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Priorities Determination of Using Bioresources. Case Study of *Heracleum sosnowskyi*

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***Abstract* – Multicriteria analysis methodology used in the paper allows to evaluate the use of potential bioresources with high added value by prioritizing products from invasive species. The method is applied for the hogweed *Heracleum sosnowskyi* Manden, which occupies large areas in Latvia and poses great problems in using agricultural land. It is combated purposefully, generating significant amount of biomass waste. The results of TOPSIS multicriteria analysis used with 14 indicators, show that hogweed can be used for production of different pharmaceutical, food, soil fertilizer and chemical materials with a high added value. Pharmaceutical products have the highest potential for production of polysaccharides that can be used in food and pharmaceutical industries.**

***Keywords* – Added value; bioeconomy; hogweed; invasive species; multicriteria analysis**

1. INTRODUCTION

Globalization has integrated widely dispersed human communities into a worldwide economy. This process provides many benefits through the movement of people and goods, but also leads to the intentional and unintentional transfer of organisms among ecosystems that were previously separate [1]. The vast majority of these organisms are unable to survive in an unfamiliar environment without human intervention and eventually die off. But some species manage to adapt to their new surroundings and eventually establish themselves in the wild, where they can cause significant ecological and economic damage. These are known as invasive alien species (IAS). IAS are defined as species whose introduction and spread outside the natural ecological range pose real threat to biodiversity, the economy and human health. There are over 12 000 alien species present in Europe, of which about 15 % are invasive [2]. IAS are one of the most important drivers of biodiversity loss and there is mounting evidence that this decline in biodiversity affects the performance of ecosystems [3]. Altering ecosystems properties in turn have an effect on ecosystem services, which often result in significant harm to society, economy, and environment. It is estimated that the costs of the damage and control measure of IAS in Europe is about 20 billion euros per year [4].

For the transition from fossil-based economy to bio-based economy it is important to use underused bioresources such as seaweed, microalgae, food, agricultural or forestry wastes [5], that includes invasive species. Primary step to bioresource valorisation is exploitable compound determination, like polysaccharides, peptides, fibres, lipids, polyphenols, proteins, etc. that can be

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used with higher added value in target applications like biomaterials, chemicals, cosmetics, food, feed, pharmacy, medicine. Afterwards building cascading use or biorefinery, the residues can be used for biofuels and energy production [5]. Plant-based materials are an important source for non-animal-sourced protein, enzymes, polysaccharides (pectin or starches), essential oils, colouring or flavouring agents and fibres [5].

In Latvia, the most aggressive invasive alien species is hogweed (*Heracleum sosnowskyi* Manden) which was introduced from the Caucasus region as a potential fodder plant [6]. Since it is currently not used for feeding purposes, many people refuse from cultivation of the plant, but due to its rich sowing, hogweed have been uncontrolledly spread to a large part of Latvia's territory and has been included in the black list of invasive plants [7]. Hogweed is an invasive plant not only in Latvia, but also in several European countries and Russia [6]. With constant efforts to combat the hogweed, it continues to spread in Latvia and covers a territory of more than 10 000 ha in total [7]. Uncontrolled hogweed spreads to roadsides, ditches, neglected lands and abandoned agricultural lands. When hogweed has overtaken abandoned agricultural land, it results in a large amount of waste when eliminated [8], [9]. In order to recover the invaded land for rational use, 3–5 years of regular treatment is necessary [10]. Researches on hogweed in Latvia are mostly concentrated on elimination methods [10] and development of recommendations for municipalities for better treatment methods [11]. In total *H. sosnowskyi* occupies an area of 10800 ha in Latvia, the division between regions is the following: Vidzeme region invaded area is 4445 ha of *H. sosnowskyi*, Latgale region invaded area is 2374 ha, Riga region invaded area is 1733, Zemgale region occupies an area of 1334 ha and Kurzeme region is 916 ha of invaded area [12].

Before the hogweed was introduced in Latvia, the hogweed species spread in Russia, so more research is found in this country. Tkachenko is one of the first who started exploring the potential use of plants with added value [13]. *Heracleum* genus consists of 109 species [14]. The studies are available for various *Heracleum L.* species, but for *H. sosnowskyi* there are few [15]. The taproot extend deep enough into the ground to ensure absorption of elements from deeper layers and substratum [9]. In recent years, the chemical composition and potential use of *Heracleum sosnowskyi* Manden have been studied [6], [16]–[24]. However, there is a lack of a summary on possible products to be obtained and its generated added value. Moreover, the growing product consumption leads to new resource research and, as the bioeconomy principles are implemented, natural resources that are not yet used or fully used is highly important. Also *H. sosnowskyi* agricultural waste use as a product could give great benefits to the national economy. The aim of this study is to obtain available information from scientific literature about potential products of hogweed, to identify their added value in the context of biotechnology [25] and to prioritize products with multicriteria analysis.

2. METHODOLOGY

To achieve the aim of this study, a methodology algorithm was developed including multicriteria analysis. Multicriteria analysis was chosen because of the opportunity it presents to compare different products that are otherwise incomparable. Aim of this method is to give the opportunity to build a cascade for bioresources that is gaining higher added value from the selected resource. Methodology should be easy to adapt to different resources and different products that are already in production or at the research stage.

The main tasks set while developing the methodology was:

- To determine what products can be produced from the bioresource. Outcome of this

task is a list of various products that can be obtained from the chosen resource according to scientific literature and can be targeted for further analysis;
- What is the added value of the products? Outcome is a valuation of previously determined products and their added value based on a bioeconomy value added pyramid;
- What are the production or research development priorities in relation to the specific resource? Outcome is a comparison for product valuations to set priorities on product production based on a multicriteria analysis. It is a product score that allows to determine which product would give higher added value.

The algorithm of the methodology consists of five main steps: bioresource, products that can be obtained, added value of the products, priority of chosen products and recommendations for development.

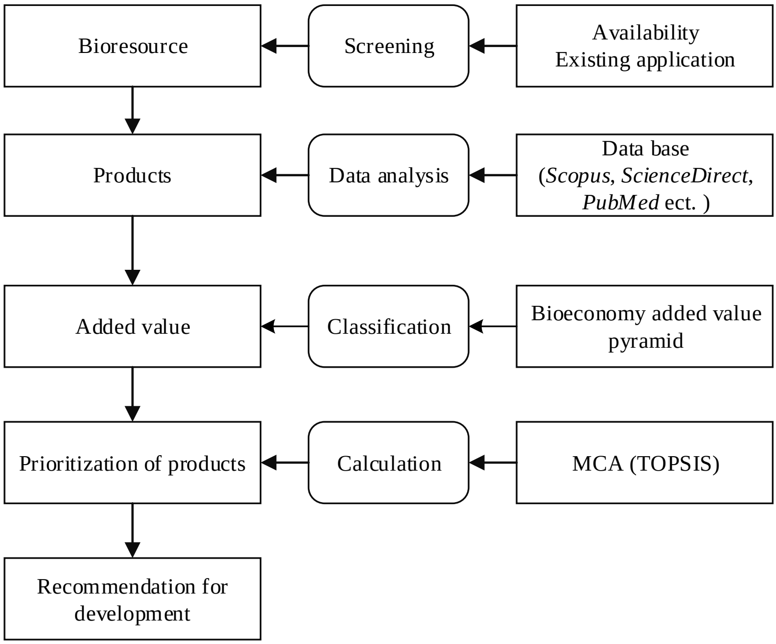

Fig. 1. The algorithm of the methodology.

Bioresource module is the first selection criteria for a bioresource and its availability of this resource and existing application in the studied region (see Fig. 1). If the bioresource has an existing application with high added value or high-volume products that cannot be replaced in the studied region, this bioresource is not taken for further analysis. If the bioresource is available, but not in an efficient amount (e.g. just in some small regions and not widespread throughout the country), the bioresource is not selected. Screening provides the bioresources, that are wide spread and available and with low added value product application or no existing application in the studied region, was selected for further analysis. It means that bioresource is a waste, in this particular study – invasive species that is wide spread in Latvia.

Second model provides data about potential products that can be obtained from selected bioresource based on peer-reviewed scientific articles. The products are classified according to the usable part of the resource, the substance to be obtained and the type of use according to scientific articles. Products are classified based on parts that are being used as a resource for the product. It is important for taking further steps and give recommendations on cascade type production. But in this study priorities are determined for primary use of the resource.

The third module is the added value module that is based on bioeconomy pyramid of the value added where they are sorted by their characteristics and end use sector. Highest added value is for pharmaceuticals and fine chemicals, that are first taken to further analysis if there is any potential for these products, next are food, then materials and last is fuel. All products selected in the second model, have been classified based on this pyramid, to see the research area that has been studied the most. Four of the higher value products are selected for further analysis to prioritize using multi-criteria analysis.

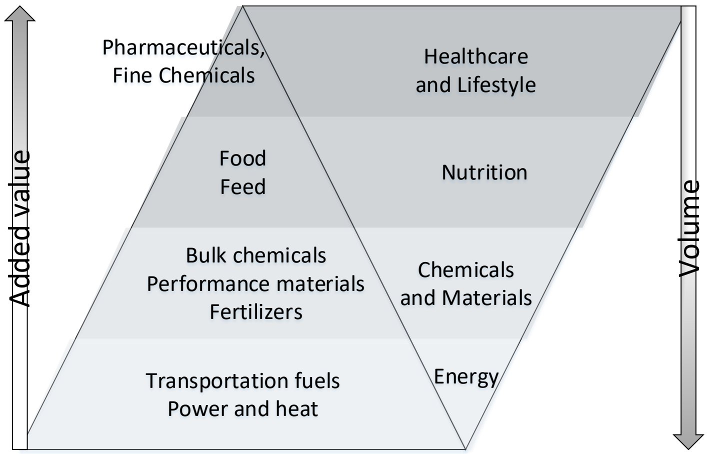

Fig. 2. The pyramid of value added in bioeconomy [26].

In order to create cascading production, it is important to identify what and with what added value can be obtained from a particular resource [25], [27]. If the product can be used with the highest possible added value, i.e. pharmacy and chemicals (see Fig. 2), then focus should be paid on further research and development, if economically viable. If none of the above products is cost-effective or cannot be used neither in pharmacy nor food, production of materials or fertilizers, only then production of energy can be considered. Therefore, after determining the added value, a multicriteria analysis is used to assess engineering, socio-economic and environmental aspects.

Last module – prioritizing of products module is based on multi-criteria decision analysis (MCDA) for decision making. There are several multi criteria decision making methods: Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT), Preference Ranking and Organization Method for Enrichment Evaluation (PROMETHEE), Elimination and Choice Translating Reality (ELECTRE), TOPSIS, Simple Multi-Attribute Rating Technique (SMART), fuzzy set theory (FTS), goal programming (GP), data employment analysis (DEA) [28].

The Analytical Hierarchy Process (AHP) uses pair-wise comparisons and has three levels: the main objective of the problem (top), multiple criteria that define alternatives (middle) and competing alternatives (bottom). The use of AHP has been restrained by the human capacity for the information process. TOPSIS mitigates the requirement of paired comparisons and capacity limitation does not dominate the process [29].

Multi-attribute Utility Theory (MAUT) is an extension of Multi-Attribute Value Theory (MAVT), it is an expected utility theory that can decide the best course of action in a given problem by assigning a utility for every possible consequence, therefore calculating the best possible utility. The advantage is that uncertainty is considered, however incredible amount of input is necessary that can lead to stronger assumptions at each level if data is not available. This method is called data intensive, it can be difficult to precisely apply and can be relatively subjective [30].

The Simple Multi Attribute Rating Technique (SMART) is one of the simplest forms of MAUT [30] and is similar to AHP, instead of hierarchy there is a value tree, where there are attributes not sub-criteria at the lowest level and values of the scores assigned are ratings. Difference between AHP and SMART is that the value tree has a tree structure and one attribute can only be connected to the higher level criterion. SMART does not have a relative method for normalizing raw scores [29]. SMART is easy to use and it allows to use any type of weight assignment technique (relative, absolute), however it is not convenient for a complicated framework [30].

The Elimination and Choice Expressing Reality (ELECTRE) method is based on making the choice of best action between given sets of actions, and can be applied to three main issues: choosing, ranking and sorting. ELECTRE application is based on two sections: construction of one or several outranking relations and exploitation procedure that is being developed on the recommendations obtained in the first section [29]. The advantage is the ability to take uncertainty and ambiguity; the disadvantage is that outcomes are hard to explain and the lowest performances under certain criteria are not displayed [30].

Preference Ranking and Organization Method for Enrichment Evaluation (PROMETHEE) is similar to the ELECTRE method, it has several iterations and an outranking method. It is easy to use, does not require the assumption that criteria are proportionate, but it does not provide a clear method for assigning weights, requires the assignment of values but does not assign a method on how to assign those values [30].

Goal Programming is a pragmatic programming method that is able to choose from infinitive number of alternatives. The major advantage is the possibility to handle large scale problems. The disadvantage is the inability to weigh coefficients [30].

Data Envelopment Analysis (DEA) is a linear programming technique to measure relative efficiencies of alternatives. It rates the efficiencies of alternatives against each other with the most effective alternative has a rating of one and all other alternatives are the fraction of one. As there are several advantages to this method, such as the possibility to handle multiple inputs and outputs, uncovering relationships other methods cannot, the significant disadvantage is that it does not deal with assumptions and all data should be precisely known [30].

Among these models, the most applied models are AHP and TOPSIS, where TOPSIS is the second most popular method [28]. By distribution of MCDA application areas by method is proven that for environmental strategy and sustainable manufacturing and engineering chosen method in 40 % cases is TOPSIS method [31]. TOPSIS is known for its computational simplicity and easy application in comparison with other MCDA methods. TOPSIS method provides several advantages such as opportunity for unlimited range of criteria and performance attributes, preferential ranking of alternatives to understand the difference and similarities between alternatives, avoidance of pairwise comparison (like it is for AHP), relatively simple calculation process without a necessity for special programs [32]. Disadvantage for TOPSIS method is that it does not consider the correlation between attributes [30].

Products with higher added value are defined through the multicriteria analysis Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and prioritized for further investigation or commercialization purposes or cascade type of production analysis. TOPSIS compares the set of alternative products by identifying weights for each indicator, normalizing the scores and calculating the distance between each product (alternative) and the ideal alternative and the negative ideal alternative. The ratio between separation from the negative ideal and the sum distance from the ideal and negative ideal alternative is calculated.

Benefits for TOPSIS is that only judgments needed are weights [31]. TOPSIS allows to prioritize the best of number of products that otherwise could not be comparable. It is based on the concept that chosen products should be as close as possible to the ideal solution [33]. Therefore, the results for products that are closest to one, are the priority for primary product production. Economic, technological and environmental criteria is used for this analysis to determine the priority. TOPSIS method main benefits in comparison with other MCDM methods are the ease its to implement and understand and that it can be implemented without special computing programs [34].

Recommendations for development are given to clearly state the results of the analysis that can be useful for production or cascading production development from the selected bioresource. The best product is determined with value closest to one, which is closest to ideal position and with the higher priority. If the products that are with higher priority, can be combined with those that have lower priority (use different parts of the plant or use residues from primary product production), that it is advised for cascading or biorefinery production.

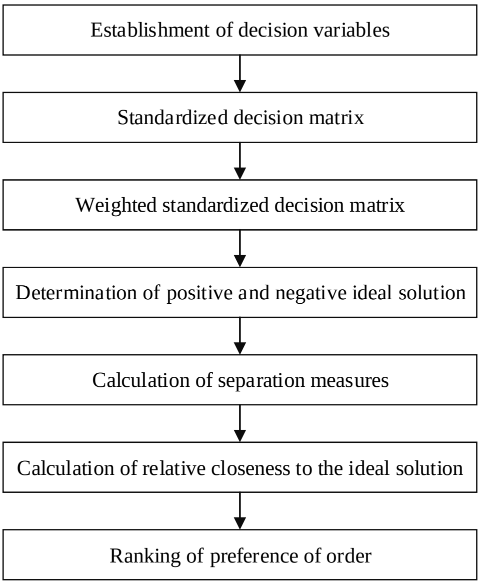

Fig. 3. The algorithm of multicriteria analysis (TOPSIS).

The TOPSIS method is used for the analysis of multicriteria (see Fig. 3) as described in previous studies where this method was used to determine bioproducts production priorities from forest resources [35]. Previous studies on forestry resources proved to be an effective way for how to mutually compare the products with TOPSIS method and to recommend them for commercialization [36], so for this resource methodology, criteria are adapted taking into account the specifics of the plant. Engineering, economic, environmental and climate criteria are selected. In total 14 indicators were used for multicriteria analysis and each indicator was weighted on the expert-based score. It is possible to use other methods for score estimation, for example decision making team judgment or field of expertise, objective weighting. Objective weighting is based on mathematical computation and is used in cases when it is not possible to obtain subjective weights [37]. In this case expert-based weighting is used in order to achieve results that are closer to the real life situation.

The classical TOPSIS method for single decision making can be expressed as follows:

Construction of the decision matrix $X = (x_{ij})$ and weight determination (weight factor) $W = [w_1, w_2, \ldots, w_n]$, where $x_{ij} \in R$, $w_j \in R$ and $w_1 + w_2 + \ldots + w_n = 1$.

Normalization of values were carried out by a standardized form [29]:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \ , \tag{1}$$

where

n_{ij} normalized value;

i 1, …, m;

j 1, …, n.

Weighted normalized decision matrix is calculated as:

$$v_{ij} = w_j n_{ij} \, , \tag{2}$$

where

w_j the weight of the j-th criterion, $\sum_{j=1}^{n} w_j = 1$.

Separation measures calculate distance from the positive ideal and negative ideal solution [29]:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} \ , \tag{3}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \ . \tag{4}$$

Final step is to calculate relative closeness to the positive ideal solution [29]:

$$R_i = \frac{d_i^-}{d_i^- + d_i^+} \;, \tag{5}$$

where $0 \leq R_i \leq 1$.

Expert selection was based on their expertise in bioeconomy and value-added products, interviews were held and discussion about score to each indicator to select the most appropriate and most perspective bioproducts.

3. Results

In total 15 publications (starting from 2006) were compiled for *H. sosnowskyi*, in which the potential products are defined [6], [13], [15]–[24], [38], [39]. Nine of them are publications from 2015 to 2017 from which it can be concluded that interest and research on the valuable composition of hogweed is increasing. A large proportion is devoted to research on the production of food and agricultural feed from the hogweed [6], [9], [13], [17]–[19], [23], [39], emphasizing the acquisition of polysaccharides from the hogweed. The plant has great potential in the pharmaceutical industry [13], [16]–[18], [21], [23]. One research is available on the material from the hogweed [13], but there is a potential for use in agriculture as a fertilizer [38] and antifungal agent [13], [20], [22], [38].

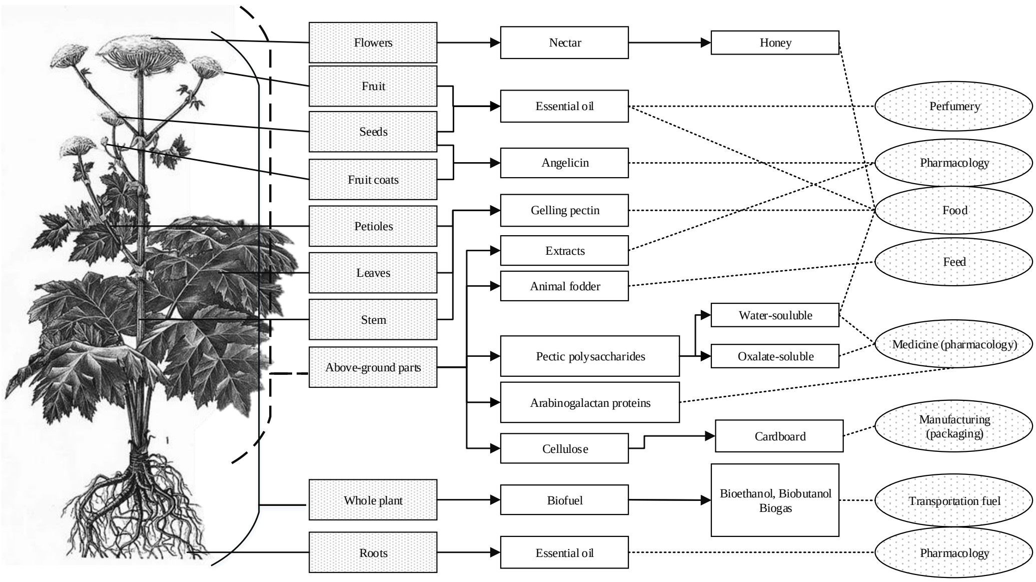

Fig. 4. Product classification according to the parts of the resource to be used.

All parts of *H. sosnowskyi* plant can be used to produce products. As shown in Fig. 4, it is possible to obtain honey from the flowers which can be used in the food industry [39]. It is possible to extract essential oils from its fruits and seeds, which can be used in perfumery, in food and in pharmacy [20], [22]. From seeds and fruit shells it is possible to obtain furanocoumarin – an organic chemical compound derived from plants – angelicin, which can be used in pharmacy [21]. Pectin from the trunk, leaves and stalks can be used as a thickener in food, for example, as gelatin [19]. A variety of extracts can be obtained from the surface of the plant which in general, *Heracleum* L. genus contains with characteristics of antimicrobial, antipyretic, immune stimulant, analgesic and vasodilator properties and can be used for enzymes and psoriasis [18]. Silage may be prepared for fodder from the green mass, or be grazed fresh for cattle or sheep [7]. Studies are available on the production of polysaccharides from hogweed pectins [18], [23] and arbaniogalactan proteins [17], that can be used in the food and pharmaceutical industries. Hogweed can be used for the production of cellulose, further for production of cardboard [13]. Biofuels can also be obtained from the whole plant. There are studies available on the production of bioethanol and biobutanol [40], [41], and biogas production [42]. Essential oils used in pharmacy can be obtained from the roots and fruits [16].

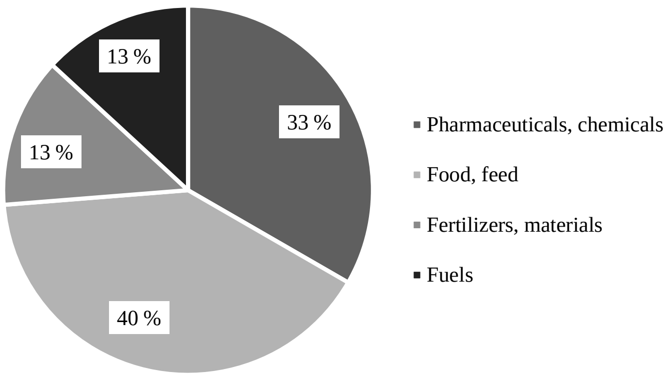

Fig. 5. Classification of the studied products by added value.

So far, the highest emphasis in researches is the second phase of the bioeconomy pyramid – food and feed 40 % with high added value, the next is the use in pharmaceuticals with the highest added value (33 %), and equal parts divide fertilizers and materials with transport fuels (the lowest added value) 13 %, see Fig. 5. Subsequently, four products – angelicin (pharmaceuticals), polysaccharides (food, pharmaceuticals), essential oil (food, pharmaceuticals, perfumery), cardboard (materials) were raised for multicriteria analysis as they are in this case, products with high added value according to bioeconomy added value pyramid. Theoretically, more products could be obtained from lignocellulosic residues, but in this case only the studied products from hogweed were analysed. In the future there could be more promising products with higher added value.

After discussion and interview of bioeconomy experts with high expertise in the field of environmental science, similar to previous studies on forest products [35], the weights are given to each indicator that has been used in this evaluation.

TABLE 1. INDICATORS AND WEIGHT FOR EACH INDICATOR DETERMINED BY EXPERTS

Indicators	Weight
Production process readiness level	0.07
Resource consumption amount	0.08
Product market	0.28
Complexity of technological process	0.05
Specific water consumption	0.02
Specific electricity consumption	0.08
Specific thermal energy consumption	0.07
Waste and residues from production	0.04
Specific by-product amount	0.03
Product selling price	0.03
Product effects on environment	0.03
Product effects on human health	0.04
Product compliance to eco-design principles	0.05
Start-up costs	0.14
Total	1

As stated by the experts, the most important indicators are economic indicators (such as product market, product selling price and start-up costs). Engineering indicators (like production readiness level, resource consumption amount and complexity of technology) and environmental and climate indicators (specific water, electricity, thermal energy consumption, waste and residues from production, by-product amount and effects on human health and environment) take equal parts; the weight for each indicator is shown in Table 1.

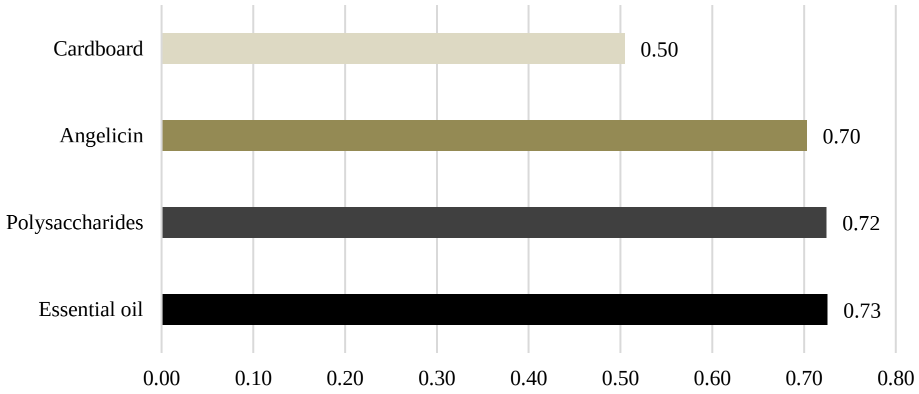

Fig. 6. Multicriteria analysis results for four selected products.

According to the results of the multicriteria analysis (see Fig. 6), it appears that the greatest potential is for essential oil production, then polysaccharides that can be used in food and pharmacy and have high added value. Close results are for angelicin, which, like polysaccharides, can be used in food and pharmacy and have high added value. All of these three products show very close results and can be advised as potential product production. The selected product for the analysis – cardboard was with a lower added value but with the possibility to use large quantities of green mass. The results of the cardboard analysis show inferior results compared with the selected products and is not recommended for further development as the primary product. However, materials and biofuels can be produced from the green mass that is left over from essential oil, polysaccharides or angelicin production. But such biorefinery from hogweed is not yet studied. Therefore, theoretically cardboard or other products from cellulose can be used as secondary product production after essential oil extraction. Specifics with the hogweed is that its sap is toxic and in combination with skin and ultraviolet radiation can cause high degree burns [43]. Every product that contains green biomass hogweed sap, should be tested very carefully.

To build a cascade, there would be a need to determine values for all the products and select the value frame to primary, secondary etc. products. In this study the priority was to select only primary, values from 0.7–1.0 are suitable for primary product production, all that is below 0.7 can be used as secondary or tertiary product production. It is also possible to use it as part of biorefinery concept.

3.1. Angelicin

Angelicin is furanocoumarin isolated from *H. sosnowskyi* fruits, as they are mainly localized in fruit coats, by cold stratification treatment (90 days, 2–3 °C). The content of angelicin ranges from 11.8 to 29 mg/g in the fruit coats depending on the plant collection location. Litter from seeds can produce around 60 kg/ha of angelicin [21]. The price for angelicin is about 128 EUR/10 mg [44]. Angelicin has antiviral activity and application for angelicin is mostly for psoriasis and cancer treatment. There are researches proving that angelicin can be used against gammaherpesvirus [45]. However, more research has to be done to ensure the best technology to obtain this compound and economic and environmental evaluation before production.

3.2. Polysaccharides

Research about isolating polysaccharides from *H. Sosnowskyi* above-ground parts was conducted by using the water extraction method. After homogenizing fresh plant material, it was extracted with 90 % ethanol (at 55 °C, twice for 2 h). The material was then air dried and treated with distilled water at 70 °C for 2 h. Fivefold extraction applied. Extract from each step was collected separately, centrifuged and concentrated [23]. Using a water extraction method, obtained results were five polysaccharide fractions, that contained 23–58 % of D-glucuorin acid residues and 6.6–9.1 of protein [23]. Price for D-glucuorin acid is 25 EUR/10 mg and for protein is very variable [46]. Further studies are needed to determine protein-pectin bonds [18].

3.3. Essential Oil

Essential oil from *H. sosnowskyi* seeds consists of six major compound groups: coumarins, its derivatives of which are responsible of photodynamic effect, furanocoumarins, hydrocarbons, alcohols, esters, that are also responsible for active features and aldehydes [22]. Coumarins are of high value secondary metabolites with wide range of pharmacological properties [47]. Essential oil volatile aroma compounds from *H. sosnowskyi* fruits were obtained using hydro distillation. Material with water were heated for 2 h at 100 °C, vapors were condensed by cold refrigerant for 120 min. Then transferred to 2.5 mL vials kept at –15 °C. For extraction of furanocoumarins fruits were air dried, crushed, extracted by hexane in room temperature for 24 hours, filtered. Solvent were removed by vacuum evaporator with water bath temperature of 40 °C. Residues were freeze-dried for 24 hours [24]. Essential oil yield is from 3.5–4.5 % from dry mass of the plant material. Main compounds from analysis were aliphatic esters (83–91 %), alcohols (4–4.6 %) and terpenes (2–3 %). From Aliphatic esters main compound in *H. sosnowskyi* essential oil were octyl acetate (43 %). The extracts of Heracleum species show moderate effects in comparison with antibiotics. Overall essential oil from Heracleum species show antibacterial, antifungal, insecticidal, cytotoxic, inflammatory, analgesic, antioxidant and antiviral effects [24].

4. Conclusions

Multicriteria analysis provides the ability to search for invasive species use to address the acute problems of agricultural land use. From invasive plants, it is possible to produce a variety of products significant for the national economy. Use of invasive species in products would create both economic and environmental benefits. The application of multicriteria methodology allows to find priorities of use of *Heracleum sosnowskyi* as bioresource for production of bioproducts with high added value. Based on the results of the multicriteria analysis, the best potential has three pharmaceutical products: polysaccharides, angelicin and essential oil.

However, there are still a lot of problems to start the use of *Heracleum sosnowskyi* as a bioresource. For example, lack of harvesting methods: how to collect effectively and safely the green mass of hogweed for manufacturing purposes. And how to ensure, that the use of this species does not contribute to further spread, but helps eliminating species. Further research should concentrate on such products that can be obtained from hogweed, that can be obtained from other bioresources, so when hogweed is eliminated, there is a possibility to continue production from other resources without great adjustments.

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