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CHALLENGES AND OPORTUNITIES IN GREEN PLASTICS: AN ASSESSMENT USING THE ELECTRE DECISION-AID METHOD

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Abstract

Bioplastics are biobased materials, usually easy biodegradable, derived from renewable resources. Evolution of bioplastics production is related to: bio starch and starch mixtures (74.5%); bioplastic products from fermentation (13%), bioplastic from petrochemicals materials (12.5%). They are seen as a viable solution to avoid some environmental impacts caused by the use of fossil-based conventional plastics. In this context, the general objectives of this study entail the analysis and selection of the optimal alternative of bioplastics able to be used for packaging production, considering social, economic and environmental criteria. In order to accomplish these objectives, we applied the ELECTRE method (*ELimination Et Choix TRaduisant la RealitÉ*), a multi-criteria analysis method. Application of this method enables the use of qualitative and quantitative discrete criteria, making also possible alternatives ranking. The application of ELECTRE method in our study consisted in selecting different types of bioplastics which were compared considering some consistent criteria so as to assess their economic and environmental performances. Based on the application of multiple criteria evaluation we concluded that bioplastics, in particular polyhydroxyalkanoates (PHAs) are suitable from economic and environmental points of views for manufacturing and utilization of packaging.

Key words: bioplastic, indicators, ELECTRE method, multi-criteria analysis, polyhydroxyalkanoates

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1. Introduction

Human society continuously aspires to achieve economic development and well-being in order to secure higher living standards and to protect and improve the environment, both for present and future generations (Fortuna et al., 2012; Gavrilescu, 2004; Ghinea et al., 2014a; Koroneos et al., 2012). It is considered that these two aspirations are in the core of sustainable development concept based on ecosystem - eco-efficiency dualism (Simion et al., 2013; Teng and Wu, 2014). Movements towards sustainability address, among others, various categories of materials which incorporate nonrenewable resources, such as fossil fuels, and energy. All these generate economic, social and environmental negative impacts and high carbon footprints during the whole life cycle. This is why

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today, biobased production largely seen as a central element of bioeconomy is gaining against the conventional oil and petrochemicals industries (Gavrilescu and Chisti, 2005; OECD, 2014). Biofuels, bio-based chemicals and bio-based plastics represent a vast network in the public policy which try to reconsider the balance among sustainability of materials, energy, fuel (Gavrilescu, 2014a, b; OECD, 2014).

In particular, the challenges for the future of bio-based plastics are particularly important, both in terms of sufficient material resources supplying, and waste management (Iwata, 2015; Peelman et al., 2013; Yu et al., 1998). Curently, there are a number of obstacles that should be overcome to ensure a sustainable life cycle for bioplastics (emergence of renewable biomass sources of carbon, price in comparison to oil-based plastics). Therefore, it is necessary to intensify the analyses of strengths and weaknesses, threats and opportunities regarding sustainability biodegradable plastics in terms of considering the economic, social and environmental challenges, along the whole life cycle (Iles and Martin, 2013).

Apart from resource conservation goal, the current policy on bioplastics is focused on bio-waste management considering prevention, reuse and recycling in order to reduce and valorize the amount of waste produced (Briassoulis, 2001; Dace et al., 2014; Fortuna et al., 2011; Ghinea et al., 2014b; Şchiopu and Ghinea, 2013). Waste composition makes the process of degradation and natural elimination by the action of microorganisms more difficult, leading to increased remanence period, especially when waste contains conventional plastics (De Feo et al., 2013; Gavrilescu, 2008; Heaney et al., 2011; Hermann et al., 2011; Hlihor et al., 2014a). Environmental and landscape degradation, emissions and odors create a negative impact (pollution by organic substances, nitrites, nitrates, heavy metals and other elements) on life quality for the surrounding communities.

All these can lead to soil, water and air pollution (Gavrilescu et al., 2015; Hlihor et al., 2014b; Pogăcean et al., 2014; Simion et al., 2013b). Some efficient solutions addressing packaging end-of-life can play an important role in the development of sustainable waste management, because resource waste and environmental impact can be reduced, while providing economic and social benefits (Gavrilescu and Chisti, 2005; Rossi et al., 2015).

In this framework, the main objective of this work was to find from several alternatives the most sustainable bioplastics for packaging production, which use material resources and energy without compromising the possibilities of meeting the needs of future generations. We applied the ELECTRE method for a set of bioplastics in order to choose the most suitable for packaging considering the economic, social and environmental criteria.

2. Plastics – characteristics and impacts on environment and human health

2.1. Some characteristics of plastic products and waste

The global plastic production was 230 million tons in 2009, and more than 99% was due to polymeric materials obtained from fossil resources (Rose and Palkovits, 2011).

According to ISO 472 (2013) plastic "*contains as an essential ingredient, a polymer with a high average molecular weight and at some point in the processing, can be poured through the flow into final products*".

Plastic materials are used for a large variety of products, in particular for packaging (bags, cups, glasses, cutlery, casseroles, plastic bottles, recipients for shampoos and toys). At the end of their life they become waste generating additional pollution, which can induce negative impacts on the environment and human health, because of their composition (Gregory, 2009; PlasticsEurope, 2011; Peelman et al., 2013) (Table 1).

Table 1. Impacts of plastic waste in aquatic environment

Impact	*Effect*	*References*
Landscape degradation	Economic repercussions for the tourism industry	Barnes et al. (2009); Sivan (2011)
Hindering activities in marine industry	Repercussions to maritime transport, fisheries, energy production, aquaculture	Barnes et al. (2009)
Destruction of the aquatic environment	Demage (fall of feathers from birds) and death marine birds, mammals, fish and reptiles	Gregory (2009)
	"Suffocation" and the destruction of plankton and phytoplankton due to the accumulation of "plastic mountains"	Weiss et al. (2012)
	Disequilibrium of marine habitat due to "plastic mountains" expansion (disappearance of marine species)	Hall et al. (2010); Weiss et al. (2012)
	Issue of toxins from the plastic on fish communities (death of fish species)	Rochman et al. (2013)

Plastics can be classified in many ways, depending on polymeric molecules contained and procedure of polymerization and processing (Sahoo and Ali, 2008; Tachwali et al., 2007). The most known polymers are (Fig. 1): polyethylene terephthalate (PET or PETE); high density polyethylene (HDPE); polyvinyl chloride (PVC); low density polyethylene (LDPE); polypropylene (PP); polystyrene (PS); other plastics (polycarbonate and polylactide).

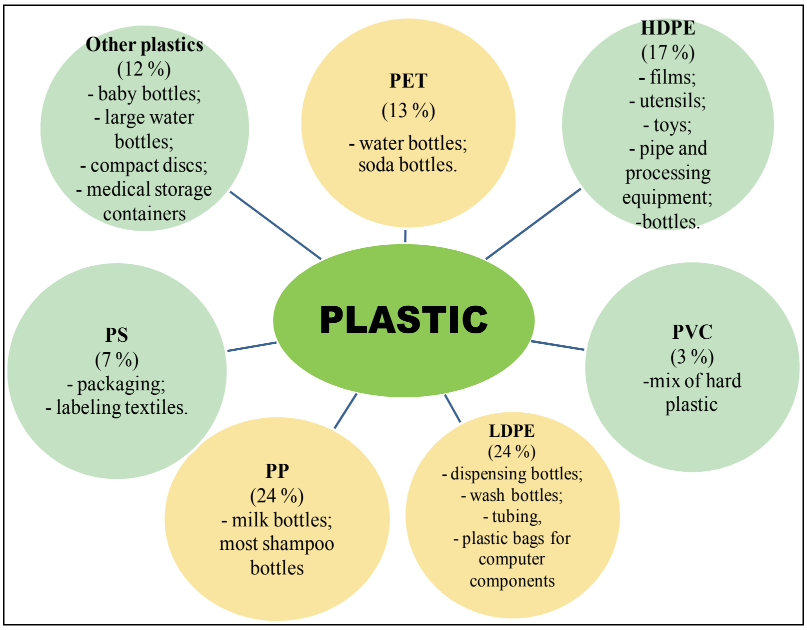


Fig. 1. Areas of utilization for various plastics

Petroleum deriving plastics are widely used not only due to their outstanding mechanical properties, low cost, light weight and high energy efficiency, but also for their stability, durability and chemical and biological inertness. Half of plastic wastes generated in Europe are landfilled. This situation should be prevented, because plastic can contain dangerous elements and undesirable emissions can be generated by landfiling (Groot et al., 2014; Song et al., 2009). The plastic wastes disposed in landfills frequently experience photo oxidation and degradation, resulting in small fragments and particles, which can absorb toxins and toxic chemicals, entering into the food chain, where they can exert toxic effects (Roy et al., 2011).

2.2. Challenges and opportunities in green plastics

Information on biodegradation of petroleum-deriving polymers and plastics is generally limited to biodegradable synthetic polymers, such as poly(vinyl alcohol), aliphatic polyesters, polycaprolactone, and polyamides, oligomeric ethylene, styrene, isoprene, butadiene, acrylonitrile, and acrylate (Shah et al. 2008). In this context, another category of plastics, based on biopolymers (polymeric biomolecules) starts to become increasingly more a sustainable alternative to fossil-based polymers (Gavrilescu and Chisti, 2005).

According to IUPAC, "*biobased polymer derived from the biomass or issued from monomers derived from the biomass and which, at some stage in its processing into finished products, can be shaped by flow*" (Vert et al., 2012).

The advantage of biopolymers against conventional petrobased polymers is represented by the fact that they can be produced by living organisms, from renewable bio-based resources. Some biopolymers can be used as plastics, replacing the conventional, and petrobased plastics.

In terms of biodegradability, all plastics will be degraded in time, but the conventional plastics face with a long duration of degradation, for hundreds of years (Groot et al., 2014). On the other hand, bioplastics are biodegradable products that can degrade quickly in raw materials (under defined conditions of degradation process) and can improve the soil quality and support plant growth. Bioplastics obtained from renewable bio-based resources or organic wastes are considered environmentally friendly, having the potential to alleviate pollution issues caused by plastics.

A significant increase in the production of bioplastics at a level comparable to that of conventional plastics could have a positive impact on the environment, by reducing greenhouse gas emissions, space for waste storage, and the risk of for marine pollution and on human health (Sheldon, 2014). Although research in the field of bioplastics began a few decades ago, the products made of these materials have appeared on the market in the past decades (Freemantle, 2005). Since the 80s, researches were undertaken throughout the world for biopolymers assimilation, but the most funds for these types of researches were allocated in the United States and Japan (Ritter, 2002). The development perspective of material production from biodegradable bioplastic is primarily optimistic, the experts estimating a production of over 5 million tons by the end of 2020 (Shen et al., 2009).

The assimilation of bioplastics could be an optimal solution both for reducing plastic waste and food waste prevention and valorization, given the loss of about 1.3 billion tonnes of food in each year at global level, according to program of the United Nations Environment Programme (UNEP)

(Melikoglu et al., 2013). Vegetable fats and oils, corn starch, pea starch or microbiota are considered as raw materials for bioplastics. According to production method, bioplastics can be classified as (Cooper, 2013):
- made from vegetable resources (BMS): corn, potato, wheat, rice, beets, cellulose, starch etc.;
- synthesized from renewable sources: polylactic acid (PLA), poly glycolic acid (PGA), polycaprolactone (PCL);
- produced by microorganisms or genetically modified: polyhydroxyalkanoates (PHAs), PolyHydroxyButyrate (PHB), PolyHydroxyButyrate-co-valerate (PHBV);
- mixures with biodegradable polymers: Poly vinyl alcohol (PVOH), Polycaprolactone (PCL).

The new bioplastics are characterized by a specific combination of rigidity and elasticity compared with both existing bioplastics and with traditional plastics. For example, a plastic obtained from spinach is more elastic, while plastic produced from rice husk is more firmly (Zhao et al., 2002).

Bioplastics are used extensively in modern society for packaging, agriculture, transport, household utilities (Fig. 2).

3. Methodology

3.1. Multicriteria decision analysis (MCDM)

Multicriteria analysis was developed in 1960 as an instrument for decision making, and has become increasingly used in the projects management (Phillips, 1984). The main steps of multi-criteria analysis are (San Cristobal, 2012; Tsiporkova and Boeva, 2006):

1. establishment of the decisional context, such as goals of project which is evaluated and its feasibility;
2. definition of options, which meant to identify alternatives that will be considered;
3. definition of criteria, identification and definition of all the criteria relevant to the problem decision;
4. achievement of the performance matrix, which describes the intended performance of each option according to the criteria;
5. standardization of scores for each criterion to a common scale interval (usually with values ranging from 0-1 or -100);
6. weighting of criteria for relative quantification of each criterion in the decision process;
7. hierarchy of options: in this stage the decision maker has to select the most appropriate method for ranking alternatives;
8. examination of results: in this step the expert analyzes the results and presents them in a comprehensive manner;
9. sensitivity analysis: to validate alternative assessment, and ranking the alternatives resulted from decision process.

Multicriteria analysis methodology includes complex methods such as (Choi et al., 2015; Milutinović et al., 2014; Soltani et al., 2015): Analytical Hierarchy Process (AHP); ELECTRE I; ELECTRE II; ELECTRE III; Organization, Rangement et Synthese De Donnes Relationnelles (ORESTE); - Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE); Simple Multi-Attribute Ranking Technique (SMART).

The models of multicriteria analysis can be used in different areas such as: waste management (Generowicz et al., 2011; Ghinea and Gavrilescu, 2010; Ghinea et al., 2014a; Soltani et al., 2015), hydrology and water management (Hyde et al., 2005; Pedrero et al., 2011; Scholten et al., 2015; Sudhakaran et al., 2013), energy management (Kowalski et al., 2009; Troldborg et al., 2014; Wang et al., 2009), and others.

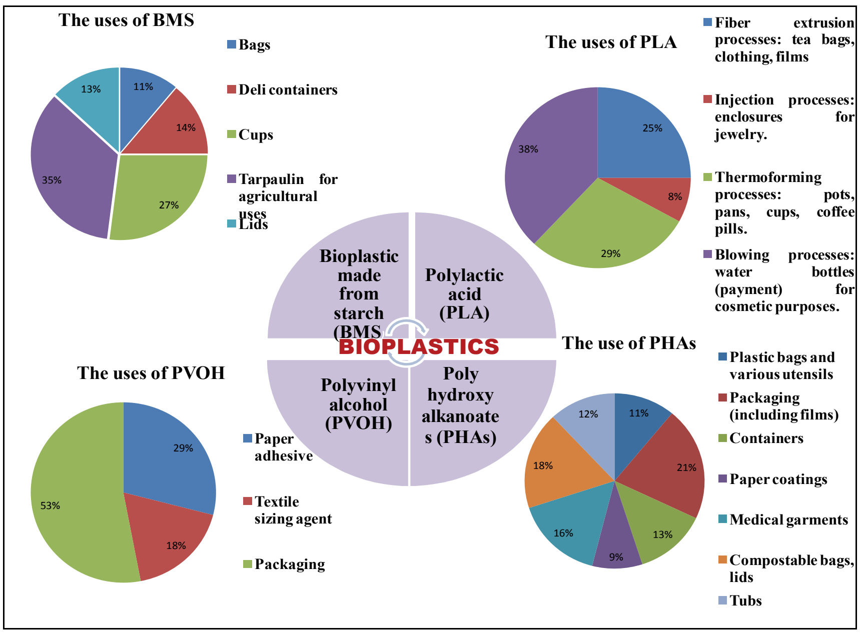


Fig. 2. Applications of bioplastics

3.2. ELECTRE method

In order to achieve the objectives of this paper, ELECTRE - a multicriteria evaluation method was applied. This method was developed in France, and applied particularly in European countries (Roy, 1993; Roy and Vanderpooten, 1996). It is based on the concept of *Upgrademay* to eliminate alternatives that are in a certain sense "dominated". The notion of "dominance" within the framework provided by *Upgrademay* is a generalization of the classical dominance and uses weightings to rank the criteria (some of them have more influence than others on the decision).

Roy (1993) described *Upgrademay* concept as follows: alternative *Ai*, outperforms the alternative *Ak*, if, given the preferences of the decision maker, the quality evaluation of alternatives and problem context, there exist enough arguments to decide that *Ai* is at least as good as *Ak* and there is no obvious reason to contradict the affirmation. Based on this idea, a series of procedures for concretizing *Upgrademay* concept as a way of multicriteria decision support have been developed (Iazzolino et al., 2012). In general, two steps are necessary for applying ELECTRE method (Hatami-Marbini and Tavana, 2011):

- specifying a precise way of determining the *Upgrademay* existence between two alternatives;
- combining *Upgrademay* evaluations for ranking of the alternatives.

Application of multi-criteria analysis methods, such as ELECTRE, in environmental management is based on (Kaya and Kahraman, 2011):

- existence of multiple criteria evaluation;
- participation of decision makers;
- complexity and subjectivity of the evaluation process.

ELECTRE Methodology has been developed through a series of different versions (I-IV); ELECTRE I is designed for a problematic choice of alternatives considered, ELECTRE II, III and IV are designed for extreme situations arising from the proposed variants and ELECTRE TRI has been designed for a problematic sorting from considered variants. Another type of variant from ELECTRE is TOPSIS method (Wang and Triantaphyllou, 2008). ELECTRE method is based on the evaluation of two indices, the concordance and discordance indexes, defined for each pair of alternatives (Bojković et al., 2010). Like other methods of multi-criteria analysis, ELECTRE has the same steps (Vahdani et al., 2010):

- specifying alternatives and criteria;
- performance evaluation according to criteria;
- establishing the weights associated criteria that determine their relative importance.

The essence of ELECTRE method is to identify the relationships of dominance, and its purpose is that a subset noted "*E*" should have as few elements that will represent the alternative candidate for final decision (Vahdani et al., 2010). The main advantages offered by ELECTRE method in the environmental decision-making can be synthesized as follows (Aiello et al., 2013; Kaya and Kahraman, 2011):

-possibility to analyse complex environmental issues;
-active participation of environmental factors in the decision making process;
-application of scientific methods in decision making.

ELECTRE method was used in several areas: Kaya and Kahramanv (2011) combined AHP and ELECTRE methods for environmental impact assessment; Hatami-Marbini et al. (2013) used a fuzzy group ELECTRE method for safety and health assessment in hazardous waste recycling facilities; Choi et al. (2015) applied this method for rehabilitation of water distribution system.

In our study, the bioplastic evaluation was performed by applying ELECTRE method and by using selected criteria that address both objectives associated with current trends in waste management as well as global environmental indicators (e.g. quantity of emissions generated). The alternatives were established in order to minimize the amount of waste landfillled, increase the quantity of produced energy, obtain raw materials for bioplastic and reduce greenhouse gases emissions.

The ELECTRE method was applied in order to find the most suitable solution for obtaining bioplastics used for packaging production, by respecting the criteria of sustainable development, from the economical, social and environmental points of view, thus contributing to the development of the market for raw materials and to promote the use of products derived from biopolymers. We also used concordance and discordance indicators and threshold values for calculation purposes. Each type of bioplastic was evaluated from social, economical and environmental point of view. The steps followed in this study are illustrated in Fig. 3.

4. Case study

Starting from the premise of Environmental Action Programme 7: "Turning Waste into Resources", which proposes to increase the sustainability towards "zero waste", and transform waste into valuable materials and energy resources, in this study we evaluated the economical, social and environmental performance of various bioplastics used for packaging production.

Most used bioplastics, to obtain packaging are: polylactic acid (PLA); polyhydroxyalkanoates (PHAs); bioplastic made from starch (BMS); cellulose and its derivatives; polyvinyl alcohol (PVOH); biodegradable aliphatic and aromatic copolyesters (European Bioplastics, 2013). To achieve our objectives we focused on the use of polylactic acid (PLA), Polyhydroxyalkanoates (PHAs), bioplastics obtained from starch (BMS) and polyvinyl alcohol (PVOH).

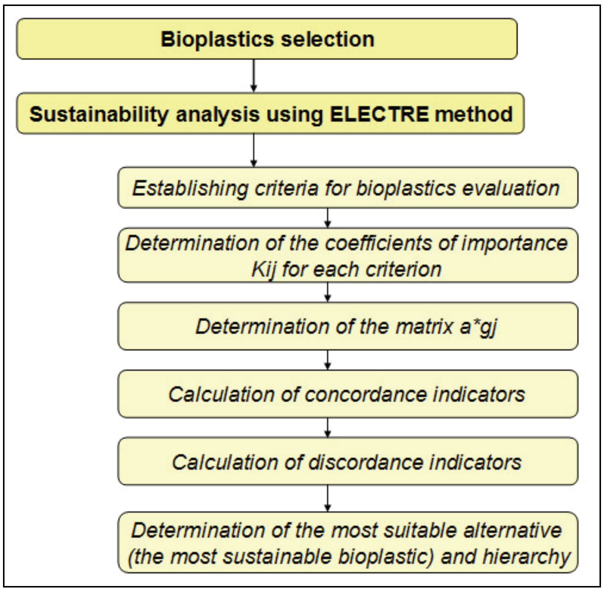


Fig. 3. Stages developed in the study of plastics sustainability applying ELECTRE method

(i) Polylactic Acid (PLA)

Polylactic acid is thermoplastic aliphatic polyester produced from renewable resources. It is biodegradable under certain conditions, such as in the presence of oxygen, and is difficult to recycle. PLA posesses high values of tensile strength and modulus, is a polymer that has many properties comparable to other plastics (Auras et al., 2004).

(ii) PolyHydroxyAlcanoate (PHA) and PolyHydroxyButyrate (PHB)

PHA and PHB are bioplastics in the form of granules. PHA is more rigid, being used in a more limited area for bottles and agricultural land cover, when is necessary, while PHB is used for plastic bags and various utensils (Cavalheiro et al., 2009; Chen et al., 2007). The process for producing these bioplastics consists of incubating in bioreactors large amounts of bacteria, until their number increase greatly, reaching to point of ”stress” as an alarm caused by environmental change. When bacteria transform nutrients through fermentation, until get to 80% by weight, bacteria are “purified” and the bioplastics are extracted (Adamus, 2012).

Shen et al. (2014) obtained PHB from organic waste through a process consisting of two stages and which is focused on volatile fatty acids intermediaries. Cavalheiro et al. (2009) obtained PHB using *Cupriavidus necator* and waste based on glycerol. PHA was obtained from waste pulp by Queirós et al. (2014). Polyhydroxybutyrate-co-valerate (PHB_V), a member of the family of PHB has gained a lot of attention as a green material. It is a brittle and crystalline material with short pendent side-groups on its backbone (Singh et al., 2008).

(iii) Bioplastic made from starch (BMS)

Current bioplastics are generally made from starch derived from corn, rice, sugar cane or potato. Starch from plant sources is very attractive due to low costs, its existence in large quantities in renewable materials, and processing due to the possibility of the extruder and thermoforming used in the processing of biopolymers (Freire et al., 2009; Singh and Nath, 2013).

Bioplastics made from starch can be processed using common methods of processing synthetic polymers (Chaudhary et al., 2008). Making biodegradable protective packaging will help in building top of starch and starch reactivation of domestic factories, and bring substantial benefits to the environment and society, by preserving and protecting ecosystems (Araujo et al., 2004).

(iv) Polyvinyl alcohol (PVOH)

Polyvinyl alcohol is a biodegradable vinyl polymer, used for coatings, adhesives, and as additive in paper and board production.

The advantages of bioplastics types used in our study are presented in Fig. 4 (Accinelli et al., 2012; Akaraonye et al., 2010).

5. Results and discussion

5.1. Sustainability evaluation of bioplastics using ELECTRE method

Multi-criteria analysis was applied to rank and select the best type of bioplastic used for packaging production considering the social, technical and functional performances and the influence of economic and financial factors, according to specific legislation on public procurement.

Also, the aim of this work was to investigate the biodegradation potential benefits, achieved by applying the proposed solutions, harmonization with the priorities of EU legislation, cost of project implementation, and amount of waste possible to recover, energy recovered from bioplastics waste such as BMS, PLA, PHAs and PVOH.

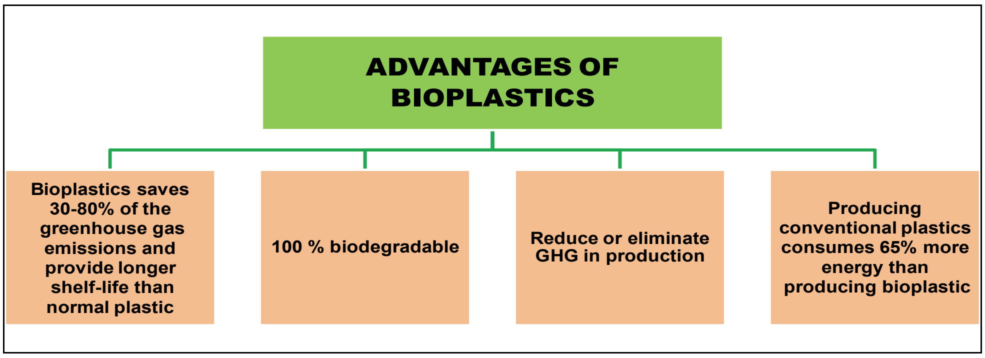


Fig. 4. Advantages of bioplastics

We applied the ELECTRE method to compare the alternatives (bioplastic categories) noted $\mathbf{V_1}$- $\mathbf{V_4}$ in terms of the criteria $\mathbf{C_1}$ - $\mathbf{C_6}$, which are described below.

To achieve the objectives of this study, we have applied the ELECTRE method considering the steps described in the section 2, as follows:

a. Establishing criteria for bioplastics evaluation

We proposed the folowing type of bioplastics denoted as $\mathbf{V_1}$ – $\mathbf{V_4}$, which are considered project alternatives, (Table 2):

$\mathbf{V_1}$ – Bioplastic Made from Starch (BMS);
$\mathbf{V_2}$ – Polylactic Acid (PLA);
$\mathbf{V_3}$ – Polyhydroxyalkanoates (PHAs);
$\mathbf{V_4}$ – Polyvinyl Alcohol (PVOH);

Criteria for assessment of variants are denoted as $\mathbf{C_1}$ – $\mathbf{C_6}$:

$\mathbf{C_1}$ – benefit achieved by applying the solution (reporting in thousands EUR);
$\mathbf{C_2}$ – harmonization with the priorities of EU legislation (will give marks);
$\mathbf{C_3}$ – the degree of degradation for bioplastics (will give marks);
$\mathbf{C_4}$ – cost of project implementation (reporting in thousands EUR);
$\mathbf{C_5}$ – amount of waste recovery (reporting in %);
$\mathbf{C_6}$ – energy recovered from waste (reporting in %).

These criteria focused on sustainable development indicators (social, economical and environmental) (Fig. 5).

b. Determination of the coefficients of importance K_{ij} for each criterion

After we established alternatives of bioplastics and evaluation criteria, we have selected the evaluation team, which is represented by a biologist, an analyst, a process engineer, and an engineer specialized in waste management.

Also, we gave scores from 6 to 10 (6 represents low participation for each criterion and 10 means active participation) to each team member according to the six criteria established. The importance coefficient K_{ij} was calculated with Eq. (1), where: $\sum n_{ij}$ is the sum of the importance coefficients according to some criteria where the notes for variant *i* are greater or equal compared to the notes for variant *j*; $\sum\sum n_{ij}$ is the sum of the importance coefficients.

$$K_{ij} = \frac{\sum n_{ij}}{\sum\sum n_{ij}} \tag{1}$$

The results obtained after the calculation of K_{ij} are presented in Table 3. Determination mark from notes of appreciation a^*ij helped us to bring in the same unit mass concentrations, which are expressed in different units.

Application of ELECTRE method is based on two groups of indicators, namely: concordance (*Cc*) and discordance (*Cd*) indicators.

c. Calculation of concordance indicators

Determination of concordance indicators that indicate in which way a^*gj version is surpassed to the variant a^*hj was performed using Eq. (2) (Herghiligiu and Lupu, 2012; Herghiligiu et al., 2013; Lupu et al., 2006, 2012), where: C_{vgvh} is the concordance indicator; K_j is importance coefficient from the *j* criterion; a^*_{gj}, a^*_{hj} represent the appreciation notes.

$$C_{VgVh} = \frac{1}{\sum_{k=1}^{n} kj} \sum_j kj \; ; \; a^*_{gj} \geq a^*_{hj} \tag{2}$$

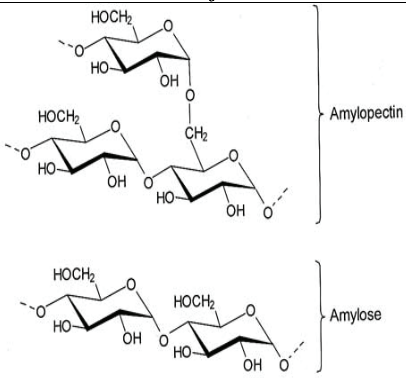
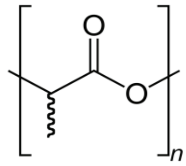
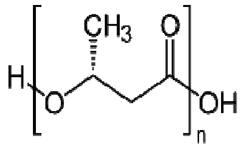
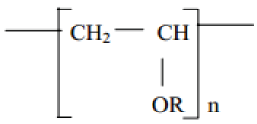
After finalizing calculations, we obtained the following indicators of concordance: 0.7, 0.5, 0.5 for BMS 0.49, 0.69, 0.5 for PLA, 0.48, 0.48, 0.48 for PHAs and 0.5, 0.5, 0.68 for PVOH. The structure of the concordance matrix is presented in Table 4.

d. Calculation of discordance indicators

Eq. (3) was used for the calculation of discordance indicators (Herghiligiu and Lupu, 2012; Herghiligiu et al., 2013; Lupu et al., 2006, 2012), where: *d=ecart* represents the maximum distance a^*_{gj} between the appreciation notes awarded = 1.

$$Dvgvh = \begin{cases} a^*_{gj} > a^*_{hj} \\ \frac{1}{d} \max \left| a^*_{gj} - a^*_{hj} \right| ; a^*_{gj} \leq a^*_{hj} \end{cases} \tag{3}$$

Table 2. Characteristics of bioplastic types used in this study

Type of bioplastic	*Characteristics*	*Chemical formula*
Bioplastic made from starch (BMS)	Bioplastics obtained from starch (extracted from corn, potato, etc.) are currently the most widely used, accounting for about 50% of the bioplastics market. Due to their thermal characteristics, these bioplastics can help bring additives (Butterworth et al., 2013). Starch-based bioplastics can be mixed with the polyester to produce mixtures such as polycaprolactone. These mixtures are used in industrial applications are also compostable (Mahasukhonthachat et al., 2010). Bioplastic made from starch can be used for (Hasjim and Jane, 2009): bags; Deli containers; cups; Tarpaulin for agricultural uses; lids.	
Polylactic acid (PLA)	Polylactic acid is made from dextrose (sugar) extracted from renewable materials. This is the most popular bioplastic material or biopolymer and only product currently in a world-class factory (Undri et al., 2014). This biopolymer is suitable for fiber extrusion, and can easily be replaced by polypropylene (PP). PLA can be easily degraded (respecting certain conditions of temperature and humidity). The products of the PLA can be composted in industrial installations where the temperature (700 ^oC) and humidity (70% RH) can be controlled (Garlotta, 2001). PLA can be used for (Bordes et al., 2009; Petersson et al., 2007): fiber extrusion processes: tea bags, clothing, films; injection processes: enclosures for jewelry; thermoforming processes: pots, pans, cups, coffee pills; blowing processes: water bottles (payment) for cosmetic purposes.	
Polyhydroxyalkanoates (PHAs)	PHAs are biological polyesters are produced by microorganisms, and may also be biodegradable by a large number of different microorganisms. The polymers are produced through a fermentation process, which involves feeding sugar and microorganisms (Cyras et al., 2007). PHAs can be used for (Reddy et al., 2003): plastic bags and various utensils; packaging (including films); containers; paper coatings; medical garments; compostable bags, lids; tubs.	
Polyvinyl alcohol (PVOH)	Polyvinyl alcohol is produced by conversion of biobased ethylene (from biobased ethanol) to biobased vinyl acetate, polymerization polyvinyl acetate and to biobased, biobased hydrolysis to PVOH. As the main raw material used in the manufacture of polyvinyl alcohol is vinyl acetate monomer type (Guohua et al., 2006). PVOH is a bioplastic; in the form of a granular powder whith white or cream color. Depending on the obtaining method, PHOV can be of two types, partially hydrolyzed or fully hydrolyzed. PHOV partially hydrolyzed, is used in the food industry (for obtaining packages). This type of bioplastic is used to obtain packaging with protective role of moisture absorption (Pavol et al., 2002). Areas of use the Polyvinyl alcohol (PVOH) (Guohua et al., 2006; Pavol et al., 2002): paper adhesive; textile sizing agent; packaging.	 where R = H or $COCH_3$

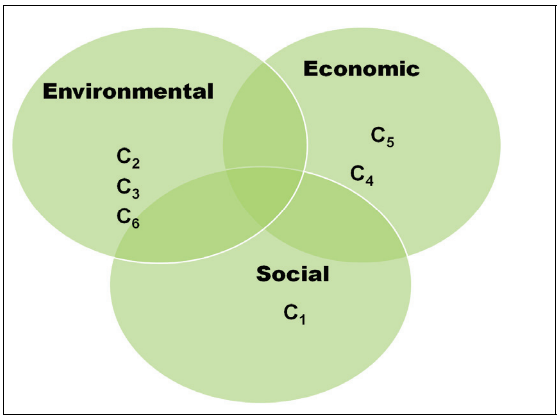


Fig. 5. Criteria taken into account for obtaining sustainable bioplastics

After the calculation of discordance indicators the following values were obtained: 0.6, 0.8, 1 for BMS indicators, 0.5, 0.5, 1 for PLA; 0.6, 0.9, 0.4 for PHAs and 0.8, 1, 0.5 for PVOH. In Table 5 is presented the discordance matrix structure.

e. Determination of the most suitable alternative

Establishing of the suitable alternative was performed by using the difference method and the concordance and discordance matrices.

The difference between the two matrices represents the best option. We have evaluated all variants, the final selection, favoring the variant V_3 (PHAs) followed by V_1 (BMA), V_4 (PVOH) and V_2 (PLA)(Fig. 6).

5.2. Analysis of solution from the point of view of ELECTRE method

ELECTRE method is specially adapted to environmental and sustainability problems, because this it searches the best compromise between all decision criteria and not the solution (if only some criteria are optimized).

The type of decision problem approach resulted by applying ELECTRE method leads to results oriented for decision making. Following the development of this problem, with entering values instead of the criteria, the results of this case are more precise and easier to interpret.

The final classification of multi-criteria analysis process by applying ELECTRE method was conducted based on selected criteria which addressed both objectives: current trends of waste recovery (recovery material and energy resources) and environmental global indicators (amount of emissions generated).

The results depend on the input data, criteria such as the: benefit achieved through applying the solution, harmonization variant, with the priorities of legislation, possibility of bioplastics degradation, the quantity of emissions for greenhouse gases responsible for global warming emitted by stations / installations in the environment, cost of project implementation, quantity of waste recovery and the quantity of material resources and energy recovered. Four criteria were represented as beneficial attributes and two criteria were represented as cost attributes.

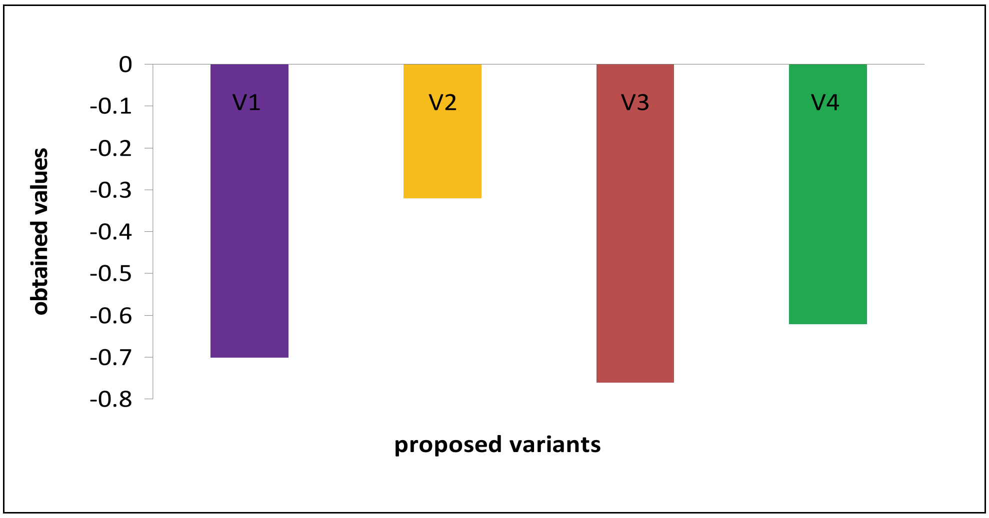


Fig. 6. Results obtained after applying the difference method

Table 3. Determination of appreciation notes matrix, function, utility

	C_1	C_2	C_3	C_4	C_5	C_6
V_1	0	0	1	1	0.8	1
V_2	0.3	0.5	0	0.5	0.8	1
V_3	1	0.5	0.5	0.1	0.5	0.3
V_4	0.5	0.8	0.5	0.50	0	0.2
K_{ij}	0.15	0.16	0.16	0.17	0.18	0.18

Table 4. Concordance matrix

V \ *V*	V_1	V_2	V_3	V_4
V1		0.7	0.5	0.5
V2	0.49		0.69	0.5
V3	0.48	0.48		0.48
V4	0.5	0.5	0.68	

Table 5. Discordance matrix

V \ *V*	V_1	V_2	V_3	V_4
V1		0.6	0.8	1
V2	0.5		0.5	1
V3	0.6	0.9		0.4
V4	0.8	1	0.5	

Fig. 6 illustrates the results obtained by applying ELECTRE method. The results are favorable for the alternative addressing the polyhydroxyalkanoate, followed by alternative that involves obtaining bioplastic made from starch. The lowest results are for bioplastics as polylactic acid and polyvinyl alcohol.

Results are mainly confirmed by high rates of material resources or energy recovery and reduction of the amount of emissions generated by PHAs. The conclusion is supported by the fact that polyhydroxyalkanoate are biological polyesters which are produced by microorganisms, and may also be biodegradable by a great number of different microorganisms.

6. Conclusions

In this study a multicriteria evaluation method was applied for the determination of the bioplastics optimal alternative which can be used in packaging production. The analysis was performed using the ELECTRE method, which quantifies the relative importance of the criteria considered. The choice of thresholds is determined by the specificity of each criterion in order to reflect the decision maker preference.

The alternatives proposed (BMS, PLA, PHAs, PVOH) are evaluated based on six criteria considering three sustainable development indicators: social, economical and environmental. The *environmental criteria* aspects focused on harmonization with the priorities of EU legislation, the degree of bioplastics degradation and energy recovered from waste. *Economic criteria*, focused on benefits achieved by applying the solution and cost of project implementation, while social criteria includes benefits of project implementation.

The alternatives can be ranked after the evaluation from the most favorable option to the less favorable as following: PHAs>BMS>PVOH>PLA. PHAs are the most suitable alternative in terms of production from both environmental and economical criteria. Our analysis nevertheless shows that PHAs may have some advantages, compared to the BMS, PVOH and PLA. This result is an important step for sustainable development in terms of the use of biomass, the possibility of plastic recycling, and waste energy recovery. The interest and usefulness of this variant should be analyzed further.

It can be concluded that ELECTRE is an efficient method which can respond directly to the concerns of policy makers by ranking of criteria and will remain a valuable instrument for decision making.

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