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# APPLICATION OF LCA ENVIRONMENTAL MANAGEMENT TECHNIQUE IN DESIGN OF TECHNOLOGICAL INNOVATIONS

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**Abstract:** In the sustainable development model, environmental protection is closely related to economics and politics. The changes in economics are much faster than the changes in legislation. Economic, political and environmental protection elements should constitute one cohesive, efficient system to effectively respect sustainable principles. Compliance with the requirements of environmental quality and sustainable development can be achieved by maintaining the highest quality of the environment, while minimizing the use of natural resources and environmental threats by eco-designing new technological solutions. The attitude to the natural environment resulting from the concept of sustainable development is very diverse, but usually there are two views. The first view is related to sophisticated scientific theories and tries to show the consequences of our modern industrial activity. The second view refers to moral values such as responsibility for the earth, future generations or nature. LCA (Ecological Life Cycle Assessment) is particularly important in shaping the environmental policy used in the evaluation of innovative solutions such as the re-use of polymer waste for the production of flocculants and superplasticizers. The aim of the research is to evaluate the production technology of a new generation of polymers. The LCA environmental management technique was used to evaluate the new products, which allowed choice of the right solution that could reduce the negative environmental impact of new products obtained from polymer waste.

**Keywords:** sustainable development, environmental management, LCA, polymer waste, newly synthesized polymers

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## Introduction

The progress of science and technology raises the quality of life, but through new technologies also leads excessive exploitation and depletion of natural resources, disasters, as well as ecological and social catastrophes. Economic growth and the development of civilization is limited to the future needs of the growing world population through the idea of sustainable development and it is a conscious attempt to avoid self-destruction and maintain the natural environment in a proper state with consciously controlled progress of civilization.

Sustainable development ensures harmony on three levels: social, economic and ecological (Pabian 2012, p. 7). When considering the economic aspect, we mean an entrepreneur running a business that uses natural resources and emits pollution to the environment. The activity of entrepreneurs is primarily focused on financial

profits, while they do not take into account the negative effects of their operations. This is a typical model of the economist and social attitude of the 20th century. The next century is aimed at implementing the principles of sustainable development and drawing the public's attention to the ecological aspects (Pabian 2017, p. 125). First and foremost, local communities are looking for development that is compatible with nature, which will have a minimal impact on our planet and its natural resources. Current social attitudes should change towards eco-development. The development of civilization has meant that humanity needed and still needs increasingly more resources from the natural environment, moreover, it largely uses non-renewable resources such as lignite, bituminous coal or crude oil. The progress of science and technology has led to the development of various industries causing noise, emissions of harmful compounds to the atmosphere, contributing to depletion of the ozone layer or the increase in temperature on the globe. Visible climatic changes have highlighted problems related to environmental protection and the use of renewable sources, e.g. solar energy or wind. The increasing climate changes have prompted many people to study, analyze and develop a global action plan (Brown, Flavin 2000, s. 5).

The breakthrough event was the announcement in 1969 of the UN Secretary General's report - Sith U Thant, entitled "Man and his environment". The report covers issues related to: the destruction of arable land, reduction of open areas, unplanned development of urban areas, irreversible extinction of many forms of plant and animal life, environmental pollution as well as propagation of the protection of environmental elements, e.g. water, soil, air. From that event, awareness about the major threats to civilization began to grow. Sithu U Thant referred to many countries due to their large scale environmental problems and called on countries to rationally use the Earth's resources, and above all, to protect ecosystems. The UN Secretary did not only convince us that the joint action of all states can improve the conditions on our planet, but also for the first time raised the global problem of environmental protection in the international arena and initiated the creation of an ecological movement.

In the years 1984-1987 Gro Harlem Brundtland was the chairman of the UN commission, who in one of his reports presented the idea of sustainable development. The Commission developed the concept of a social program and sustainable development, and the posed thesis was: "Stable development means development that meets the current needs without depriving future generations of the ability to meet their needs". Sustainable development ensures harmony on three levels: social, economic, ecological, and none of which should negatively affect the other. Sustainable development ensures such activities that enable the satisfaction of basic human needs, through the rational use of existing natural resources. The exploitation of natural assets must take place in such a way that future generations can also use them. The challenges of sustainable development can be achieved by integrating environmental, economic and social policies (Seroka-Stolka et al. 2017, p. 116; Seroka-Stolka 2012, p. 125).

The ideas and assumptions of sustainable development were adopted by international society, at the "Earth Summit" in Rio de Janeiro, which took place in

1992 (Rio declaration, 1992). The "27 Principles of Sustainable Development" constituting a whole and complementing each other and covering the issue of the right of living beings to a healthy and creative life in harmony with nature, reduction and elimination of unsustainable systems of production or consumption and peace, development and environmental protection.

At the "Earth Summit", a second document entitled "Global Action Program - Agenda 21" was also adopted, which presents the method of developing and implementing sustainable development programs in the perspective of the 21st century (Agenda 21). The document contains 40 chapters dedicated to saving the environment on our planet. The main issues are social and economic, strengthening the role of social groups and organizations, and in order to ensure sustainable development, protection as well as management of natural resources. The development of Agenda 21s and conferences resulted in the establishment of government committees for sustainable development and the establishment of local Agenda 21s, which are a very beneficial element of development, providing accurate and well-considered activities leading to local development in accordance with the established norms and principles of sustainable development. Currently, many solutions are co-financed by the European Union, which supports activities carried out paying special attention to sustainable and deliberate development.

In 1997, a conference was held in Kyoto, Japan, aimed at signing a treaty to reduce the emissions of six greenhouse gases, including: carbon dioxide $CO_2$, methane $CH_4$, nitrous oxide $N_2O$, $SF_6$ sulfur hexafluoride and industrial gases, greenhouse HFCs - hydrofluorocarbons and PFC – perfluorocarbons. The protocol established "flexibility mechanisms" that enable: international trade in greenhouse gas emission permits, which allows industrialized countries to buy or sell quotas for emissions, the principle of joint action, the Clean Development mechanism and the possibility of obtaining credits for activities related to emission reduction. The Kyoto Protocol was not ratified until February 16, 2005 (Dz.U. 2005 nr 203 poz. 1684). The main condition for its entry into force was the "2 times 55" rule, which stipulated that the protocol could come into force if it was recognized by at least 55 countries producing a minimum of 55% of global carbon dioxide emissions compared to 1990. As a result, the protocol was signed by 141 countries producing a total of 61% of global greenhouse gas emissions. The delay in implementing the legal act was mainly caused by Russia's reluctance to ratify the provisions of the protocol.

The next event was the European Union summit in 2001 in Gothenburg called: "A Sustainable Europe for a Better World: A Strategy for Sustainable Development for the European Union". The issues raised at the summit concerned global warming caused by excessive greenhouse gas emissions, health risks, population aging, increasing poverty, loss of biodiversity, excessive increase in transport density. In 2006, the Gothenburg strategy was revised and plays an important role in the countries of the European Union.

The United Nations organized another meeting of representatives of states, this time in South Africa in Johannesburg (South Africa). The assembly was held in 2002 under the name "World Summit on Sustainable Development", referred to as

Rio + 10. The global changes that had been carried out over the last ten years were summarized, and the topic of problems in the modern world were debated on. Actions were proposed to improve the living conditions of people and the protection of natural resources on our planet. The focus was on assessing the implementation of Agenda 21 programs by local governments, which motivate individual entities to act for environmental protection and sustainable development (Papuziński 2005). The European strategy for sustainable development is a challenge for the countries belonging to the community. Poland was obliged to implement this policy by joining the EU in 2004. One of the key requirements is ongoing assessment of environmental performance. To assess the potential industrial activity, application of the Life Cycle Assessment technique is proposed, which is used to identify potential environmental impacts of products or technology. According to the requirements of the ISO 14000 standards environmental protection can mean above all the sustainable use of resources, protection of biodiversity and the ecosystem. All of these tasks involve a life cycle assessment that can be used to quantify natural resources and assess the quality of the ecosystem and impact on human health. The article uses the LCA technique to evaluate the designed technology for the production of a new generation of polymers (Bajdur 2011).

## Importance of LCA in design of technological innovations

In designing innovations, ecology is one of the most important issues at present. The term that is widely used in the field of technological innovation is eco-innovation, closely related to the way in which we use natural resources and how we produce and consume. An approach in accordance with the principles of sustainable development, that is taking care of a climate that is conducive to people and caring for the natural environment, is important in creating innovation. Climate and environmental protection are recognized worldwide as common challenges. In December 2015, representatives of 195 countries and the European Union signed the Paris Agreement.

The basic agreements are:

- global warming should be reduced well below two degrees Celsius. To do this, efforts must be made to stop the temperature increase by 1.5 degrees Celsius,
- from the middle of the 21st century, greenhouse gas emissions should be reduced to zero,
- developing countries should be financially assisted in climate action and adaptation to the consequences of climate change,
- national climate protection plans should be established and implemented.

Therefore, tools to study the environmental impact of technologies are necessary. LCA is a method that allows the environmental load caused by a given product, production process or activity to be estimated by determining the consumption of energy and materials as well as pollutants discharged into the environment; assessment of the environmental effects related to energy consumption, materials and emissions; and finally, assessing the possibilities of

improving the environmental impact. Life cycle analysis is therefore a diagnostic tool useful in environmental management. As a result of using LCA, the company's managers identify areas that are a source of special burdens for the environment or human health. LCA analysis, in contrast to traditional methods of environmental management, allows:

- comparison of alternative products and production technologies,
- identification of places generating the greatest impact on the environment throughout the whole life cycle,
- establishing criteria for eco-labels in order to identify the best eco-friendly products,
- comparison of alternative methods of waste disposal.

The possibility of evaluating the product from cradle to grave means that no stage of the product's existence is omitted, which makes it possible to make full comparisons describing environmental threats created by it. This new approach, which focuses on the product, allows the causes of environmental pollution to be eliminated and not the "repair" of their effects (Kowalski, Kulczycka, Góralczyk 2004, p. 164). This is of particular importance in the design of technological innovations (Bajdur 2008, p. 196; Bajdur 2009, p. 118).

## Research methodology and results analysis

### Research methodology

On the basis of technological tests conducted on a quarter-technical scale concerning the use of the produced polymers using polystyrene and novolak waste, a life cycle assessment (LCA) was carried out. This technique allowed identification, quantification and assessment of the potential impact of the polymers selected for the study (flocculants) on the quality of the environment. The analysis was carried out using the SimaPro program, selecting the research method: *Eco-indicator 99*. In this method, an assessment-oriented approach was applied at intermediate (impact categories) or final points (injury categories). The impact of potential damage to the environment is related to damage:

1. to human health expressed as the number of deaths and years of life in disability (the unit is DALY - disability-adjusted life year). The damage model is based on impact categories: carcinogenic factors, the influence of organic and inorganic compounds on the respiratory system, climate change, ionizing radiation and depletion of the ozone layer;
2. deteriorating the ecosystem quality, expressed as disappearance of specific species in a given area and at a specific time (the unit is PDF.$m^2$.year - Potentially Disappeared Fraction of species over a certain area over a certain time). The model includes impact categories such as: ecotoxicity, acidification/ eutrophication, land development (including land takeover as well as its transformation);
3. related to the consumption of raw materials, expressed as the additional amount of energy necessary for the future extraction of mineral resources and solid

fuels (the unit is the excess energy expressed in MJ), and the model is based on the consumption of mineral resources and fossil fuels.

These impact and damage categories relate to different reference items, therefore in order to use dimensionless degrees of validity, the result should be deprived of the dimension. Standardization serves this purpose. Damage categories are standardized at the European level (damage caused by one European per year). The data has been updated for the most important types of emissions. The last stage of assessing the impact of the life cycle on the environment is the weighing process, in which the results of standardization are multiplied by appropriate subjective validity coefficients. Calculations in the employed *Eco-indicator 99* version are based on the average time perspective.

The assessment of the impact on the environment was carried out using the LCA technique including four stages in accordance with the guidelines:

Stage I included the definition of:

- the purpose of the analysis, i.e. to determine the environmental impact of the production process of a new type of flocculants obtained using polymer waste,
- the scope of research including the chemical modification process of the new generation of flocculants.

In Stage II, a balance analysis of the system, and data inventory based on the technological assumptions of production of polymeric flocculants were carried out. In Stage III, the environmental impact assessment of the life cycle of new flocculants was performed, and the results of the research were interpreted in the fourth stage (Bajdur 2011, p. 50).

**Analysis of research results**

Environmental life cycle assessment (LCA) in the evaluation of the impact of potential products on the environment is a technique that primarily allows the possibility of conducting a full life-cycle analysis, and thus the production processes, as well as credible and reliable identification of the environmental risks and environmental impact of new products. The new generation of waste-based polymers are water-soluble and have the properties of flocculants reducing the pollution parameters in mine waters (Bajdur et al. 2016, p. 1058). The results of the analysis of research carried out using the LCA technique to assess the impact of modified polymeric waste (polystyren and novolaks) on the environment confirmed that LCA is an appropriate method to assess the environmental impact of new products (flocculants) used in the process of industrial wastewater treatment. The weighted histograms present the environmental impact of the potential flocculant (PSP polymer - waste polystyrene, PS-N-T, PA-N-SE polymer - waste nowolaks) production processes (*Figure 1*).

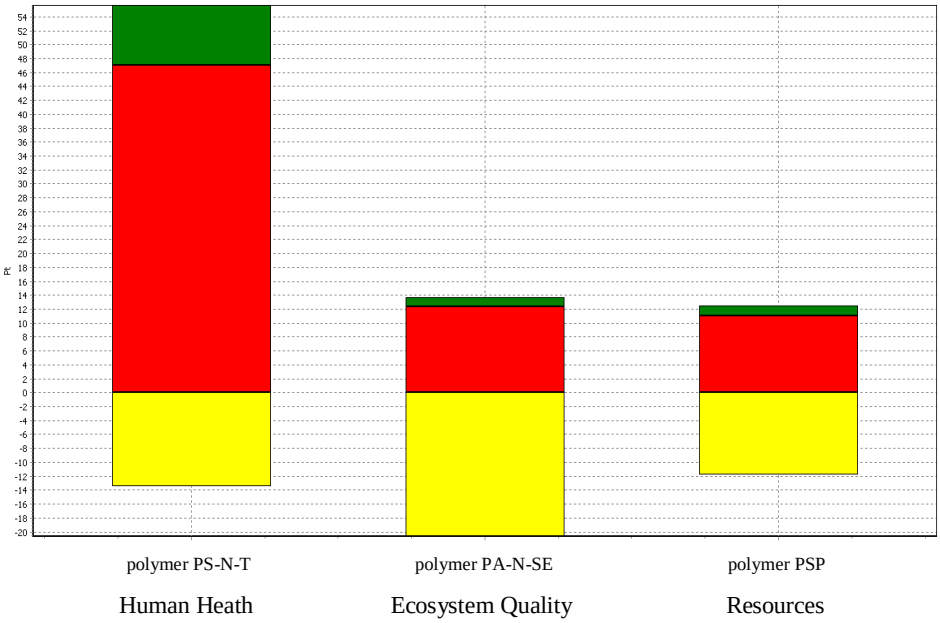


**Figure 1. Comparative histogram of weighing for production processes of PSP, PS-N-T, PA-N-SE**

Source: Author's own elaboration using SimaPro program (Instytut Gospodarki Surowcami Mineralnymi i Energią, Polska Akademia Nauk, Kraków)

The weighted histogram for the polymer production process (*Figure 1*) show that in all of the damage categories: human health, ecosystem quality and resource consumption, sulfuric acid, which is used for the production of polymeric flocculants, has the greatest negative impact. Calcium carbonate, soda and electricity have much smaller shares.

The weighted histogram of the polymer production process presented above shows that tin chloride and nitric acid in the human health category have the greatest negative effect. The life cycle assessment of new flocculants has shown that the acquiring flocculants from novolak waste is very beneficial for the environment due to the high toxicity of waste phenol-producing resins under the influence of physical factors, e.g. on landfills. The LCA analysis showed that the reuse of selected polymer waste is the right direction to obtain substrates in order to obtain polymeric flocculants whose synthesis reduces the negative impact on the environment.

## Conclusions

The use of LCA in the design of technological innovations is in line with the principles of sustainable development (Kulczycka, Henclik 2006, p. 43). The article presents the influence of the process of the potential production of a new

generation of polymers on human health, ecosystem quality and resource consumption. LCA analysis does not replace the need to carry out environmental impact assessments, but it is a good method that allows credible and reliable compilation of the results of research in the areas shown in the histograms. Activities aimed at disseminating application of the LCA method allow a high ecological level to be achieved in the designed technologies. The LCA analysis is aimed at eliminating environmentally unfriendly technologies and allows one to select the best technical solutions in the aspect of environmental protection (Bajdur et al. 2018, p. 2561). It is important to estimate the health risk which is a multi-step procedure that allows, among others, one to determine the effect of chemicals found in the environment on human health. LCA not only has so-called "internal" applications, but above all, the field of "external" applications is of particular importance in creating and implementing the country's environmental policy.

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# ZASTOSOWANIE TECHNIKI ZARZĄDZANIA ŚRODOWISKOWEGO LCA W PROJEKTOWANIU INNOWACJI TECHNOLOGICZNYCH

**Streszczenie:** W modelu zrównoważonego rozwoju ochrona środowiska jest ściśle związana z ekonomią i polityką. Zmiany w ekonomii przebiegają znacznie szybciej niż zmiany w prawodawstwie. Elementy ekonomiczne, polityczne i ochrona środowiska naturalnego powinny stanowić jeden spójny, sprawnie działający system, aby efektywnie respektować zasady zrównoważonego rozwoju. Zgodności wymogów jakości środowiska i zrównoważonego rozwoju można osiągnąć, utrzymując na maksymalnym poziomie jakość środowiska, minimalizując zarazem stopień wykorzystania zasobów naturalnych i zagrożeń środowiskowych poprzez ekoprojektowanie nowych rozwiązań technologicznych. Wynikający z pojęcia zrównoważonego rozwoju stosunek do środowiska naturalnego jest mocno zróżnicowany, zwykle jednak występują dwa poglądy. Pierwszy pogląd związany jest z sofistycznymi teoriami naukowymi i próbuje pokazać konsekwencje naszej współczesnej aktywności przemysłowej. Drugi pogląd odwołuje się do wartości moralnych, takich jak odpowiedzialność za Ziemię, przyszłe generacje czy naturę. Szczególne znaczenie w kształtowaniu polityki ekologicznej ma LCA (*Life Cycle Assessment* – ekologiczna ocena cyklu życia) wykorzystywana w ocenie innowacyjnych rozwiązań, jak na przykład ponowne wykorzystanie odpadów polimerowych do produkcji flokulantów i superplastyfikatorów. Celem badań jest ocena technologii produkcji nowej generacji polimerów. Zastosowano technikę zarządzania środowiskowego LCA do oceny nowych produktów, co pozwoliło na wybór odpowiedniego rozwiązania, które mogłoby zredukować negatywny wpływ na środowisko nowych produktów pozyskiwanych z odpadów polimerowych.

**Słowa kluczowe:** zrównoważony rozwój, zarządzanie środowiskowe, LCA, odpady polimerowe, nowosyntezowane polimery