldwide phosphorus (P) crisis has been predicted in the past ten years by many researchers and organizations who sought alternative resources of P. The source-separation of urine is being widely considered as a suitable waste stream for P recovery to mitigate the shortage of P while also preventing the eutrophication of the receiving waters. In dense cities, urine separation and Phosphorus recovery as described can be efficiently implemented in every building. Therefore, based on the results obtained in the study by Mbaya et.al [31], the urine separation and P recovery system is strongly recommended to be implemented in buildings of dense cities.

There is a relation between waste management, reflecting pollutant emissions in life cycle analysis and risk assessment [32]. Finally, the studies are not equally distributed around the world. LCA and waste management had been described in several book chapters, for example Kasemsap [33] indicates advanced issues of environmental management by Life Cycle Assessment (LCA) and life cycle costing; waste management, environmental sustainability, and environmental benefits; Solid Waste Management (SWM); electronic waste management; construction waste management; and the importance of Municipal Solid Waste Management (MSWM). Authors speak about the benefits of the LCA in the area of waste management in different ways, for example saving water, energy and materials, reducing the negative environmental impacts, preventing pollution, preserve natural resources, reducing environmental risks, etc., aiming toward sustainability. New approach to life cycle assessment means IMPACT 2002+, which proposes a feasible implementation of a combined approach, linking all types of life cycle inventory results. The IMPACT 2002+ method presently provides characterization factors for almost 1500 different LCI-results [34].

6. Conclusion

Presently, still more increased emphasize is given to the technologies development, saving the living environment. It means not only energetically saving technologies, but also total approach with goal to minimize all not demanded environmental influences of the operation or single production and products use. It is important to always choose technological process that is environment saving – with all the consequences.

The reason of such behavior is mainly population growth, limited stocks of raw materials and increasing pollution of the living environment. Due to the gas crisis, ecology activities started to be critically orientated mainly to the package technique, package materials and single packages.

In this connection, the study provides evaluation of the life cycle assessment used as method for comparing environmental influences of the products, the services and the single production with regard to their life cycle with present consideration of emission of all production elements to the living environment during production, as well as the use and the disposal of the products. Processes of raw material obtaining, material and energy production and subsidiary processes are considered as well.

The study is expected to enable the decision makers and managers of production to select the best alternative with respect to energy use, and environmental and economic constraints. The main reason of the study was general extension of proper manipulation and disposal of used packages with the aim to optimize their parameters and minimize the damage of the living environment, mainly in connection with sources used, the way of production, transport and distribution, consumption and disposal after life cycle termination.

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