Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **8** (2021) (2) 555-563

Environmental Innovations: Advances in Engineering, Technology and Management, EIAETM, 19th-23rd October, 2020

POLYMER MATERIALS: BIBLIOGRAPHIC DATA ANALYSIS AND TREND DETECTION*

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Abstract

Alternatives to waste management methods include the reorganization, recycling, and creation of environmentally friendly biodegradable polymer materials based on renewable resources, plant, and textile waste. The goal of this study is to analyze bibliographic data and identify trends in research on polymer materials of different genesis, with particular attention to research on the production and use of biopolymers. VOSviewer v.1.6.15 is used to present the analysis results. Environmental impact areas in the life cycle of traditional polymers have been analyzed. The network of main bioplastics clusters is visualized within the framework of modeling the dependencies on the main keywords in the analysis of the dynamics of publication activity, the main trends in the development of new biodegradable materials are revealed. A comparative review of the environmental impact of different types of bioplastics is made by the life cycle assessment method.

Keywords: bibliographic data, bioplastics, identify trends, life cycle assessment, polymer materials

1. Introduction

Synthetic polymers in their composition may contain hazardous substances (formaldehyde, phenol, cadmium, lead, etc.), is an additional factor that, taking into account the summation effect may cause significant adverse changes in the human body at all levels of the organization - from the cell to the organ system. Modern plastic waste is a serious problem on a global scale. Recycling of household wastes from polymers acquires special importance, which should be carried out at special processing plants within the framework of the general strategy of increasing the level of ecological safety in the region and preserving the environment safe for human life. The production of polymers from plants and other renewable raw materials in

* Selection and peer-review under responsibility of the EIAETM
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the world has increased rapidly in recent years. Thus, bioplastics account for approximately 1 % of 335 million tons of plastics produced annually (ECTC, 2020).

The massive use of oil-based polymers and their inappropriate treatment of waste has resulted in serious global environmental problems due to their non-degradable nature. Knowledge of pollutant emissions from pyrolysis and the burning of starchy films is important because it can reach landfills mixed with conventional polymers and thermally decompose in uncontrolled fires. On the other hand, controlled heat treatment can lead to the thermal valorization of waste (Moltó et al., 2020).

The results of (Walker and Rothman, 2020) suggest that much of this variation is related to the applied life cycle assessment methodologies, especially about end-of-life treatment, the use of credits for absorbed carbon dioxide, and the distribution of multifunctional process effects. Life cycle assessment challenges are recognized, especially in complex, geographically diverse, and young industries such as biopolymer-based polymer production. It is proposed that Product Environmental Footprint (PEF) standards (JRC EC, 2010) be more widely used to homogenize the methods used and to enable meaningful comparisons between LCA studies on fossil and bio-based polymers and between studies on the same polymers.

This study is aimed at analyzing bibliographic data and identifying trends in research on polymer materials of different genesis with special attention to research into the production and use of biopolymers.

To achieve the aim, the following tasks are set: a review of the environmental impact profile in the life cycle of synthetic polymers; analysis of trends in the production and use of biological polymers; visualization of the network and overlapping by biopolymer life cycle parameters.

2. Material and methods

2.1. Basics of the life cycle assessment method (LCA)

The study is conducted following ISO 14040/14044 standards, describing the potential environmental life-cycle effects associated with a case study in which biopolymer parts replaced traditional polymer parts with the same useful function.

A full life cycle analysis of all environmental impacts ensures that the principle of sustainable development is realized, as it reveals the reasons for violations of this principle. Thus, at the current stage of economic development and environmental management, the environmental and economic analysis of the interaction with the environment of manufactured and consumed products becomes one of the effective methods that allows not only to assess the level of impacts but also to determine measures to reduce them (Antelava et al., 2019).

Since a production system is a physical system, every single process in it is subject to the laws of mass and energy conservation. Single processes are connected by flows of semi-finished products and/or waste streams intended for processing, product flows with other production systems, and elementary flows from the environment (ISO 14044, 2006).

These steps should include the following actions (Pelikh et al., 2003):

- presentation in the form of a block diagram of a set of single processes that should be included in the system model;
- a detailed description of each process and a list of data categories associated with each process;
- development of a list of terms, their definitions, indicating the units of measurement;
- description of the data collection model and calculation methods for each data category required for life cycle assessment;

- developing guidelines to ensure that certain special cases and deviations or other features that may occur during the preparation of data are clearly understood.

2.2. Methods of visualization and network analysis

For visualization VOSviewer v.1.6.15 is used, which allows presenting the results of analysis by methods of "bibliographic combination", citation and co-authorship, interrelation of keywords. The "bibliographic combination" visualization allows us to judge how publications by shared information sources in a given research area are related.

The network analysis allows us to reveal regularities in the joint works of individual authors and scientific organizations. However, possibilities of application of the network analysis for science metric researches are realized to the full extent only in the presence of the machine-readable information on scientific communications of scientists, about the received results and application of specialized tools in the field of bioplastic production.

3. Results and discussion

Environmental laws around the world are becoming more stringent, requiring the abandonment of some methods and providing a new impetus for the development of others. Little suitable polymeric materials are being disposed of or taken to a landfill. This is because their volume does not change over time. Correspondingly, the area occupied by landfills should be continuously increased, which leads to the withdrawal of large areas from the economic turnover, long-term pollution of the environment and is not rational from the energy point of view. However, this method is still widely used in Ukraine today.

The system of synthetic polymers product formation is shown in Fig. 1, starting with the operations of the withdrawal of raw materials and progressing through the manufacture of materials, parts, assembly, use, and closure of options for disposal and recycling.

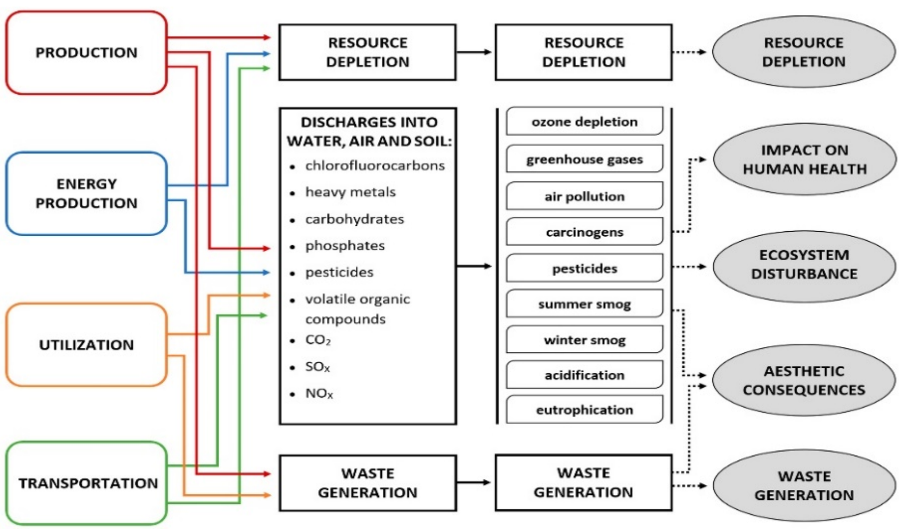

Fig. 1. Environmental impact profile in the life cycle of conventional polymers. Based on the data (O'Neill, 2002)

Typical environmental impacts in this example include the use of natural resources and energy, greenhouse gas emissions, and volatile organic compounds, including monomers and waste generation (Koffler and Zahller, 2012). Polymer products are becoming increasingly sophisticated in terms of their operational properties, while polymer waste management methods are developing and becoming more complex.

Various methods of obtaining water-soluble polymeric materials are known. Thus, water-soluble sheets and film materials, containers, and packaging can be produced with oxy-propyl cellulose. Water-soluble bags for agriculture and household services are produced by introducing modified starch into polymer compositions. However, in the production of polymers, decomposable costs are generally higher than in the production of conventional plastic materials. Photobiodegradable polymers used as packaging materials do not protect package components from UV light. The toxicity of the decomposition products of such materials has not been sufficiently studied, as this requires special toxicological studies (Platt, 2006). Choosing the right plasticizer in a plastic formulation is a fundamental step to achieve convenient physical and thermomechanical properties for each final application. Polyols are widely used as plasticizers in many bioplastics, mainly glycerine (Aguilar et al., 2020).

The reuse of polymer waste is a necessary part of any production process. For this purpose, the waste is recycled into recycled material or directly into products, the original polymer synthesis products are regenerated and returned to production as secondary raw materials, and composite materials are obtained. Recycling technology is developed for all main types of waste that are returned to production or added in the amount of 5-10% to the primary raw materials (Sperber and Rosen, 1974).

At recycling the structure, physical-mechanical and rheological characteristics of most polymers change. Therefore, the study of the impact of recycling rates on the properties of plastic masses is a necessary condition for the proper choice of technological mode of processing and areas of application of materials made of waste (Hopewell et al., 2009).

Fig. 2 shows a graph illustrating the dynamics of publications of the results of research in the field of bioplastic production. As can be seen in this graph, the topics studied since 2008 are becoming more and more relevant and the number of publications has started to grow rapidly. This has been facilitated by the emergence of a green economy and the awareness of global environmental issues related to the use of synthetic polymer materials and the generation of polymer waste.

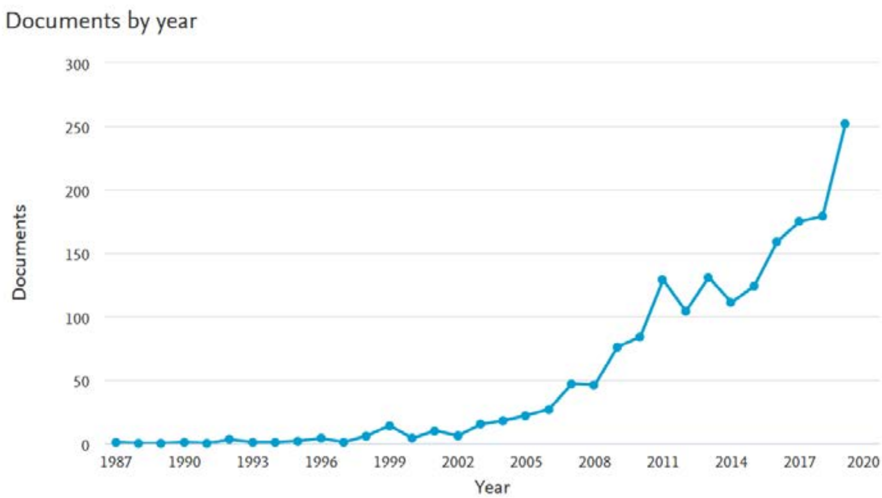

Fig. 2. Publishing trends (number of papers) in the area of bioplastic (using Scopus Database)

Publishing activities in the field of bioplastics production are widely understood in various fields of science and technology (Fig. 3). Thus, a significant activity of applied research in the field of application of biopolymers in materials science, chemical engineering, ecology, agricultural and biological sciences, and others. This shows the interdisciplinary of the topic and its wide demand in various fields of science and technology.

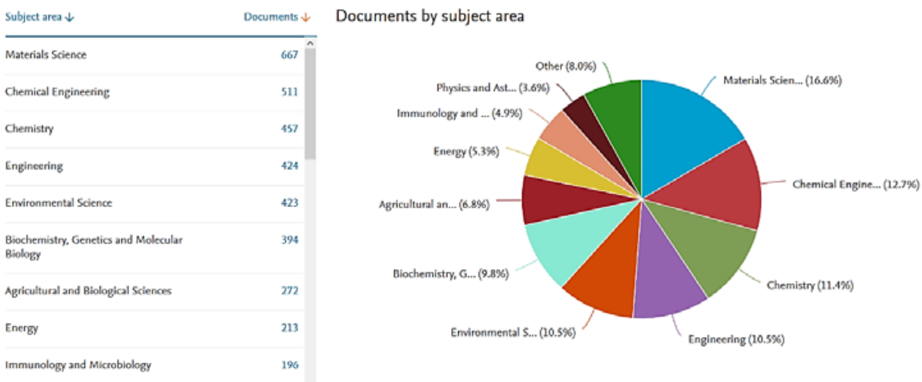

Fig. 3. Papers under the topic of bioplastic production classified by field (Scopus Database)

The research is carried out using the VOSviewer software tool, which was used to create maps based on network data and visualize them. This software is used to identify the relationships between key terms as markers of key scientific research and gaps in knowledge as a beacon for further research. The clusters were identified and the linkages between them analyzed (Fig. 4).

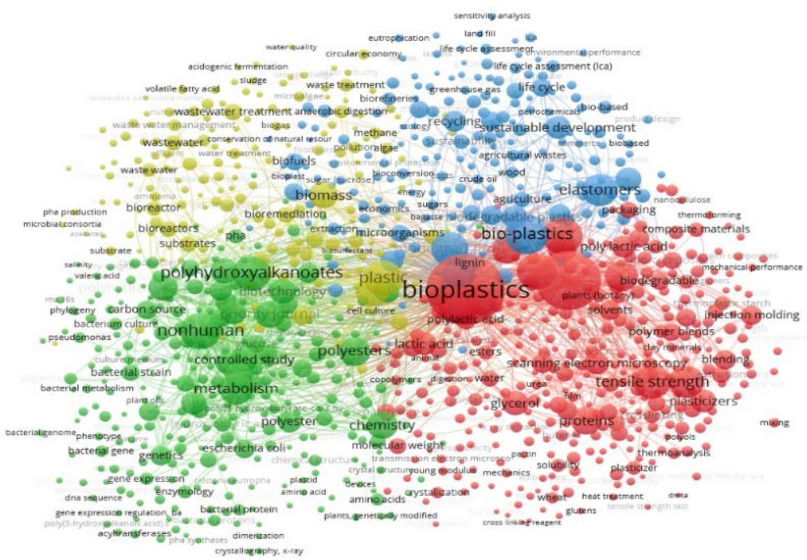

Fig. 4. General network visualization (constructed via VOSViewer v.1.6.15): 4 clusters, 98121 links, 214187 total link strength

- **1st cluster (red)** is an environmental issue of plastic production associated with the greenhouse effect and compounds that are used to produce biodegradable polymers;

- **2nd cluster (yellow)** is the production of biofuels and bioplastic under wastewater anaerobic treatment;
- **3rd cluster (green)** is the production of biomass and its production technology, the use of various biological agents with an emphasis on the metabolism of the microorganisms involved in obtaining bioplastics and fixation of CO_2;
- **4th cluster (blue)** is associated with different fields of bioplastic application, LCA, and sustainable development.

All clusters are united by common research thematically and regionally.

The name 'biodegradable' speaks for itself - as already mentioned, in six months soil microorganisms will convert them to water, carbon dioxide, or methane with a residue of no more than 10% that can be used in compost. Conditionally, they can be divided into the following large groups: polylactide (PLA), i.e., lactic acid-based polymers formed after lactic acid fermentation of sugary substances; polyhydroxyalkanoates (PHAs), products of microbial processing of plant sugar; and starch-based materials. There are also materials based on lignin, cellulose, polyvinyl alcohol, caprolactone, and others.

It is possible to distinguish the main directions of work on new bipolymers:

- obtaining polymers of a certain structure, exposed to microorganisms;
- development of compositions based on ordinary polymers with specific additives is a source of microorganisms nutrition;
- creation of polymers, which begin to decompose under the influence of UV-light and end up under the influence of microorganisms.

The overlay visualization shown in Fig. 5 has been chosen as a more effective tool for checking the latest trends with an analysis of time scale elements.

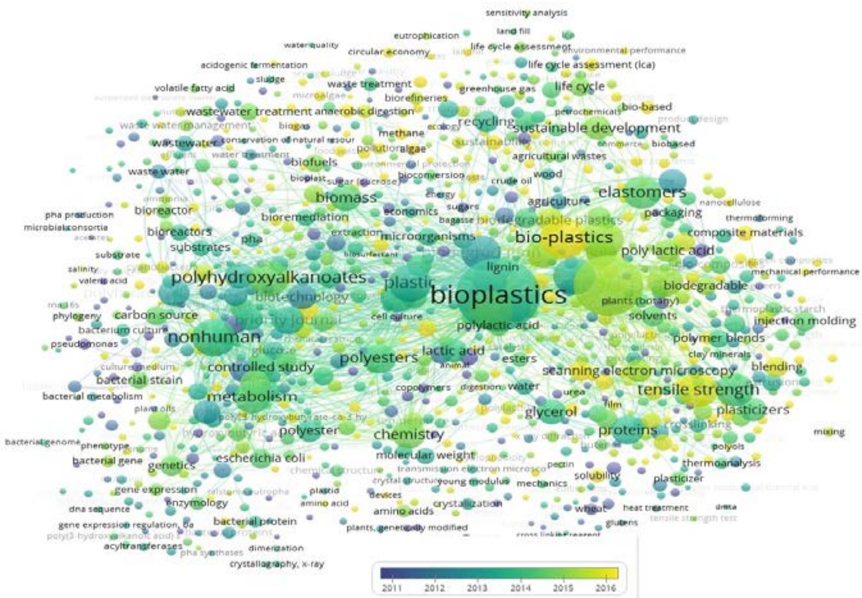

Fig. 5. Overlay visualization of most frequent terms (constructed via VOSViewer v.1.6.15), where the score of the item is the time since publication

The more frequently the term is mentioned in research publications, the larger the radius of circles. However, the colour classification depends on the year of publication (on average for a cluster), the most recent cluster publications are shown in yellow. The main cluster nuclei are defined by terms that include bioplastics, biomass, and renewable sources for biopolymer production.

According to (Gironi and Piemonte, 2011; Biron, 2020) constructed a diagram (Fig. 5). The comparison is based on some of the most important environmental impact indicators: energy required and CO_2 emissions for plastics from renewable and non-renewable source: thermoplastic starch (TPS), polylactic acid (PLA) and polyhydroxyalkanoate (PHA) and traditional plastics (high and low-density polyethylene, nylon 6, polyethylene terephthalate (PET), polystyrene (PS), polyvinyl alcohol (PVOH) and polycaprolactone.

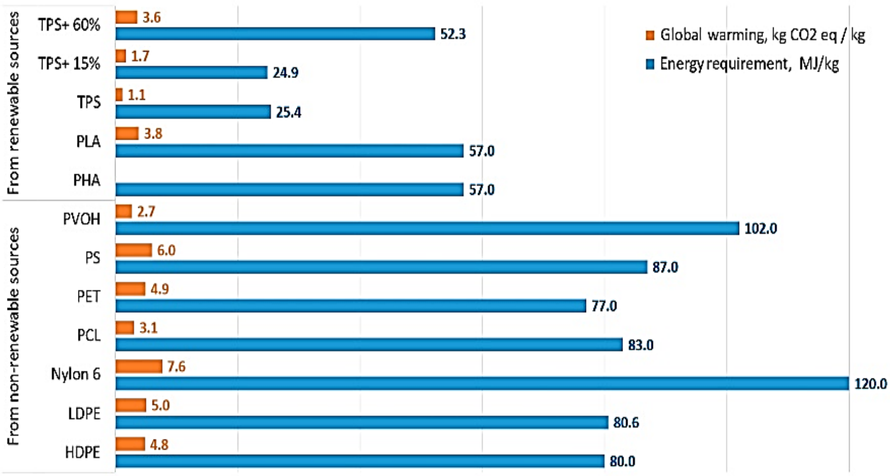

Fig. 5. The energy required and CO_2 emissions for various types of plastics. Based on the data (Gironi and Piemonte, 2011; Biron, 2020)

It should be noted that polymers from renewable sources have lower energy costs and CO_2 emissions than non-renewable, which is primarily due to the raw materials used in the polymer production cycle. Today, many manufacturers strive to produce bioplastics from agricultural waste, sewage sludge, and cellulose leftovers from wood processing. Active sludge is characterized by a sufficiently high content of total nitrogen, which is part of the protein. The organic part of the activated sludge contains up to 62% protein. The protein from the activated sludge was excreted as a result of sludge treatment by weak alkaline solution with subsequent neutralization of the protein solution. The preparation obtained in this way contains about 13% of total nitrogen and a large amount of phosphorus (Chernysh et al., 2018). Hydrolysis products characterize activated sludge protein as a nucleoprotein with a high phosphorus content (up to 1.8%). This is twice as high as the phosphorus content of casein (Evilevich, 1965). Wei Zhang et al. (2018) researched the use of activated sludge as a protein raw material for plastic products. From activated sludge, 10 to 20% of the bacterial protein was extracted, quite peculiar, and in many respects different from ordinary plant proteins and casein (Zhang et al., 2018). In (Conca et al., 2020), the production of polyhydroxyalkanoates (PHAs) integrated with nitrogen removal from anaerobic sludge water using nitrite was investigated on a long-term experimental scale.

The main advantages of biopolymers include low oxygen barrier, which allows their use as a material for food packaging, resistance to biodegradation under normal conditions, full solubility under specially created or natural conditions, therefore - no problem with waste disposal, independence from the supply of petrochemical raw materials.

The main categories of products in which the application of biopolymers is currently indicated are food packaging; bags and bags for food and waste; film for agriculture;

clothing; food containers; consumer goods; display; electronics products; furniture; office equipment; surgical threads; medical implants. The majority of bioplastics produced in the world is used to produce packaging materials. Bioplastics biodegradable is also widely used in medicine. Polymers made from biomolecules are better compatible with human tissues and are easier to dissolve than "traditional" plastics.

Among the disadvantages of biopolymers, production is high priced due to low production volumes and significant costs of technology development, insufficient technical equipment, lack of experience in various fields of biopolymers, difficulties in processing on traditional equipment. Besides, the mechanical properties of materials subjected to biodegradation are inferior to conventional polymers.

However, the demand for biodegradable materials in the world is very high and this is facilitated by legislation and regulations of EU countries. For example, the Council and European Parliament Directive 94/62/EC provides for the use of 15% recycled polymers in the manufacture of polymer packaging, negatively affecting product quality. Therefore, when using biodegradable polymers, there is a need for secondary data. Packaging made of them is not recycled but must be buried and destroyed. The EU Directive also prohibits the joint disposal of different types of waste and special composting areas are available for biodegradable packaging. It is possible to adjust the technological process of biogas production. This is one type of closed life cycle production and consumption of materials and products.

4. Conclusions

Recycling polymer waste contributes to the preservation of natural resources, as most polymeric materials are produced through oil and gas processing. The development of polymer waste recycling using some traditional polymers and their composites, such as polyethylene, polypropylene, and polystyrene, and the introduction of the concept of mechanical, chemical recycling, and use of energy potential is relevant in this direction. Alternatives to solid waste management practices are the reorganization, recycling, and creation of environmentally friendly biodegradable polymer materials based on renewable resources, plant, and textile waste. Environmental impact directions in the life cycle of conventional polymers are analyzed. The dynamics of research development in the field of bioplastics production are analyzed. Bibliometric analysis using the visualization method is carried out and helped to identify trends in the research of bioplastic production processes, as well as to identify areas of relationships between the main key terms. The relationships in keyword clusters by research objects are simulated, and the main trends of new biodegradable materials development are revealed. A comparative review of the environmental impact of different types of bioplastics is made.

Acknowledgments

This work has been supported by the Slovak Grant Agency for Science (Grant No. 1/0419/19). Research Project was carried out as planned research projects of the Department of Applied Ecology, Sumy State University, connected with subjects “Reduction of technogenic loading on the environment of enterprises of chemical, machine-building industry and heat, and power engineering” according to the scientific and technical program of the Ministry of Education and Science of Ukraine (state registration No 0116U006606).

References

Aguilar J.M., Bengoechea C., Pérez E., Guerrero A., (2020), Effect of different polyols as plasticizers in soy based bioplastics, *Industrial Crops and Products*, **153**, 112522. DOI: 10.1016/j.indcrop.2020.112522.

Antelava A., Damilos S., Hafeez S., Manos G., Al-Salem S.M., Sharma B.K., Kohli K., Constantinou A., (2019), Plastic Solid Waste (PSW) in the Context of Life Cycle Assessment (LCA) and

Sustainable Management, *Environmental Management*, **64**, 230-244. DOI: 10.1007/s00267-019-01178-3.

Biron M., (2020), *A practical guide to plastics sustainability: concept, solutions, and implementation*, William Andrew; Elsevier, Oxford; Cambridge, On line at: https://www.elsevier.com/books/a-practical-guide-to-plastics-sustainability/biron/978-0-12-821539-5.

Chernysh Y., Balintova M., Plyatsuk L., Holub M., Demcak S., (2018), The Influence of Phosphogypsum Addition on Phosphorus Release in Biochemical Treatment of Sewage Sludge, *International Journal of Environmental Research and Public Health*, **15**, 1269. DOI: 10.3390/ijerph15061269.

Conca V., da Ros C., Valentino F., Eusebi A.L., Frison N., Fatone F., (2020), Long-term validation of polyhydroxyalkanoates production potential from the sidestream of municipal wastewater treatment plant at pilot scale, *Chemical Engineering Journal*, **390**, 124627. DOI: 10.1016/j.cej.2020.124627.

ECTC, (2020), World biopolymers market 2019-2020, *ECTC Chemical Technologies*, On line at: http://ect-center.com/blog/biopolymers-market-2019.

Evilevich A.Z., (1965), *Sediments of sewage. Removal, treatment, use*, (in Russian), Stroyizdat, Leningrad, Russia.

Gironi F., Piemonte V., (2011), Bioplastics and Petroleum-based Plastics: Strengths and Weaknesses, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **33**, 1949-1959. DOI: 10.1080/15567030903436830.

Hopewell J., Dvorak R., Kosior E., (2009), Plastics recycling: challenges and opportunities, *Philosophical Transactions of the Royal Society B: Biological Sciences*, **364**, 2115-2126. DOI: 10.1098/rstb.2008.0311.

ISO 14044, (2006), ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines, International Organization for Standardization, On line at: https://www.iso.org/standard/38498.html.

JRC EC, (2010), Product environmental footprint (PEF) guide, JRC European Comission, 873782, On line at: https://ec.europa.eu/environment/archives/eussd/pdf/footprint/PEF%20methodology%20final%20draft.pdf.

Koffler C., Zahller M., (2012), *Life cycle assessment of polymers in an automotive assist step*, Technical report, PE International, Inc., Boston, MA, USA, On line at: https://plastics.americanchemistry.com/Education-Resources/Publications/Life-Cycle-Assessment-of-Polymers-in-an-Automotive-Assist-Step.pdf.

Moltó J., López-Sánchez B., Domene-López D., Moreno A.I., Font R., Montalbán M.G., (2020), Pollutant emissions during the pyrolysis and combustion of starch/poly(vinyl alcohol) biodegradable films, *Chemosphere*, **256**, 127107. DOI: 10.1016/j.chemosphere.2020.127107.

O'Neill T.J., (2002), Life cycle assessment and environmental impact of poymeric products, Rapra review reports, Rapra Technology Ltd, Shawbury, Shrewsbury.

Pelikh A.S., Chumakov A.A., Barannikov M.M., Bokov I.I., Dreev G.A., Pronchenko A.G., Popeta G.G., (2003), *Organization of entrepreneurial activity*, 2nd, (in Russian), Pelikh A.S. (Ed.), Mart, Moscow, Rostov-on-Don.

Platt D.K., (2006), *Biodegradable polymers: market report*, Rapra Technology, Shrewsbury, Shropshire, U.K.

Sperber R.J., Rosen S.L., (1974), Reuse of polymer waste, *Polymer-Plastics Technology and Engineering*, **3**, 215-239. DOI: 10.1080/03602557408545028.

Walker S., Rothman R., (2020), Life cycle assessment of bio-based and fossil-based plastic: A review, *Journal of Cleaner Production*, **261**, 121158. DOI: 10.1016/j.jclepro.2020.121158.

Zhang W., Alvarez-Gaitan J., Dastyar W., Saint C., Zhao M., Short M., (2018), Value-added products derived from waste activated sludge: A biorefinery perspective, *Water*, **10**, 545. DOI: 10.3390/w10050545.