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Evaluation of reed biomass use for manufacturing products, taking into account environmental protection requirements

I. Muizniece*, V. Kazulis, L. Zihare, L. Lupkina, K. Ivanovs and D. Blumberga

Riga Technical University, Institute of Energy Systems and Environment, Azenes iela 12/1, LV-1048 Riga, Latvia
*Correspondence: indra.muizniece@rtu.lv

Abstract. In many countries reed is considered as invasive or unnecessary plant, because it is spreading rapidly, causing decrease in biodiversity and creating unacceptable living conditions for many bird species in their natural habitats. Due to environmental considerations it is necessary to cut reed, to decrease their over exceeding growth. Reed burning or leaving for decomposition on fields, that has been practiced until now, creates additional carbon dioxide air pollution. Therefore, the question on what to do with cut reed has become vital from environmental protection perspective. In addition, this question applies to bioeconomy principles in compliance with their use in national economy, which makes it clear, that solutions for the use of reed biomass for production have to be found. But any production process can leave a negative effect on surrounding environment. Further to product production, economic motivation, possible market and availability of resources are primarily essential to see whether it is worth to produce the product at all. Therefore, reed biomass use possibilities in production have to be analysed as a complex question, taking into account environmental and climate, economic and technological aspects. In this study, solutions to perspective reed biomass use are evaluated, considering environmental protection requirements. For this task, multi-criteria analysis method TOPSIS is used, which includes 11 environmental and climate, economic and technological criteria. Evaluation includes both – already existing and new products that are divided in 3 sectors: power industry, construction and other products. Results of the research clearly state, which of reed biomass made products are perspective, taking into account not only traditional economic and technological aspects, but also environmental and climate aspects.

Key words: reed, multi-criteria analysis, TOPSIS, bioeconomy.

INTRODUCTION

Reed *(Phragmites)* is a perennial grasses herb that forms a dense and broad crops. Reed is found in wetlands, in standing water, in coastal areas and even as floating islands in the water. Reed is very adaptable to changes in the environment and can grow in many ecosystems and plant communities, including wetlands, coastal swamps, inland lakes and rivers, mountains, deserts and cities (Meyerson et al., 2016). In ecological succession water bodies and wetlands overgrow with reed and, when reed stands are gradually aging, they produce sufficient fertilizer and waste, draining the area with time and creating the possibility of developing bushes and trees in this environment. Reed is considered as one of the most invasive plant species in the world (Uddin et al., 2017).

Over the past 150 years, reed has grown exponentially and most reed stands form a dense monoculture because reed is monodominant (Dubrovskis & Adamovics, 2012). Reed provides cover for fish and invertebrates in lakes and rivers, produces oxygen, and is a nutrient for individual fish and other animals.

Changes in the chemical composition of the soil which are caused by human intervention (e.g. agriculture, livestock farming, industrialization, nutrient deposition, etc.) can create conditions that favor the introduction of reed in this ecosystem (Uddin & Robbinson, 2018). The expansion of invasive plant species can have dramatic effects on local ecosystems (Gordon, 1998). Changes in reed volume can also be considered as an indicator of the health of water bodies. Also the number of reduced reed can be related to water quality problems – pollution and herbicides. From 1,170,000 measurement sites in 33 European surveyed countries was determined that 35% of soil and groundwater pollution was made up of heavy metals (Panagos et al., 2013). Reed absorbs not only nutrients from the water body, but also polluting elements. The reed absorbs nitrogen (N) and phosphorus (N) which are dissolved in water, as well as heavy metals, therefore reed can be used to purify water bodies from these elements which increasingly come into water bodies as a result of human activities from agricultural land fertilization, waste, scum, overflows etc. (Cicero-Fernandez et al., 2017). Reed is intensified due to agricultural fertilizers that enter into the soil. Reed best absorbs nutrients up to 3-year age, because in this period reed are growing very fast (Adler et al., 2008). Reed indirectly affects the nitrogen cycle, because on the roots of reed certain denitrifying bacteria can grow. Reed promotes the sedimentation of suspended solids by reducing the rate of flow (Zhu et al., 2015), prevents erosion by stabilizing the soil (Horpilla et al., 2013). Although reed, on the one hand, competes with other plants, they can also contribute to the diversity of the biotope by increasing the wealth of fish and invertebrate taxonomy (Thomaz et al., 2007).

Reed can compete and occupy another plant site, as they have several benefit:

- reed can reach nutrients with rhizomes where they are not available to other plants;
- reed can reach nutrients with rhizomes where they are not available to other plants;
- they can change the soil by creating favorable conditions for them (Windham & Lathrop, 1999);
- reed genetically identical stalks can be interconnected with rhizomes, thus forming a single plant and it is not known how big and the old reed clone can develop. Stems that grow under unfavorable conditions can get nutrients from the rhizomes;
- reed can easier survive at rising water levels than other plants;
- increased levels of nitrogen contribute to reed reproduction;
- the rise of the CO2 level in the atmosphere is promoted by plants such as reed with C3 photosynthesis pathway.

Up to now reed is mainly perceived as an invasive plant, whose further spread should be limited to preserve biodiversity. Rather than as a valuable, so far not fully used and undervalued bioresource which could be used to produce a variety of products, including high value added products. On the issue of reed management and utilization, its dual nature appears – on the one hand, the requirements of environmental protection, which restrict the area of reed, and, on the other, business interests, where the economic justification and long-term availability of the resource are the most important. Therefore, this issue needs to be seen as a complex system in which one process has an impact on

the other in order to find a compromise solution for the sustainable use of reed in the national economy, while respecting environmental protection requirements.

Currently, the use of reed in the national economy has the following positive aspects:

- do not have to be cultivated (no planting and fertilization required);
- grow in water bodies (places that are not suitable for the production of other crops and do not compete with the food industry);
- the use of reed in the national economy reduces the emissions of CO^2 and CH_4 in the atmosphere;
- clean up sediment of water bodies from nitrogen, phosphorus and the content of heavy metals if they are harvested.

By studying the distribution of reed, the possibility of using reed biomass in the national economy for the production of various products and its environmental impact, the dual nature of the investigated issue has been revealed:

1. it is necessary to restrict the spread of reed to prevent the overgrowth of the water bodies and to preserve the biodiversity what best to do in the summer when reed is green;
2. in order to use reed biomass as a raw material to production, entrepreneurs are primarily interested in the economic justification of this product, the long-term availability of the market and raw materials.

The first point is mainly for municipal and lake operators, while the second one is for entrepreneurs. In order to achieve a sustainable solution in the long term, it is necessary to find a compromise between these two sides, and only then will it be possible to ensure that the reed area does not uncontrolled increase and does not become an invasive plant that reduces biodiversity, while at the same time benefiting from its economic and social benefits.

Therefore, the research subject of this study is: Which products are prospective from reed to observe the environmental protection requirements?

By analyzing literature on the various products from reed biomass and from discussions with environmental protection requirements, it was concluded that in order to combine the interests of nature conservation and business, the most problematic issues are:

- **reed mowing time**

To reduce the area of reed, they need to be mowed in the summer when they are green, but for most products is required dry reed that is mowed in winter, because the transportation and drying of green reed is not economically viable. Till now there are no information about experience about possibility to mow reeds during the summer and then dry mowed reeds naturally in the field, as it is done with hay. But that would be possibility how to get and transport dry reed and also reduce its areas. If reed was only mowed in winter for product production, it would not affect the further spread of these areas, only reducing the size of the decomposition of reed biomass and pollution and emissions.

- **long-term stable and predictable reed biomass availability**

In order to start commercial production of a product using reed biomass, it will be essential for any entrepreneur to have the resources available in the required amount and in the long-term. At present, there are no research reports available to report developers that would clearly demonstrate the specific volumes of reed biomass that will be

available now and in the future in a specific area. In addition, starting the production, where the raw material is biomass of reed, the necessary amount should be available near the production site. Also, the diverse management of reed does not guarantee the availability of this resource. As a limiting factor, the seasonal nature of reed production should also be mentioned.

Therefore, the authors of this study came to the conclusion that for using reed biomass in the national economy is recommended to produce products for which:

- **reed biomass would be an alternative to the use of any other biomass in whole or in part**

If reed biomass could be used to produce products for which currently is used another biomass or replace part of another biomass, then the availability of resources would not be so significant. In this case, the use of reeds would depend solely on their relevance to the particular product and on the economic justification for their purchase and use, which might be even more advantageous in some cases if it is compared to other types of biomass. As well as the seasonal nature of reed extraction would no longer be decisive for them to not to be used when it is economically viable.

- **the moisture content of reed biomass is not significant**

In this case, there is a greater chance of getting raw material from the reed areas that are mown both in summer and winter. There will only be a difference between the cost of transportation of green and dry reed.

In addition, the principles of bioeconomy must also take into account in the economic development, which include the rational and efficient use of science-based local bioresources (European Commission, 2012; Blumberga et al., 2016). The use of reed for the production of products is absolutely in line with the principles of biotechonomy, because it has so far been incomplete used and undervalued resource, which was mostly considered to be cumbersome and associated with the extra costs of managing it. Although in this study is examined the possibility of using reed biomass for the production of various products, including products with low added value (direct energy combustion), it is clear that biomass of reed can also be used to produce products with higher added value (e.g., an extract that can be used in pharmaceutical industry and cosmetics).

The above-mentioned restrictive factors and many others have to be taken into account in order to determine the prospective use of reed biomass for the production of products in order to promote not only development of national economy and the use of a bioresource that is so far not fully exploited in accordance with the principles of bioeconomy but also to comply with environmental protection requirements.

Therefore, the aim of the study is to carry out a feasibility study on the use of reed in the national economy, observing environmental protection requirements. A multicriteria analysis method was used to achieve the goal, which allows for the consideration of different, mutually incomparable factors, also taking into account the importance of each of them in this case.

MATERIALS AND METHODS

In this study, the multi-criteria analysis (MCA) – TOPSIS (*Technique for Order Preference by Similarity to Ideal Solution*) method – was used (Jahan et al., 2016). It is a type of analysis that takes into account the influence of several factors. An analysis of

MCA TOPSIS provides an assessment of the situation as close as possible to the real situation. With this method it is possible to compare several alternatives and identify the best of the considered options, taking into account the various influencing criteria. In this study, alternatives are various products from reed biomass, which are not mutually compatible without an analytical approach. Multi-criteria analysis in the TOPSIS method evaluates the alternatives in relation to the ideal possible solution. The alternative which is closest to the ideal variant is considered as the best. The TOPSIS method is based on five calculation steps. The first step is to gather information about alternatives and selected criteria. In the second step of the calculation, these data are normalized. The next step is to normalize the data with the weight values and calculate the distance from the maximum and minimum values (distance from the ideal variant) (Lu et al., 2007; Doumpos & Grigoroudis, 2013; Ishizaka & Nemery, 2013).

To use this method (Fig. 1), information and data from scientific literature and other reliable sources of information (project reports, information which is provided by related industries, project data, etc.) were used to compare products from reed biomass. In the case of lack of data, an environmental engineering assessment, which is based on information on similar products, was taken into account.

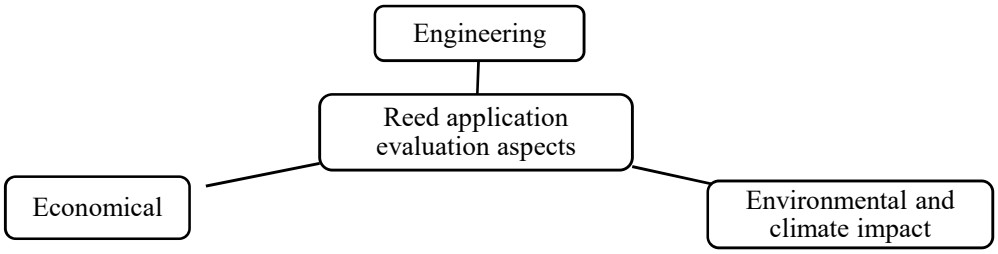

Figure 1. Grouping of evaluation aspects of reed application.

The used method – MCA TOPSIS – has proved itself in a similar study which was carried out by the Institute of Energy Systems and Environment of RTU 'Forest biomass – new products and technologies' in 2016 where was analyzed the potential for commercialization in Latvia of various innovative products that can be made from low-value forest biomass (RTU, 2017).

In this study, in order to determine the most promising products from reeds in the TOPSIS method in accordance with the requirements of environmental protection, the main factors, which are affecting the research issue, were defined as 11 indicators (Table 1).

To determine the significance or weight of each of the raised factors, the assessment of nature conservation experts was used. Using this method to evaluate the product, the subjectivity of the evaluators is reduced because it is based on reasonable numbers or expert judgment.

Table 1. Indicators which are included in the multi-criteria analysis

Indicators of engineering index	Indicators of the climate and environmental impacts	Economic Indicators
• The stage of manufacture of the product; • used amount of reed resources (%) in the final product; • the complexity of the technological process; • the possibility to replace other biomass with reed biomass which so far is used to produce the particular product	• The amount of CO_2 emissions which is arisen in the production process of product; • the consumption of resources (energy, water, chemicals) in the production process of the product; • the impact of raw material extraction and production processes on the environment (air, water, soil, living organisms); • the impact of the product on human health	• product outlet market; the necessary investments for launching the product; • product added value

RESULTS AND DISCUSSION

Within the framework of this study, using the TOPSIS multi-criteria analysis, 11 products were analyzed in order to identify the most promising products from reed, observing environmental protection requirements: thermal insulation panel of reed, sound insulation panel of reed, roofing of reed, fuel from reed for direct combustion, reed composite material (with clay), reed composite material (binder of fossil origin), biogas, extract, bioethanol, activated carbon, paper and cardboard. First of all, the selected products were evaluated in terms of sectors: construction, energy and other products that are not relevant to the two sectors which are mentioned above.

The weight which is given by experts in the field of nature protection to the included indicators in the multi-criteria analysis is summarized in Table 2. The weight of all indicators should be 100. As it can be seen, according to experts, the most significant indicator is the impact of the raw material extraction and production process on the environment (air, water, soil, living organisms) and the consumption of resources (energy, water, chemicals) in the production process of the product.

Table 2. Results of determining the weight of multi-criteria analysis indicators

Criterion	Weight
The stage of manufacture of the product	11
Used amount of reed resources (%) in the final product	6
Outlet market of product	11
The complexity of the technological process	8
The amount of CO_2 emissions which is arisen in the production process of product	5
The consumption of resources (energy, water, chemicals) in the production process of the product	12
The impact of raw material extraction and production processes on the environment (air, water, soil, living organisms)	17
The impact of the product on human health	9

The possibility to replace other biomass with reed biomass which so far is used to produce the particular product	7
The necessary investments for launching the product	8
Product added value	6

The results of the multi-criteria analysis are summarized in Table 3.

For the construction industry, five products were analyzed, from which sound or thermal insulation panels of reed were equally well and promising, and the most ancient and most commonly used type of reed – the product – roofing of reed. The production of reed composite material with binder of fossil origin is definitely not supported because the production of this product does not match the requirements of environmental protection.

Table 3. Results of the evaluation of the product from reed using a multi-criteria analysis

Product	Result of Multi-Criteria Analysis	Place
Thermal insulation panel of reed	0.826	1
Sound insulation panel of reed	0.826	2
Roofing of reed	0.789	3
Direct combustion	0.685	4
Reed composite material (with clay)	0.628	5
Biogas	0.578	6
Extract	0.559	7
Bioethanol	0.538	8
Reed composite material (binder of fossil origin)	0.469	9
Activated carbon	0.393	10
Paper and cardboard	0.343	11

For the energy sector, three products were analyzed, of which the best result was fuel from reed for direct combustion. This is mainly due to the fact that the launch of this product requires relatively less investment because the production process is simpler.

In the 'other products' category were included only three products. Of the analyzed, the greatest potential has extract from reed. In this case, for reed extract production, extraction in water technology without any chemical adding is used. So it is environment friendly production process. It should be noted that this product has the highest added value of all analyzed, since it can be used in pharmaceutical and cosmetic production, and its production corresponds to the principles of bioeconomy.

By comparing all of the eleven analyzed products from reed, the most promising products, in compliance with environmental protection requirements, are reed panels for thermal insulation and sound insulation and roofs from reed (Table 3). The first three products with the highest ratings in the multi-criteria analysis are products from the construction industry. These are not products with the highest added value, but in any case, from the environmental and climate point of view, are better than products for energy sector, as they can replace the products which are made from fossil fuels and temporarily store carbon so that it does not enter the environment and does not contribute to climate change.

The results which are obtained in this study are considered as a feasibility study in order to have a clear direction for future research. In order to more fully assess the compliance of the most promising products with the requirements of environmental

protection, it would be necessary to make and compare their life cycle analysis to determine their long-term impact on climate and environment. From a business perspective, for the most promising products is also required detailed economic and market analysis.

The results show that, in view of environmental protection requirements, the most promising products are those whose production is required dry, winter-mown reed. Which, in turn, does not coincide with the interests of managers of reed areas who want to reduce these areas and therefore mowing is done in the summer when the reeds are green. In order to find a solution to this controversial situation, planed and well-considered management of reed area is needed, which would include those areas where it is necessary to eliminate reed stands, mow in summer, and the rest in winter, in order to ensure availability of the resource in the long term.

CONCLUSIONS

Reed is a widespread invasive plant, the management and control of reed is complex and resource-intensive. From an environmental point of view, reed areas should be reduced. But from the point of view of the bioeconomy and sustainable use of resources, reed is little used and undervalued bioresource that could be used to produce products and get economic benefits. There is a number of inconsistencies between the two sides in terms of availability and quality of resources, which is why it is best to use reed as an alternative to other bioresources for the production of products.

A multi-criteria analysis has been conducted to determine which products can be promising from reed biomass with respect to environmental protection requirements. The obtained results show that the most promising are products related to the construction industry – thermal insulation and sound insulation panels and roofing from reed. However, for the production of these products is required dry, winter-mown reed, the harvest of which would not affect the spread of reed areas. Therefore, for the management of reed areas is required planned and prudent management that would include areas where it is necessary to eliminate reed stands, mow in summer, and the rest in winter, in order to ensure the availability of reed biomass resources for long-term production of products and to prevent uncontrolled reed areas.

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