# IMPACTS ON CLIMATE CHANGE GENERATED BY POLYVINYL CHLORIDE (PVC) AND POLYHYDROXYALKANOATES (PHAs) PRODUCTION: A COMPARATIVE APPROACH

## IMPACTUL PRIVIND SCHIMBĂRILE CLIMATICE GENERATE DE PRODUCȚIA POLICLORURII DE VINIL (PVC) ȘI A POLIHIDROXIALCANOAȚILOR (PHAs): O ABORDARE COMPARATIVĂ

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***Abstract.*** *The plastic industry has always been considered a major consumer of energy, natural resources, especially non-renewable fossil fuels, causing significant threatens for the environment. This situation is amplified by the impacts generated during the production and utilization of plastics. The processes applied for plastic manufacturing using petroleum-based raw materials have significant implications for* $CO_2$, $CH_4$, *Volatile Organic Compounds (VOC) emissions occurrence. For this reason, in this paper we have analyzed two plastic production processes: of polyvinyl chloride (PVC) based on non-renewable resources, and polyhydroxyalkanoates (PHAs) biopolymers, respectively using recycled organic waste as raw material transformed by aerobic and/or anaerobic bioprocesses. Environmental impacts of these two processes were evaluated by applying Life Cycle Assessment methodology. The results have shown that PVC production has a considerable contribution to climate change compared with PHAs. Recycling of organic waste for biopolymers manufacturing proved to be a sustainable alternative, since the emissions are significantly lower compared with those from PVC production.*

***Key words:*** *biopolymers, Life Cycle Assessment, polymers, plastic, process*

***Rezumat.*** *Industria de mase plastice a fost întotdeauna considerată un mare consumator de energie, resurse naturale, în special combustibili fosili neregenerabili, având consecințe semnificative pentru calitatea mediului înconjurător. Această situație este amplificată de impacturile generate în timpul*

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*producției şi utilizării materialelor plastice. Procesele aplicate pentru fabricarea plasticelor folosind materii prime pe bază de petrol generează emisii de $CO_2$, $CH_4$, compuși organici volatili (COV). Din acest motiv, în această lucrare am analizat procesele de producție a două tipuri de materiale plastice: policlorura de vinil (PVC), din materii prime pe bază de resurse neregenerabile şi polihidroxialcanoații (PHAs), din deşeuri organice reciclate, transformate prin bioprocese aerobe și/sau anaerobe. Impacturile de mediu celor două procese au fost evaluate prin Analiza Ciclului de Viață. Rezultatele analizei au arătat că procesul de producție al PVC contribuie într-o măsură mai mare la generarea de impact în mediul înconjurător asociat schimbărilor climatice decât producția se dovedește a fi o alternativă durabilă, deoarece emisiile sunt semnificativ mai mici comparativ cu cele rezultate din producția de polimeri convenționali.*

***Cuvinte cheie:*** *biopolimeri, Analiza Ciclului de Viață, polimeri, plastic, proces*

## INTRODUCTION

Global warming is a phenomenon that occurred as a direct consequence of increased greenhouse gas emissions (GHG) - especially carbon dioxide ($CO_2$) into the atmosphere (Hekkert *et al.,* 2000).

This phenomenon is the result of human industrial activities including extraction and burning of fossil fuels (oil, coal, natural gas) from which significant amounts of $CO_2$ can result. Plastics industry is among the industries using raw materials based on fossil fuels..

The plastics production has become an inseparable part of daily life despite the fact that the plastics manufacturing and their utilization can generate significant impacts in the environment due to necessary raw materials derived from petroleum and also because the finished products are not biodegradable (Gao *et. al.,* 2011). One of the most widely used polymers in the world polyvinyl chloride (PVC) has applications in manufacturing of profiles, pipes and fittings, bottles, cables, flooring, flexible tubes and profiles, film and sheets and others (Shojai and Bakhshandeh, 2011).

Recent studies have highlighted that the plastic materials can affect human health because they contain fairly large proportions of chemical additives that can be endocrine disruptors or carcinogens, or generate toxic reactions in the human body or marine animals (Andrady, 2011; Gavrilescu *et al.,* 2015; Rochman *et. al.,* 2013).

The high consumption of synthetic polymeric materials has brought increasingly into attention the impact that they generate in the environment as a consequence of emissions from the process, leading to increased global warming phenomenon, as well as due to the huge quantities of non-biodegradable polymeric waste (Rochman *et. al.,* 2013).

On the other hand, the interest for alternative solutions that could ensure the perspective for GHG emissions reduction has increased, in parallel with a decline in the volume of wastes derived from non-biodegradable synthetic polymers as well as of biodegradable organic waste (Gao *et. al.,* 2011).

In this context intense research are developed for the synthesis of organic polymeric biomolecules from organic raw materials, in particular biodegradable waste, which can subsequently be used in bioplastics manufacturing process.

In this way it is intended to diminish the environmental impacts that the production processes of traditional plastics can generate in the environment as well as those induced by the presence of non-biodegradable plastic waste.

In this paper, a sustainability analysis of two plastics production processes: a classical one, which uses raw materials from fossil fuels (polyvinyl chloride, PVC), and an unconventional one, which produces biopolymers from bio-organic waste (polyhydroxyalkanoates, PHAs) is performed.

The analysis is based on Life Cycle Assessment methodologies (LCA) and considers a number of impact categories which both production processes can generate into environment.

## MATERIAL AND METHOD

### 1. Description of the studied processes

The chemical industry produces, among others, various types of plastics such as polyethylene terephthalate (PET), high density polyethylene (HDPE), low density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS), acrylonitrile butadiene styrene copolymer (ABS). PVC it is considered to be the polymer with the lowest environmental impact (Ognedal *et al.,* 2014).

Vinyl chloride is the monomer used in large quantities in the plastics industry, especially for manufacturing of vinyl polymers and copolymers with great importance for the industry and consumption.

Polyhydroxyalkanoates (PHAs) are biodegradable polymers obtained from biomolecules produced by microbial biosynthesis using available and renewable carbon sources. PHAs are biodegradable and can be used in the production plastic biomaterials (Cyras *et al.,* 2007).

Assimilation at industrial level of bioplastics production could generate a sustainable solution for reducing the consumption non-renewable resources and the impacts caused by their exploitation during plastics production processes. Moreover, this could lead to the reduction of waste plastic quantities bearing in mind that currently about 1.3 billion tons of plastic waste are recorded every year at a global level, according to the United Nations Environment Programme (UNEP) (Melikoglu *et al.,* 2013).

Table 1 presents the characteristics of PVC and PHAs production processes.

### 2. Life Cycle Assessment (LCA)

Life cycle assessment is an objective method used to evaluate the environmental impacts associated with a product, process or system, on the whole life cycle, including the extraction and purchase of raw materials, production, distribution, use, reuse/recycling, final disposal (Ghinea *et al.,* 2014). For correct application of this impact assessment methodology four stages are necessary to be performed (Ghinea *et al.,* 2014; ISO 14040, 2006).

LCA methodology was applied to evaluate different systems: municipal solid waste management (Ghinea and Gavrilescu, 2010; Ghinea and Gavrilescu, 2011; Ghinea *et al.*, 2012; Ghinea *et al.,* 2014), paper making industry (Petraru *et al.,* 2011; Ghinea *et al.,* 2014), biogas (Cozma *et al.,* 2013), construction and demolition waste management (Simon *et al.,* 2013). By applying LCA methodology, some environmental impacts of the two industrial processes for obtaining plastic materials will be assesses and ranked.

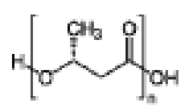
The functional units considered in this paper are represented by 1 kg of PVC and 1 kg of PHAs, respectively. In the inventory stage the necessary data were collected to establish environmental impacts of both processes studied in this context. The inputs and outputs data were determined for each production stage included in the respective processes.

The data were collected from literature, the databases of GaBi software etc. Some data were calculated and estimated based on the existing technologies or Best Available Techniques. In the assessment impacts stage, the environmental impacts for both processes (PVC and PHAs) were obtained. LCA analysis was assisted by GaBi, which is a modular software system that includes plans, flows, processes and their functions. Gabi is a commercial software tool in order to achieve the balance sheets life-cycle products by means of the data for life-cycle modeling.

In addition to the assessment a life cycle products, GaBi software can be used to: eco-design, material flow analysis, environmental balance sheets, environmental and development sustainable reports etc.

*Table 1*

**The characteristics of production processes for PHAs and PVC (Comăniță *et al.,* 2014)**

| **Caracterization** | **Processes studied** | |
|---|---|---|
| | **Conventional polymer production process** | **Biopolymer production process** |
| Classification *(depending on production way and utilization)* | Rigid polyvinyl chloride (PVC-D); plasticized polyvinyl chloride PVC-M); chlorinated polyvinyl chloride (PVC-C); copolymer vinyl chloride - vinyl acetate (VC / VAC) etc. | polylactic acid (PLA); polyhydroxyalkanoates (PHAs); starch (BMS); cellulose and its derivatives; polyvinyl alcohol (PVOH); biodegradable aliphatic and aromatic copolymers etc. |
| Chemical formula | PVC: $[-CH_2-CHCl-]_n$ | PAH:  |
| Production process | The polymerization (very exothermic reaction) is the most common process for the manufacture of polyvinyl chloride and may be performed by using three methods: bulk; emulsion; suspension. | Polyhydroxyalkanoates are bioppolymers which can be obtained by using a wide range of substrates such as renewable resources (sucrose, starch, cellulose, and triglycerides), by products (syrup, glycerine). These biopolymers can be synthesized by aerobic and/or anaerobic biological processes. |
| Emissions resulted from the process | sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), volatile organic compounds (VOC), methanol ($CH_3OH$), methane ($CH_4$), hydrogen sulfide ($H_2S$) | carbon dioxide ($CO_2$), methane ($CH_4$), nitrogen ($N_2$), ammonia ($NH_3$), carbon monoxide (CO) |

## RESULTS AND DISCUSSION

The evaluation of the environmental impacts for the PVC and PHAs production processes was performed by applying two methods based on LCA methodology included in GaBi software: CML 2001 and ReCiPe. Figure 1 illustrates the environmental impacts of PVC production calculated based on CML 2001 methodology.

Besides the global warming potential (GWP), the following impact categories were also considered: acidification potential (AP), eutrophication potential (EP), human toxicity potential (HTP), photochemical ozone generation potential (POCP).

The results are presented in the normalized values (EU 25+3).

The results obtained for PVC production show that the environmental impacts are negative and can be ranked in the following order: PH> POCP> AP> GWP> EP. Regarding the PHAs production, it can be observed from Fig. 2 that the values of the impact categories are lower than those illustrated in Fig. 1 for the PVC production, but they are also associated with negative environmental impacts. In the case of PHAs production process, the impact categories decrease in the following order: AP> GWP> PH> POCP> EP. The data obtained based on the ReCiPe method show that some of the impacts such as: climate change associated with ecosystems (Cce) and climate change associated with damage human health (CCHh) have positive values, for both PVC and PHAs production process, which means that the evaluated processes generates negative impacts on environment. Analyzing the data presented in Fig. 3 and Fig. 4 it can be concluded that global warming potential values are lower for PHAs production compared with those obtained for PVC production.

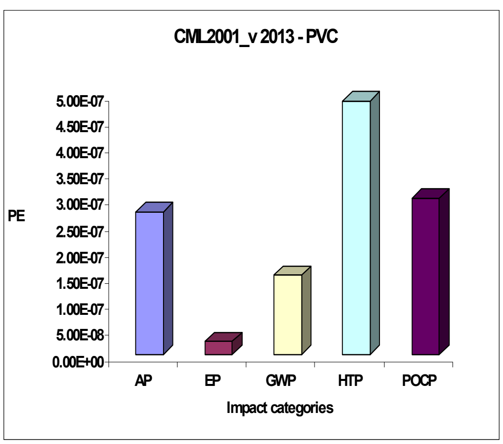



**Fig - 1.** Environmental impacts generated in the PVC production process (CML 2001 methodology)

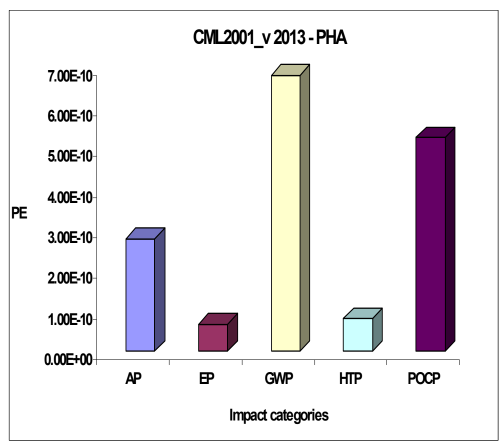



**Fig. 2 -** Environmental impacts generated in the PHAs production process (CML 2001 methodology)

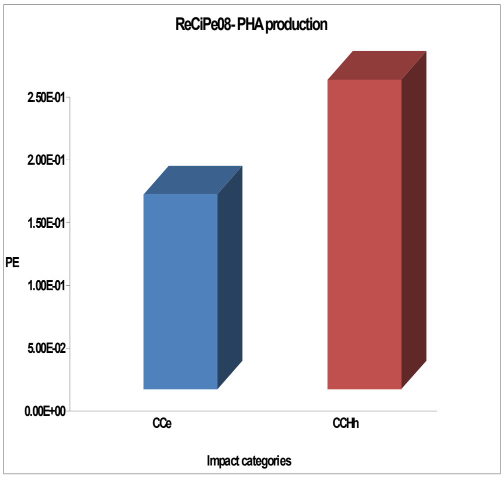



**Fig. 3 -** Global warming potential associated with PVC production - ReCiPe method

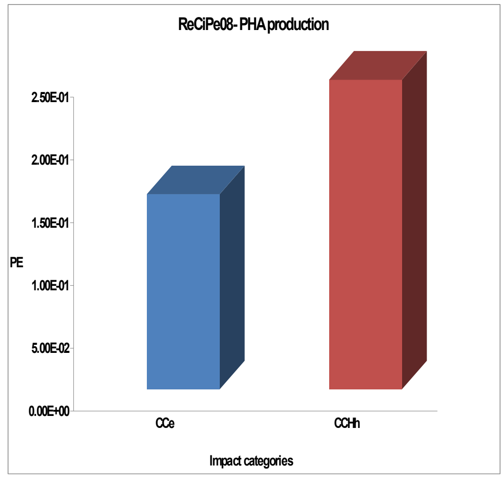



**Fig. 4 -** Global warming potential associated with PHAs production - ReCiPe method

Also CCHh impact category has higher values than Cce. In the case of the production of PVC, the contribution to global warming is the consequence of $NO_2$, VOC, $CH_4$, $SO_2$ emissions from the polymerization step.

The emissions resulted from PHAs production that contribute to global warming are $CO_2$, $CH_4$, CO, which are generated from the anaerobic digestion phase.

## CONCLUSIONS

1. In this paper life cycle assessment methodology was applied for the determination of environmental impacts caused by two industrial processes were evaluated from environmental point of view.

These processes address the manufacturing of obtaining plastics using different raw materials (based on fossil fuels and bio-organic waste, respectively) and having as final product a classic polymer (polyvinyl chloride) and a biopolymer (polyhydroxyalkanoate).

2. The evaluation was performed using CML2001 and ReCiPe LCA methods included in GaBi software.

3. After the evaluation of the impacts generated by the two production processes in the environment based on life cycle analysis methodology (LCA), it has been found that both processes induce negative impacts on environment, with the mention that the impacts generated by PVC production is higher compared to those induced by PHAs production.

4. The higher impact is associated with climate change due to the emissions of greenhouse gases.

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