RIGA TECHNICAL UNIVERSITY

Ērika Teirumnieka

SUSTAINABILITY OF HEMP USE IN ENERGY AND OTHER ECONOMIC SECTORS

Summary of the Doctoral Thesis

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Faculty of Electrical and Environmental Engineering

Institute of Energy Systems and Environment

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITYFOR THE PROMOTION TO THE SCIENTIFICDEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science, the present Doctoral Thesis has been submitted for the defence at the open meeting of Riga Technical University Promotion Council on April 20, 2023 at 2 p. m at the Faculty of Electrical and Environmental Engineering of Riga Technical University at 12/1 Āzenes iela, Room 115.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Ērika Teirumnieka ………………… (signature)
Date March 10, 2023

The Doctoral Thesis has been written in Latvian. It consists of introduction, 4 chapters, conclusions, bibliography, appendix, 77 figures, 20 tables, 16 formulas; the total number of pages is 165. The bibliography contains 184 titles.

CONTENT

INTRODUCTION

Topicality of the subject

In the situation today when energy crisis has already commenced and global supply chains of fossil and non-renewable resources and their products have been disrupted, the consequences of climate changes are felt, ensuring that the availability of local sustainable resources in the manufacturing of products and energy required by the country is coming to the fore. It is important to finding methods for potential effective and quick revaluation of the use of resources under changing environmental, economic and geopolitical conditions. This would certainly also constitute the basis for adaptation and development of technologies, which can be done comparatively quickly at the pace of development of modern innovations. In such circumstances, biotechnology and circular economy are becoming the driving force for sustainable development. Increased use of biological products and processes creates a new economy with high renewable resource efficiency and extremely low carbon emissions. Scientific research plays a key role in the development of bioeconomy. Research has shown that the number of publications in this area has increased significantly over the last decade and international chain cooperation between scientific institutions has developed [1]. Latvia is also represented in the field of bioeconomy research by Riga Technical University cooperating in the BIOEAST network [2]. Comprehensive research in the field of bioeconomy over many years has been undertaken in the Latvia University of Life Sciences and Technologies and has been elaborated in the Latvian Bioecenomy Strategy, 2030 under the auspices of the University [3].

The main focus of this research is on industrial hemp as a sustainable and bioeconomy raw material in various sectors of the economy, its cultivation possibilities, reducing the environmental burden, and the evaluation of hemp use by means of a combination of multi-criteria decision-making and life cycle analysis methods in changing economic and geopolitical conditions. A plant that meets the requirements of the bioeconomy and has great potential in the application of products is seed or industrial hemp (*Cannabis sativa L.)* [4]–[6]. All parts of the plant – stems, seeds, flowers and leaves – can be harvested and processed, making hemp a versatile plant that can be used in many ways. This means that a single crop has the potential to produce a wide range of products. Also, the research concerns a topical issue of the increase in biomass caused by the leakage of substances used in crop fertilization in water bodies, specifically in reeds, and its beneficial use. The Doctoral Thesis deals in complex with the identification of useful hemp products under specific economic and environmental conditions, for sustainable cultivation opportunities, as well as the sustainability of the hemp ecosystem, by ensuring compliance with certain bioeconomy principles. In the Thesis, the author has used an interdisciplinary hierarchical method – at the top is the field of hemp use and at the bottom is the choice of the most suitable hemp variety for cultivation and identification of invasive plant species developing in parallel to an intensive agriculture, including an intensive cultivation of hemp (see Fig. 1).

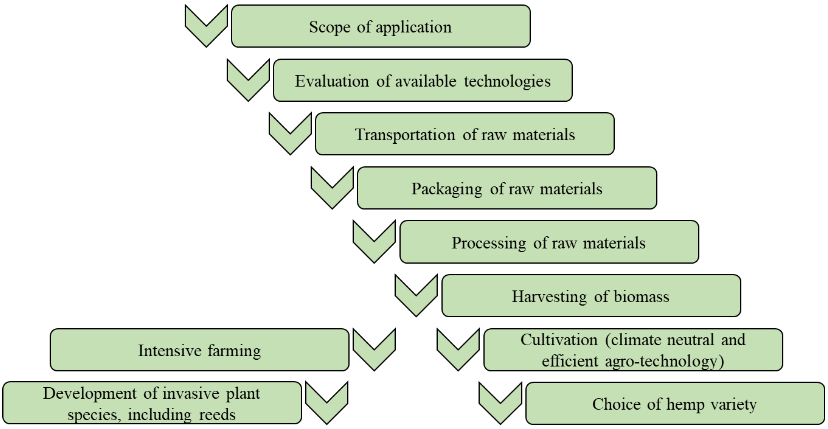


Fig. 1. Interdisciplinary hierarchical method [created by the author].

Soil is one of the most important resources of Latvia affecting biomass production. From the point of view of leaching of biogenic elements, winter rapeseed and winter wheat are the least environmentally favourable and the most polluting crops, and clover and oats are the most favourable crops, which create minor leakages [7]. A large amount of mineral fertilizers and plant protection products is used in the cultivation of rapeseed [8], which creates high N_2O emission in the air, hindering the achievement of climate goals in the agricultural sector, and depletes the soil. Consideration should also be given to diesel fuel consumed by agricultural techniques for the incorporation of supplementary fertilizers and for the spraying of plant protection products. Increasing energy use in the agricultural sector causes many environmental challenges: greenhouse gas (GHG) emissions, massive consumption of non-renewable natural resources, and environmental pollution.

According to Eurostat data, Latvia currently ranks 10th in the European Union (EU) as for areas sown under rapeseed. Rapeseed crops in the EU countries amount to 531.97 thousand ha as for 2021, while maximum areas sown under rapeseed were 6,900.62 thousand ha in 2018 (see Fig. 2) [9].

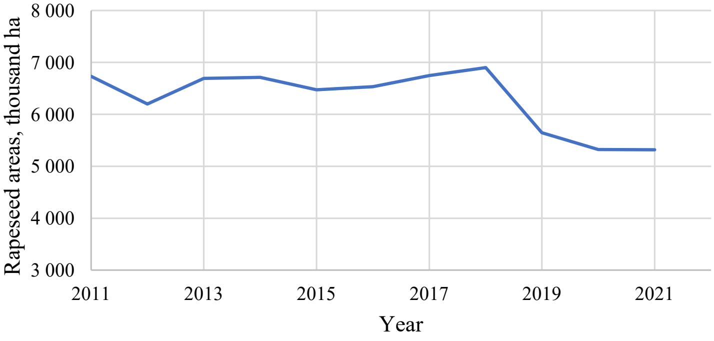


Fig. 2. Areas of rapeseed crops in the EU, thousand ha [created by the author using Eurostat data [9]].

Since 2018, areas of rapeseed crops in Latvia have not been reducing, unlike in the EU, but rather increasing and accounting for 147.4 thousand ha in 2021 (see Fig. 3). It should be noted that rapeseed areas have remained unchanged in 2020 and 2021 [9]. In view of the dynamics of rapeseed crops both in the EU Member States and in Latvia, a real possibility exists for changing Latvian crop volumes in less than 10 years. The Doctoral Thesis takes into account the possibility of replacing rapeseed crops with crops of industrial hemp (*Cannabis sativa L.),* which represents an industrial crop of high-quality seed, fiber and wood. Hemp cultivation is comparatively more environmentally friendly, since there is no need to use pesticides to grow hemp, although the use of additional fertilizers in farms of conventional type is required [10]. Cultivation of hemp prevents soil erosion, improves its structure and facilitates aeration, it is a good preceding plant for many crops because of its inhibition of perennial weeds, and the plant leaves are natural soil fertilizers.

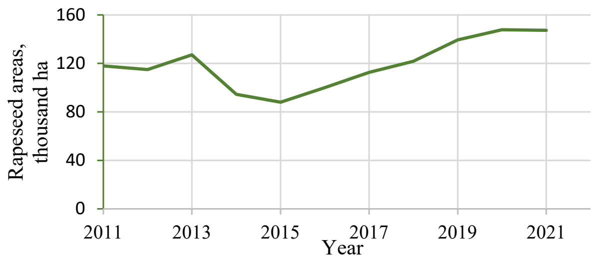


Fig. 3. Areas of rapeseed crops in Latvia, thousand ha [created by the author using Eurostat data [9]].

According to Eurostat data, areas of rapeseed crops cover up slightly more than 10 % of total crops in Latvia (see Fig. 4). It is evident that there have been periods when rapeseed areas have decreased even down to 2 % from total crop areas. This again shows the likelihood of a possibility for replacement of hemp with rapeseed within 6 to 8 years. However, in order to do so, it is important to conduct an evaluation for the purpose to identify preconditions for the increase in hemp use. The key is demand for hemp products, followed by their cultivation and processing. Evaluation of the biosystem as a whole is essential, which includes hemp as a substitute for rapeseed and the increased biomass of reeds in the natural environment due to over-fertilisation of fields.

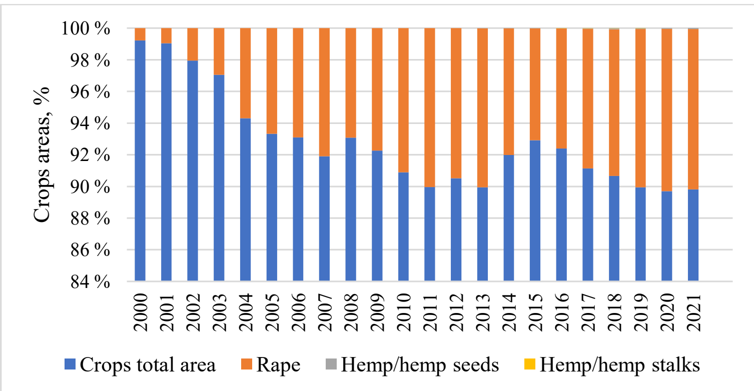
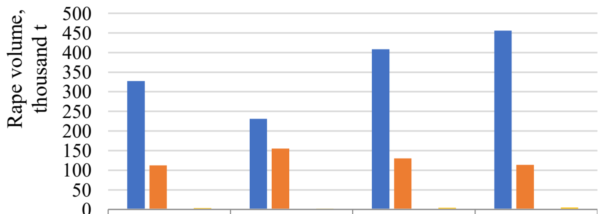


Fig. 4. Proportion of rapeseed crops in percentage from total crop areas in Latvia [created by the author using Eurostat data [9]].

According to the official data of the State Statistics of Latvia, more than 85 % of the rapeseed grown in Latvia is exported [11]. This means that rapeseed is not used effectively as a local resource for production but only creates an environmental load during cultivation as an export product. The import part is mainly composed of imports of seed material. When replacing rapeseed with hemp, analysis should be carried out in parallel regarding the possible types of using hemp and available technologies in order to create a product with the highest possible added value for export.

In Latvia rapeseed is mainly exclusively used in the production of oil and biofuels (see Fig. 5). While Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources determines production of modern biofuels, which are not obtained from food crops [12].



	2017	2018	2019	2020
1 Produced volume	327.3	231.1	408.3	455.5
6.1 Compression (for oil, biofuel production)	112.6	154.9	130.2	113.8
6.2 Seeds	0.4	0.7	0.6	0.6
6.3 Losses	3.3	2.3	4.1	4.6

Fig. 5. Use of rapeseed for oil and biofuels [11].

Meanwhile the use of hemp is extremely extensive and a large number of studies have been carried out thereon. Hemp-related patents have been issued by the U.S. Patent and Trademark Office since 1942. More than 1,500 applications have been submitted only to the U.S. Patent and Trademark Office. Inter alia, patent protection rights have been granted to approximately 500 applications. Patents are certainly registered in other countries as well, in different spheres, while the largest number of patents is registered in the pharmaceutical sector [13]. There is also a huge number of publications on hemp at different levels and in different types of publications. Hemp can serve as a raw material in production, replacing many slow-growing, difficult to obtain and scarce natural resources. Nearly every product made of wood, cotton, rapeseed or oil can also be made of hemp. Hemp can be used and processed in full without creating agricultural waste. In total, more than 25,000 products can be produced from hemp. The use and cultivation of hemp may also be hindered by the public stereotype of hemp use for production of marijuana. However, essential difference in the content of tetrahydrocannabinol (THC) psychotropic substances between hemp (*Cannabis Sativa L*) and *Cannabis indica* – hemp has <0.3 % THC, *Cannabis indica* >7 % THC – should be highlighted here [14].

The agricultural sector highly affects climate change, and it is, therefore, important to grow crops being more capable to fix CO_2 during the vegetation period. Each 1 ha of hemp crops adsorbs 4 times more CO_2 per year than 1 ha of forest [15].

Sustainability of hemp is determined by the demand for:

1) particular type of product (seeds, fiber, shives);

2) available technologies for the production of hemp-containing products;

3) efficient agrotechnology neutral for the hemp cultivation climate (see Fig. 6).

The Doctoral Thesis applies analysis of the use of hemp by means of combining the methods of multi-criteria decision-making and life-cycle analysis, so that meeting public demand for a specific product and the raw material needed for its production to be sustainable at the ecosystem level. Technological developments are taking place today at a rapid pace with rising demand and the availability of raw materials

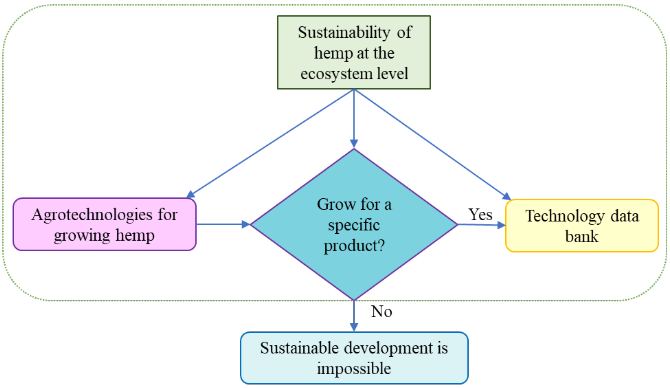


Fig. 5. Sustainability of hemp development [created by the author].

Hemp cultivation agrotechnologies have to be adapted to a specific cultivation area in order to obtain optimum results with lower investments and environmental impacts. The key is to reduce the consumption of resources for the purpose to decrease both economic costs and environmental pressures while increasing the competitiveness of hemp among other bio-resources. If the above is not met, economic sustainability cannot be achieved. The use of nitrogen mineral fertilizers in hemp cultivation is widely applied, which results in discharging emissions into air in the form of N_2O and delaying the attainment of climate targets in the agricultural sector. When analysing data of field hemp cultivation studies, solutions should be found for reducing doses of nitrogen fertilizers. At the same time, nitrogen compounds are discharged into water bodies, contributing to their overgrowing and monoculture infestations. The Doctoral Thesis, therefore, deals with this problem by making analysis of useful application of reed as the most common water plant (see Fig. 7).

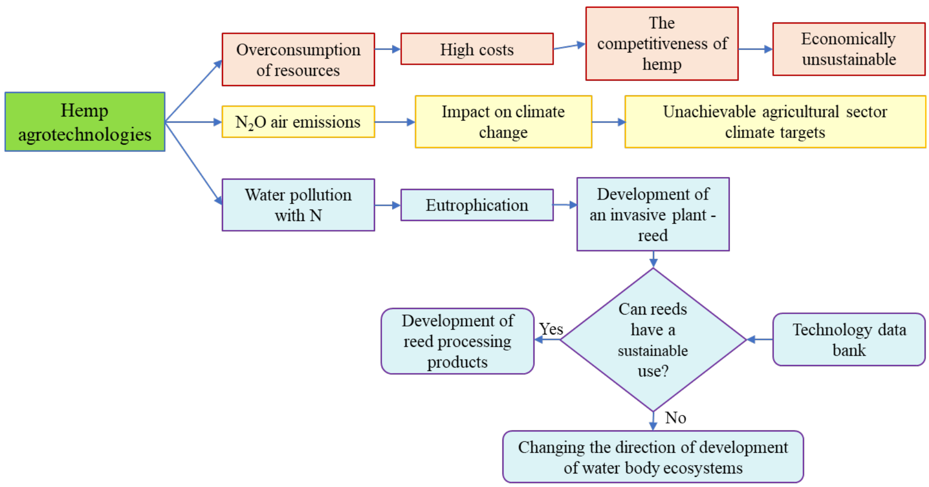


Fig. 6. Ecosystem challenges arising from the consumption of hemp nitrogen fertilizers [created by the author].

The use of each biomaterial is widely available and can successfully replace other biomaterials whose extraction and recycling lead to higher environmental pollution. Since hemp is among the fastest growing plants, the cultivation of these plants requires fewer resources than other materials. The properties of hemp fibers allow for this material to replace also raw materials derived from petroleum products.

Aim and objectives of the Thesis

The aim of the Thesis is analysis of the factors for production of hemp products having high added value to demonstrate experimentally the required conditions for sustainable cultivation of hemp (*Cannabis sativa L.*) in Latvia taking into consideration the climate change and, by combining data analysis methods, to justify sustainable use of hemp under changing environmental, economic and geopolitical conditions.

In order to achieve this aim, the following objectives were set:

1. To carry out field studies for determination of productivity of different varieties of hemp depending on the climatic factors in order to determine the most suitable varieties of hemp for the acquisition of a particular type of product for Latvian conditions (seed, fiber, shives).
2. To identify the efficiency of agrotechnological indicators: the seeding rate and the dose of nitrogen fertilizer, with a focus on obtaining a specific product for sustainable cultivation of hemp.
3. To explore the diversity of hemp products and their recycling technologies in order to identify sustainability indicators for identification of the best alternative for hemp use.
4. To evaluate usefulness of bioeconomic use of aquatic plants, reeds in particular, created by leakage of nitrogen fertilizers.
5. Experimental development of hemp products with higher added value under laboratory conditions in order to demonstrate the potential of hemp as a raw material also in the conditions of Latvia, based on specific pilot solutions.
6. By means of analysis of data and sustainability criteria, combining regression analysis, life circulation cycle and multi-criteria decision-making methods to demonstrate the usefulness of hemp and reed application under certain environmental, economic and geopolitical conditions.

Hypothesis

The cultivation of hemp (*Cannabis sativa L.*) for targeted manufacturing of hemp products with higher added value in Latvia constitutes the basis for replacing rapeseed fields until 2030.

Research structure and methods used

Research structure has been elaborated for attainment of this aim, compliance with objectives and proving hypothesis, consisting of:

1) field trials, field trial data processing;
2) laboratory experiments (sample analysis, development of composite material containing hemp concrete and hemp fiber);
3) regression analysis with getting empirical relationships;
4) analysis of multi-criteria decision-making;
5) analysis of the life cycle.

The research structure is shown in Fig. 8. Field studies have been carried out for 5 years for 4 varieties of hemp of which 2 are intended for the extraction of hemp seeds and 2 for the extraction of hemp fiber and shives. The research is focused on the effects of climate conditions, nitrogen mineral fertilizers, and sowing rate on hemp yields in order to find empirical relationship between these parameters by means of regression analysis and to identify agrotechnology indicators. Through analysis of scientific literature, as well as on the basis of personal research, indicators could be selected and alternatives singled out for the sustainable use of hemp in Latvia under changing environmental, economic and geopolitical conditions. By combining methods for multi-criteria decision-making and life-cycle analysis, the best alternatives for hemp use should be determined for the conditions in Latvia.

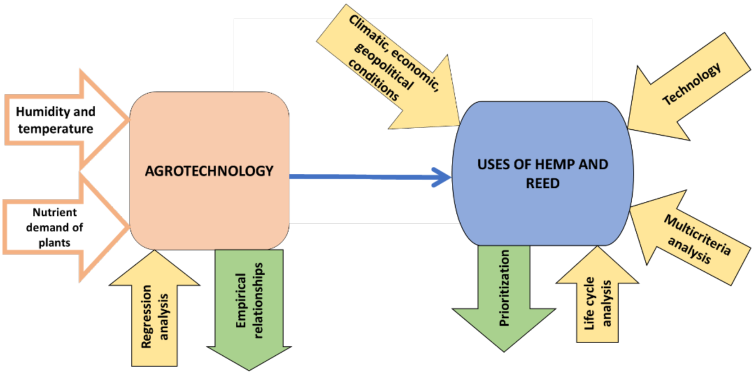


Fig. 8. Research structure [created by the author].

Scientific novelty

The Doctoral Thesis describes the sustainability of hemp at the level of ecosystem, which includes the aspects of hemp agrotechnology for obtaining a specific hemp product (seeds, fibers, shives) under changing climatic conditions, while at the same time reducing the environmental load. Scientific basis is provided for selection of the most suitable variety of hemp (*Cannabis sativa L.*) to obtain certain hemp products in the conditions in Latvia. As a result of the research, data regression analysis from field studies of hemp cultivation provides an experimental justification for reducing the doses of nitrogen additional fertilisers in order to reduce the environmental impact and to contribute to the environmental sustainability of hemp, while maintaining persistently good yields. The empirical equations found can be used for calculating the rate of additional nitrogen fertilisers, efficiency of the applied nitrogen fertilisers and hemp sowing for obtaining a certain hemp product. Multiple reduction of the doses of additional nitrogen fertilisers applied can lead to decrease of N_2O emissions from the agricultural sector, thereby contributing to the attainment of climate neutrality targets in agriculture.

Field over-fertilization resulting from the use of large amount of additional nitrogen fertilizers in the rapeseed cultivation releases nutrients into a natural environment, which contributes to rapid development of biomass in it. Scientific novelty is represented by evaluation of the use of reeds as the component of bioeconomy by means of multi-criteria decision-making method and sensitivity analysis in order to assess the stability of alternatives under changing circumstances.

An innovative methodology has been developed to combine agrotechnological and sustainability criteria and the methods of data analysis for more efficient use of hemp products in changing environmental, economic and geopolitical conditions.

Pilot solutions have been developed for hemp-containing products with high added value – hemp concrete and hemp-containing composite material. Novelty is represented by research of the production of advanced prototyping of hemp-containing bio-products, their properties and also processing techniques.

Theses put forward for defense

1. The two main aspects that determine the need to analyze the efficiency of use of nitrogen fertilizers are as follows:

• effective use of nitrogen fertilizer is economically beneficial;

• sustainable use of nitrogen fertilizer is a basic condition for Latvia's climate neutrality. Reducing the doses of nitrogen fertilizers in hemp cultivation increases the efficiency of its use, simultaneously reducing nitrogen leakage into the natural environment, and the increase of monoculture (reed in this research) biomass in water bodies, which constitutes a climate-neutral and efficient approach.

2. It is time to decide on the purpose of hemp cultivation in Latvia by defining the products with high added value. The availability of hemp processing technologies and the demand for innovative hemp-based products determine the selection of an appropriate variety and targeted cultivation of hemp for obtaining raw materials (seeds and stems).

3. There are various methods that can be used to evaluate the diversity of uses of hemp and identify the most sustainable solutions. Analysis of data and sustainability criteria, combining regression analysis, life circulation cycle and multi-criteria decision-making methods demonstrate the usefulness of hemp and reed use under certain environmental, economic and geopolitical conditions.

Practical significance of the Thesis

In the course of research, agrotechnology techniques for the cultivation of hemp (*Cannabis sativa L.*) have been determined on an experimental basis aimed at reducing the environmental load by getting good harvests with less resources. Through application of the recommendations expressed and the empirical links found in the Thesis for agrotechnology of hemp cultivation, the impact on climate from the agricultural sector is reduced due to the fact that the greenhouse gas emissions are reduced as a result of the application of less nitrogen mineral fertilizers. At the same time, the load on surface waters is reduced, as the leaching and penetration of nutrient elements into water bodies is reduced along with lower doses of nitrogen mineral fertilizers. A link has been found in the ecosystem between the growth of hemp and reed biomass in the water bodies, and this is practically important when predicting the flow of biomass resources in production.

The Thesis provides science-based information for farmers concerning the nitrogen over-consumption. The indicators examined show the need for farmers to introduce a system of indicators in order to prevent inefficient consumption of resources and to limit the transfer of chemical elements from lithosphere into hydrosphere and atmosphere and to achieve good results with less investment.

Practical importance of the pilot solutions of hemp products created in the framework of the Doctoral Thesis is presented by an opportunity to visualize the achievements of Latvian scientists and to disseminate information about the manufacturing of such innovative products more widely in Latvia. The development of pilot solutions has provided significant knowledge to carry out further research in order to reach the next levels of technology readiness for their commercialisation. The developed pilot solutions are applicable in the industry for the development of manufacturing of products having higher added value, based on the local resources**.**

Approbation of the research

The results of the Doctoral Thesis have been presented at seven international scientific conferences.

1. E. Teirumnieka, N. Patel, K. Laktuka, K. Dolge, I. Veidenbergs, D. Blumberga. Is Hemp Sustainable Energy Resource? 1st International Conference on Sustainable Chemical and Environmental Engineering, Greece, 31 August to 4 September 2022.
2. Ē. Teirumnieka, K. Pīgožnis, D. Blumberga, E. Teirumnieks, L. Lazov. Lasers Processing of Composite Materials. XXII International conference and school on quantum electronics "Laser Physics and Applications" Bulgarian Academy of Sciences, Virtual forum 19–23 September 2022.
3. A. A. Stipniece-Jekimova, E. Teirumnieka, D. Blumberga. When Reed Application is Sustainable. CONECT, Conference of Environmental and Climate Technologies, 11–13 May 2022, Latvia.
4. Ē. Teirumnieka, D. Blumberga, E. Teirumnieks, V. Stramkale. Product-oriented production of industrial hemp according to climatic conditions. Biosystem Engineering 2021, May 5, 2021, Estonia.

5. Ē. Teirumnieka, D. Blumberga, E. Teirumnieks. The application of hemp in bioeconomy. The 13th International Scientific and Practical Conference Environment. Technology. Resources. 2021, 17–18 June Latvia.
6. J. Pubule, A. Kalnbalkite, D. Blumberga, E. Teirumnieka. The use of multi-criteria analysis for an evaluation of the Environmental Engineering study programme at university. CONECT, Conference of Environmental and Climate Technologies, 15–17 May 2019, Latvia.
7. E. Teirumnieks, K. Pīgožnis, Ē. Teirumnieka, I. Bernāne, I. Jakovele. Šķiedraugu izmantošana kompozītmateriālu izgatavošanā. Latvijas Universitātes 76. Starptautiskā zinātniskā konference Zemes un vides zinātnes sesija "Vides tehnoloģijas un dabas resursu ilgtspējīga izmantošana", Rīga, 2018. gada 26. janvāris.

The research results of the Doctoral Thesis are reflected in six international scientific publications.

1. Teirumnieka, Ē., Blumberga, D., Teirumnieks, E., Stramkale, V. Product-oriented production of industrial hemp according to climatic conditions. Agronomy Research 19(4), 2026–2036, 2021. https://doi.org/10.15159/AR.21.123
2. E. Teirumnieka, N. Patel, K. Laktuka, K. Dolge, I. Veidenbergs, D. Blumberga. Sustainability Dilemma of Hemp Utilization for Energy Production. Energy Nexus (submitted for publication), 2022.
3. Ē. Teirumnieka, K. Pīgožnis, D. Blumberga, E. Teirumnieks, and L. Lazov. Lasers Processing of Composite Materials. Accepted for publication by Bulgarian Academy of Sciences. http://www.icsqe2022.ie-bas.org/proceedings.htm. Journal of Physics (submitted for publication), 2022.
4. A. A. Stipniece-Jekimova, E. Teirumnieka, D. Blumberga. When Reed Application is Sustainable. Environmental and Climate Technologies 2022, vol. 26, no. 1, pp. 697–707. https://doi.org/10.2478/rtuect-2022-0053
5. Teirumnieka, Ē., Blumberga, D., Teirumnieks, E. The application of hemp in bioeconomy. Environment. Technology. Resources. Proceedings of the 13th International Scientific and Practical Conference, 2021, VOL I, pp. 281–287, published 2021, Document Type Proceedings Paper. https://dx.doi.org/10.17770/etr2021vol1.6966

6. Poisa, L., Adamovics, A., Antipova, L., Siaudinis, G., Karcauskiene, D., Platace, R., Zukauskaite, A., Malakauskaite, S., Teirumnieka, E. The chemical content of different energy crops. Environment. Technology. Resources. Proceedings of the 8th International Scientific and Practical Conference, 2011, VOL I, pp. 191–196, published 2011, Indexed 2011-01-01, Document Type Proceedings Paper.

Patents

LV patent No. 14869 S. Pleikšnis, Ē. Teirumnieka. Concrete containing sapropel and hemp sheaves for thermal insulation of buildings, 2014. The invention refers to the extraction of thermal insulation composite material from residues of sapropel and hemp.

Other publications

1. Lazov, L., Angelov, N., Teirumnieks, E., Adijāns, I., Pacejs, A., Teirumnieka, Ē. (2021) Laser ablation of paint coatings in industry. Environment. Technology. Resources. Proceedings of the 13th International Scientific and Practical Conference. Volume III. – Rezekne, pp. 187–194. Online ISSN 2256-070X (Scopus) https://doi.org/10.17770/etr2021vol3.6662
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4. Silicka, I., Dembovska, I., Teirumnieka E., Dembovskis, I. (2020) Lyophilized Hiking Food Development Trends. Journal of Regional Economic and Social Development No. 1 (12). pp. 182–191, https://doi.org/10.17770/jresd2020vol1.12.5400
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Conference, Faculty of Artillery, Air Defense and Communication and Information Systems, pp. 21–28. http://www.aadcf.nvu.bg/scientific_events/papers/dtf2020.pdf

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Projects

Innovative solutions for processing and recycling of industrial hemp, EAFRD project No. 18-00-A01612-000026.

Aim of the project: To explore and to improve the cultivation of industrial hemp by examining the impact of cultivation technologies on hemp productivity, quantitative and qualitative parameters, output of the produce, its suitability for the manufacturing of products with high added value and to develop recommendations for optimal hemp cultivation technology in the agroclimatic conditions of Latvia.

On the basis of the results obtained from the research, the most suitable varieties for Latvian conditions for the season of 2022 – "Bialobrzeskie" to obtain fibers and shives; "Finola" to obtain seeds – have been suggested for the project partners. Table 1 shows an overview of the farms involved in the project and the varieties of hemp sown.

Table 1

The hemp varieties cultivated in farms within the framework of the project [created by the author using information from the Project No. 18-00-A01612-000026]

Year	Ltd. Jumis geo	Ltd. Atzola, organic farm	Farm Kotiņi, organic farm	Ltd. Mežacīruļi	Ltd. "Saimniecība Nākotne", organic farm	Ltd. Reits
2022	Bialo-brzeskie	Pūriņi	Pūriņi	Pūriņi	-	Bialo-brzeskie
2021	Austa	Austa	Pūriņi	Austa	-	Austa
2020	USO 31	USO 31	USO 31	USO 31	USO 31	-
2019	USO 31	USO 31	USO 31	USO 31	USO 31	-
2018	USO 31	USO 31	USO 31	USO 31	USO 31	-

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By application of the research findings obtained in the Doctoral Thesis, recommendations will be prepared in written form for the project partners regarding the selection of hemp varieties, sowing rates, and nitrogen fertilizer doses for the cultivation season of 2023.

1. SUSTAINABILITY ASPECTS OF HEMP CULTIVATION

The main emphasis in this research is placed on hemp (*Cannabis sativa L.*) as a sustainable raw material in various sectors of the national economy, which in Latvia would replace rapeseed in crops, its cultivation capacity, by reducing the environmental load, and evaluating hemp use by means of a combination of the methods of multi-criteria decision-making and life-cycle analysis in variable economic and geopolitical circumstances. It also raises the issue of increased biomass from release of nutrients used for crop fertilising in water bodies, in particular reeds and their useful application.

Eurostat data show that the agricultural sector is unable to meet climate objectives without changing access to agrotechnologies. One aspect is the use of nitrogen mineral fertilisers, since N_2O emissions into atmosphere from the agricultural sector have not shown any declining trend for many years. One of the solutions is a reduction of N_2O emissions from the use of nitrogen fertilisers. By replacing hemp with rapeseed in the areas to be planted, it would already be possible to reduce N_2O due the fact that the cultivation of hemp requires lower amount of fertilisers than that of rapeseed. In 2020, the agricultural sector has generated 87.3 % from total N_2O emissions into air. [16]

Climatic conditions are among the most significant factors affecting hemp yields [17]. The effects of these factors must be investigated at a specific site of hemp in order to assess the impact of climatic factors on yields [18]. Characteristics of the trial site: Viļāni civil parish ((N) 56°34.053′; (E) 26°58.868′), 110 metres above sea level, the terrain is mostly flat and slightly hilly, the climate is moderately continental, moderately warm and humid. Field trials have been conducted in Eastern Latvia in 2010, 2011, 2012, 2013, and 2019 using four varieties of hemp "Bialobrzeskie", "Finola", "USAO 31", and "Pūriņi". Agri-chemical indicators of soil before sowing – the content of soil organic matter from 6.5 to 7.4 %; pH from 6.6 to 7.0; P_2O_5 from 145 to 152 mg/kg of soil; K_2O from 118 to 112 mg/kg of soil. Crop rate in plots – 70 kg/ha, seeds are chemically treated. The fields were not further treated with fertilisers, so the impact of additional fertilisers on harvests is excluded. During the vegetation period, from April to September, temperatures and precipitation have been determined in order to assess the impact of climatic conditions on hemp yields depending on the variety, and to determine suitability of the hemp variety for Eastern Latvia or similar climatic conditions. Data analysis was used for the purpose to determine the most appropriate variety for a particular hemp product – seeds, shives, fibers. The yield and the content of shives were calculated as the arithmetic mean of three iterations. Plant sample analyses have been performed in the Chemical Laboratory of Rezekne Academy of Technologies by means of the national standard methods specified in Latvia. Meteorological data for the research period have been taken from Viļāni meteorological station. When assessing fluctuations in climatic conditions, a conclusion can be drawn that higher risk factors for germination can be caused by temperature increases and low levels of precipitation in May. The research has found that weather conditions are quite different from one year to another. Therefore, varieties that are less sensitive to the temperature and humidity fluctuations during sowing and at the initial stage of plant development should be selected for cultivation. Fiber yields are higher at a moderate humidity and lower temperatures. Rising temperatures significantly reduce the yields of fibers for "Finola" and "Pūriņi" varieties and slightly decrease for "USO-31", while fluctuation in temperature has virtually no effect on the yield of fibers for the "Bialobrzeskie" variety. "Bialobrzeskie" also has higher absolute figures for fiber outcome, regardless of the year of observation. However, the increase in humidity increases fiber yields for "Finola" and "Pūriņi" varieties, slightly reduces for "USO-31", and has no effect on "Bialobrezkie". The amount of shives is the smallest when there is high amount of precipitation (above 80 mm during vegetation period) and low temperature (around 12.5 °C during growing season) (see Figs. 1.1 and 1.2).

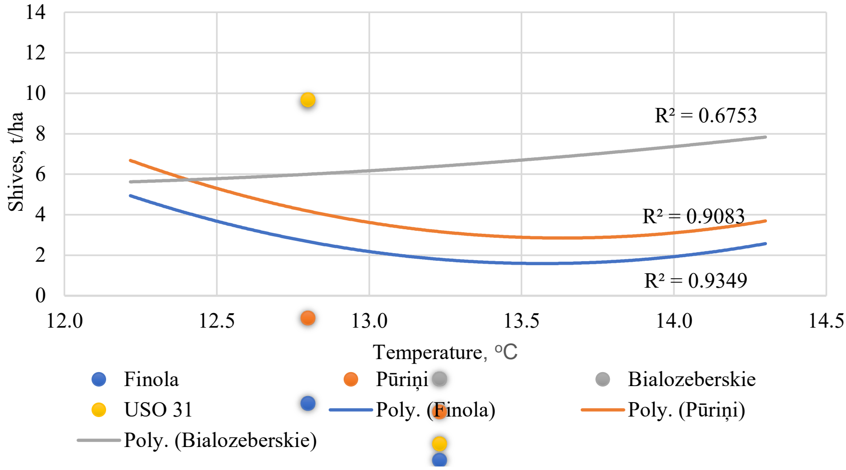

Fig. 1.1. Temperature dependency of the shive yields [created by the author using data from Viļāni meteorological station].

The analysis of climatic factors shows that the effects of temperature and precipitation on the yields of seeds, shives and fibers are highly dependent on the variety. It is thus possible to identify different varieties of hemp in order to obtain a specific hemp-containing product. Hemp yields are more heavily influenced by the amount of precipitation; with a large amount of precipitation, only biomass is not declining. The decline in yields at high humidity and low temperatures is often explained by the growth of fungi on plants.

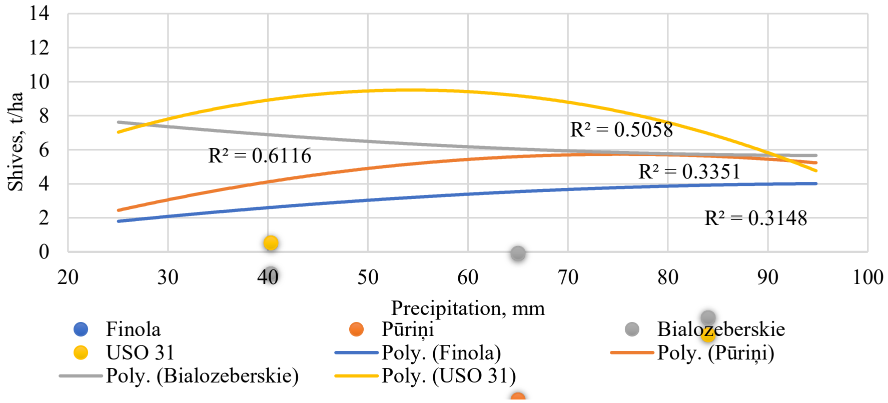

Fig. 1.2. Shive yield dependency from the amount of precipitation [created by the author using data from Viļāni meteorological station].

It can be concluded from data analysis carried out that under identical growth conditions the "Bialobrzeskie" variety is more stable and less dependent from climatic conditions in terms of fiber and shive production. Also, "Bialobrzeskie" provides higher overall green-mass yields per hectare.

For the hemp variety "Bialobrzeskie", the effect of the sowing rate on the yield of straws, bast, shives and seeds was determined. All the years of research have identified reduction of the yields of hemp straws when the hemp sowing rate is increased. This means that lower sowing standards can be applied, thereby reducing the costs for acquiring seeds, and under circumstances where there is a problem with the availability of resources, lower sowing standards can be applied and good hemp straw yields can be achieved (see Fig. 1.3).

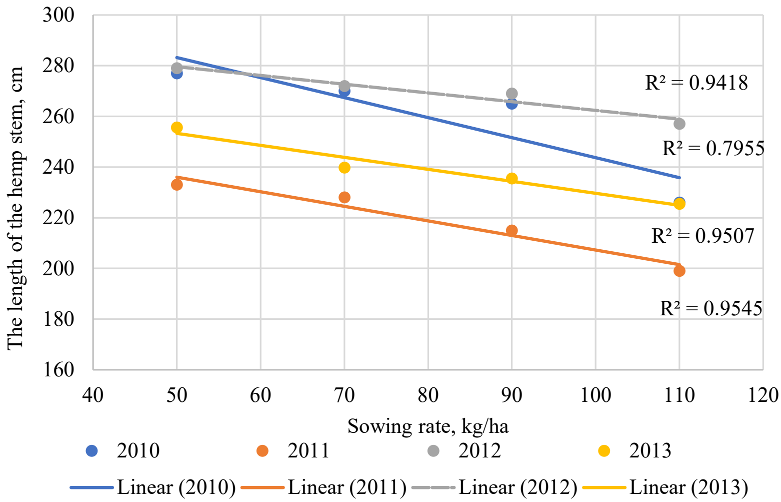

Fig. 1.3. Dependency of the straw yields on the sowing rate for "Bialobrzeskie" variety [created by the author using data from Viļāni meteorological station].

In all the years of research, straw yields are declining, notwithstanding the weather conditions. This means that there is no need for the use of high sowing rates. On the basis of the research results, the recommended sowing rate for the extraction of fibers and shives is from 40 to 60 kg/ha, while for the production of seeds 50 kg/ha, or even less. In France, for example, the recommended sowing rate is even lower, being from 40 to 50 kg/ha, with a gap between rows from 12 to 15 cm.

From analysis of the impact effectiveness of nitrogen fertilizers when compared to the yields obtained in the test field, it can be concluded that the increase in yields is observed for all the varieties under investigation. As a result of the increased dose of nitrogen fertilizers, the yield of straw ranges from 0.23 % (at *N* 30 kg/ha) to 3.4 % (at *N* 30 kg/ha). When assessing effectiveness of the used nitrogen fertilizers, it can be concluded that high nitrogen doses are leading to a relatively lower increase in straw yields. The effect of additional nitrogen fertilizers on the yields of hemp straws are shown in Fig. 1.4.

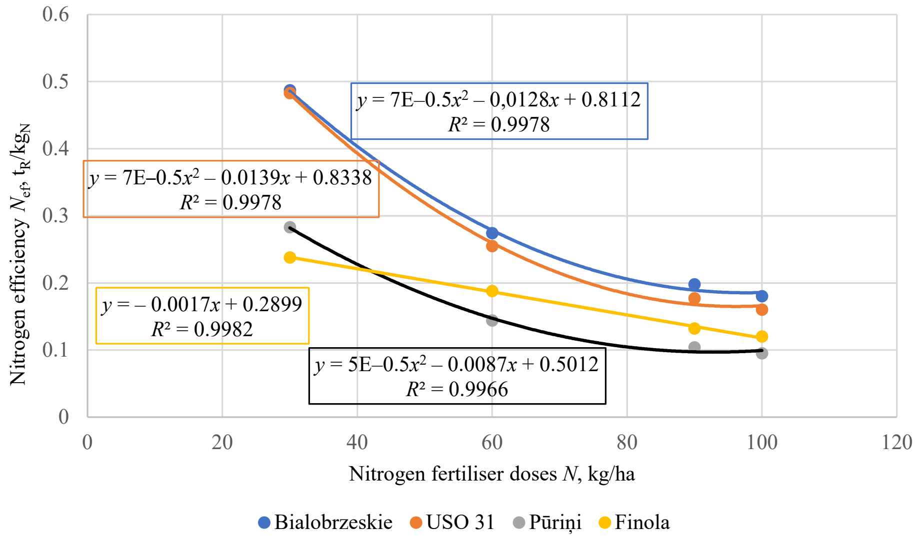

Fig. 1.4. Efficiency of the use of nitrogen in the hemp cultivation [created by the author using data from field studies in Ltd "Latgales Lauksaimniecības zinātnes centrs"].

Nitrogen fertilizer use efficiency N_{ef} is the ratio of hemp yield t_R/ha to the applied nitrogen doses N, kg_N/ha. Efficiency N_{ef} measurement unit is t_R/kg_N.

By means of the empirically obtained Equation (1) for the "Bialobrzeskie" variety, it is possible to evaluate the efficiency of using both higher and lower doses of nitrogen fertilizer. The result clearly shows the effectiveness of nitrogen fertilizers.

$$N_{ef} = 7e^{-0.5N^2} - 0.0139N + 0.8338, \qquad (1)$$

where N_{ef} is efficiency of the use of nitrogen fertilizers, t_R/kg_N, and N is the dose of nitrogen fertilizers, kg/ha.

Similar correlations have also been observed for seed and fiber yields. This demonstrates the unjustified use of nitrogen fertiliser and the need to reduce its quantity.

2. SUSTAINABILITY ASPECTS OF HEMP USE

Hemp is an old and very unique crop, which can provide a variety of products that can be very widely used. Hemp, by virtue of its characteristics, is a good raw material for the manufacturing of products being useful to the public, including oils, foodstuffs, construction materials, paper, biofuels, heating fuels, textiles, etc. (see Fig. 2.1). Hemp is a raw material for a number of products with high added value, which increases the value of hemp when compared to many other industrial crops. Cross-cutting links are visible in the use of hemp [19]. The key is the diversity of raw materials, since several types of raw materials are obtained in the hemp recycling process:

- hemp seeds,
- bast fibers,
- shives,
- leaves.

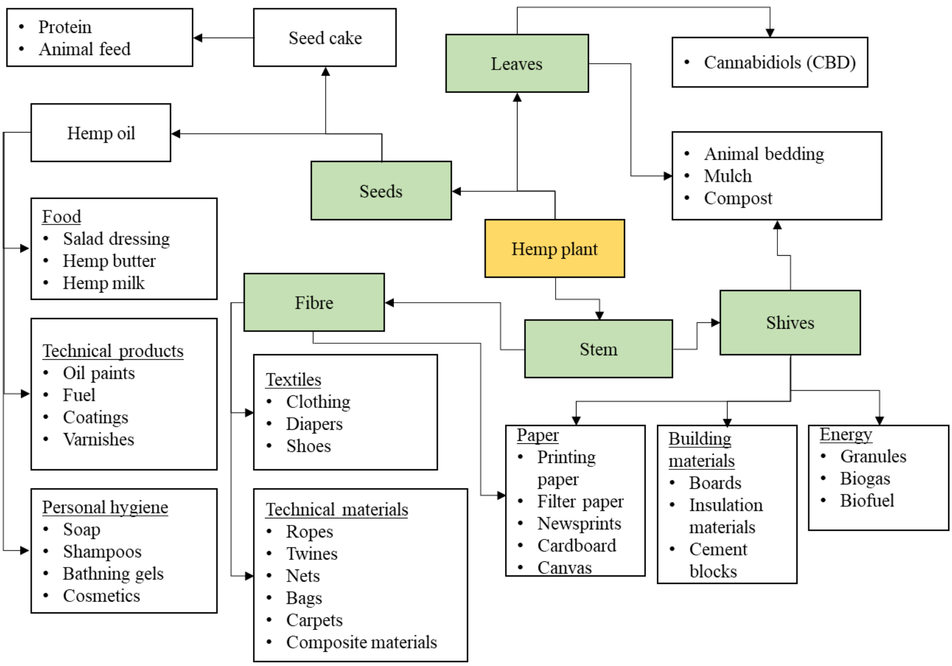

Fig. 2.1. Use of hemp in the bioeconomy [created by the author [19]].

3. PILOT SOLUTIONS OF HEMP PRODUCTS

3.1. Composite material and its processing

Composite materials consisting of fibers and binders of natural and artificial origin are increasingly used in various fields of industry. Often, the processing of the obtained materials into finished forms is difficult and expensive. Treatment of composite materials, such as milling, cutting, or grinding, is now dominant. Now, lasers are used more and more in production processes. It should be noted that modern industrial production is unthinkable without the use of laser equipment. However, when using lasers, initial adjustment of their laser parameters is necessary for optimal material processing. Considering different lasers and the materials to be processed, the parameters to be set differ and the quality of the processing to be obtained changes.

At the Rezekne Academy of Technology (RAT), samples of composite materials consisting of a binder – epoxy resin and a reinforcing material, hemp, flax and carbon fibers, were made in laboratory conditions. The obtained composite materials were studied for their properties in bending and stretching, as well as the quality of their processing with a fiber laser was analyzed. The produced, environmentally friendly composite material must also be processed in an environmentally friendly way in order to obtain the required dimensions and shape of the part. The research is focused on the evaluation of the effectiveness of the use of fiber lasers in the processing of composite materials. Lasers make it possible to process the material very precisely and quickly. The technology is environmentally friendly because it does not create, for example, dust, as it does when cutting or grinding materials.

For the production of composite material, cold lamination is used in a vacuum (see Fig. 3.1.1). Fiber fabrics are saturated with epoxy resin in a vacuum. It ensures a homogeneous material structure and does not form pores.

Developed types of composite materials:

- carbon fiber/hemp fiber, epoxy resin,
- carbon fiber/carbon fiber, epoxy resin,
- hemp fiber/hemp fiber, epoxy resin,
- flax fiber/hemp fiber, epoxy resin,
- carbon fiber/flax fiber, epoxy resin.

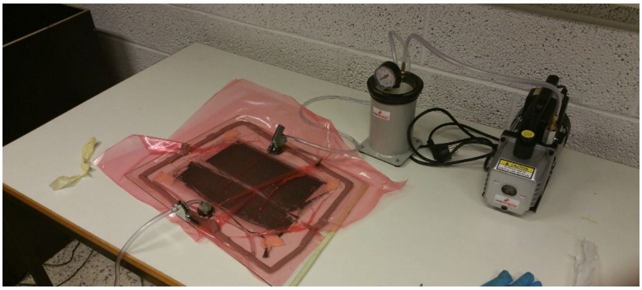

Fig. 3.1.1. Processing of composite materials.

a) b) c)

Fig. 3.1.2. Composite materials: a) hemp fiber/hemp fiber; b) carbon fiber/hemp fiber; c) flax fiber/hemp fiber [created by the author, author's photo in the RAT laboratory].

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Figure 3.1.2 shows samples of composite materials after their production.

Bending is an important mechanical indicator of a material in the manufacture of automobile and aeronautical parts. Bending tests of composite material samples were performed with the Zwick&Roell Z150 testing machine, 3 parallel measurements were performed for each manufactured sample. The obtained results can be seen in Fig. 3.1.3.

Carbon fiber/carbon fiber composite bending test:

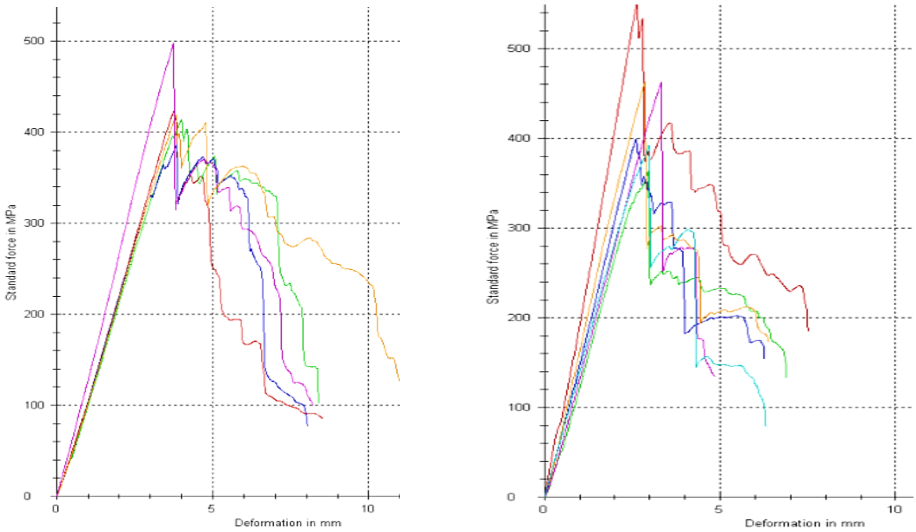
- the maximum strength limit is on average 410 MPa;
- deformation up to the limit of strength occurs approximately up to 4 mm;
- deformation lasts up to 7 mm, after which the sample collapses.

Carbon fiber/hemp fiber composite test:

- the maximum strength limit is on average 440 MPa;
- deformation up to the strength limit occurs approximately to 3 mm;

- the destruction of the material occurs in a stepwise manner, which is shown by the peaks at 3.6 and 4.3 mm.

The resulting composite bending tests show that natural fiber materials used in composites, such as hemp, are a good substitute for carbon fiber. The main advantages of natural fiber composite materials are their low weight, resistance to aggressive environments, high tensile and bending strength.



a) b)

Fig. 3.1.3. Bending test: a) carbon fiber/carbon fiber; b) carbon fiber/hemp fiber [created by the author using test results obtained with Zwick&Roell Z150 in the RAT laboratory].

Laser processing of fiber composites has several advantages over traditional processing methods:

- Laser processing is the processing of materials without the influence of physical force. This eliminates the tool use and wear (because there is none), machine tool vibrations and deflections, as well as restrictions on the shape of the product that occur during machining.
- Compared to the abrasive process, laser cutting can achieve a narrower cut width and higher cutting speed while offering better cuts.

- It is important to find optimal parameters of the laser processing process, which ultimately ensure minimal thermal damage to the material. It largely depends on material thickness, cutting speed and laser power density.
- Cutting hemp fiber composites requires less laser power than cutting carbon fiber composites. At the same laser parameters, a higher laser cutting speed can be applied to the hemp fiber composite than to the carbon composite.

3.2. Concrete from hemp shives

Concrete from hemp shives (hemp concrete) is obtained by mixing hemp shives with slaked lime (where appropriate, also additives are added) and water in certain proportions (see. Fig. 3.2.1). Hemp concrete is used as a thermal insulation material and as a filler in non-load bearing structures in wooden pillar buildings, as well as a sound insulation material.

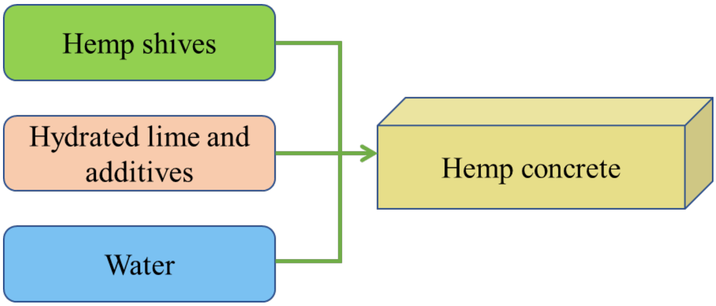


Fig. 3.2.1. Ingredients for the production of hemp concrete [created by the author].

The author of the Doctoral Thesis together with her colleagues from Rezekne Higher Education Institution (currently Rezekne Academy of Technologies) carried out research regarding extraction of thermal insulation composite materials from the residues of sapropel and hemp on the development of recipes. As a result, a patent application has been filed and a patent has been received: LV patent No. 14869, Concrete containing sapropel and hemp sheaves for insulation of buildings, 2014, inventors S. Pleikšnis, Ē. Teirumnieka. Patent owner – Rezekne Higher Education Institution.

The invention concerns sustainable construction and, in particular, the acquisition of a new ecological thermal insulation composite material.

The thermal insulation composite material from the residues of sapropel and hemp is an absolutely ecological thermal insulation material: concrete from sapropel – hemp shives (hereinafter referred to as the SHS concrete). The main binding agents are organogenic lake sediments – sapropel that replaces slaked lime in the given case. SHS uses hemp shives obtained from hemp varieties (*Cannabis sativa L.*) as a filler. Hemp shives are the residues resulting from the processing of hemp with a low bulk density. SHS concrete is breathable, therefore, favourable microclimate is provided in the room. The impact of this material on the environment is a very important one.

SHS concrete can be applied in the portions of all building enclosing structures. This material may be used in the heat insulation of floors, walls, coverings and lofts of the building. SHS concrete is made of hemp shives, sapropel and water mixture in proportions 1 : 2 : 1. SHS concrete can be used in the construction of frame buildings as well as in the construction of self-bearing walls. Given a relatively low compressive strength of the SHS concrete, it should be better used as an insulation material for self-bearing walls. First, a wooden frame of the building and a roof structure with coverings shall be formed. Such work technology also allows jobs to be performed when it is raining. While moulds for creating walls are installed, SHS concrete is filled gradually, layer after layer, with good compacting. A variety of cyclic-operated mobile concrete mixers can be used to mix SHS concrete. If the construction volumes are high, the spraying technique may be used by means of special pumps. When the material is sufficiently hardened, the walls are demoulded.

After complete drying of the material, interior finishing of the wall is made. By increasing the amount of binders (hemp shives, sapropel and water mixture in proportion 1 : 2.5 : 0.5) finished wall blocks may also be formed, while these will require special moulds and the block drying may delay the construction process.

In order to improve fire safety of SHS concrete, adding borax is recommended (up to 7 %), which prevents fire from entering the building as the temperature rises, borax releases water, the material becomes fireproof and simultaneously protects the building's wooden structures.

It is recommended that construction lime or sand (up to 8 %) is added in order to protect SHS concrete against rodents and insects.

Not only thermal but also acoustic properties of the SHS concrete are good, which differ significantly from other concretes.

Working with such material does not pose a risk to the environment and human health. It is recommended that SHS concrete is used in wooden frame buildings having no more than 2 floors.

The density of SHS concrete is between 140 and 170 kg/m. The average thermal conductivity of the material λ is 0.0552 W/(m·K).

4. COMBINATION OF DATA ANALYSIS METHODS FOR SUSTAINABLE USE OF HEMP AND REED BIOMASS IN LATVIA

In order to identify the most sustainable alternative to the use of hemp and reed biomass, the methods of a multi-criteria analysis and of a life cycle analysis were combined. As noted above, nitrogen fertilisers are widely used in agricultural crops, which, due to the high solubility of nitrogen compounds, easily transfers into hydrosphere and reaches water bodies. This contributes to the accumulation of nutrients and the intensive development of aquatic plants, thus areas of reed have particularly increased in Latvia. Consequently, it is appropriate to assess the potential for the use of both hemp as a culture to be cultivated and reed as a biomass that is increasingly growing under natural conditions.

4.1. Methodology

The research aims to assess the sustainability of the use of hemp for energy production using an integrated set of data analysis methods. In order to achieve the set task, a methodology was developed for evaluating the sustainability of hemp use. A sensitivity analysis of the results was also performed. It is possible to obtain a more complete result of multi-criteria analysis by using integrated aforementioned methods. Figure 4.1.1 shows stages of the research methodology. The TOPSIS method is the simplest and most convenient for comparing alternatives, while sensitivity analysis provides an opportunity to evaluate changes in the performance of alternatives. Life cycle analysis allows a quantitative assessment of the environmental impact of a product.

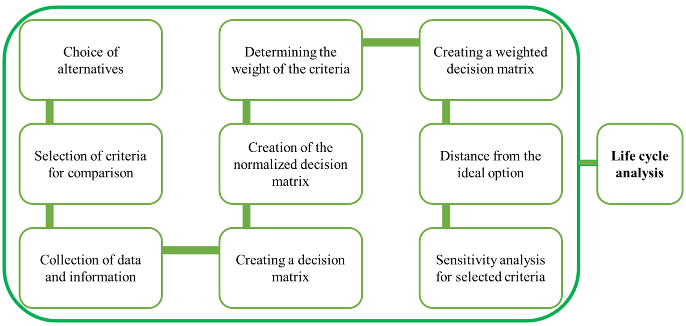


Fig. 4.1.1. Stages of research methodology [created by the author].

4.2. Examples of methods of application

4.2.1. Analysis of reed use

In order to find sustainable solutions to the problems of growing and harvesting cane, it is necessary to limit the spread of reed in orderto prevent overgrowth and maintain natural biodiversity in wetlands and lakes by harvesting green reed biomass in summer. Figure 4.2.1.1 shows product alternatives, which are also used in research. Nine alternatives were selected for analysis – three in the energy sector, three in the construction sector, one in medicine, and two innovative products. Alternatives that have been well known for a long time, such as reed roofing, as well as those that have been described in the literature only in recent years, have been chosen.

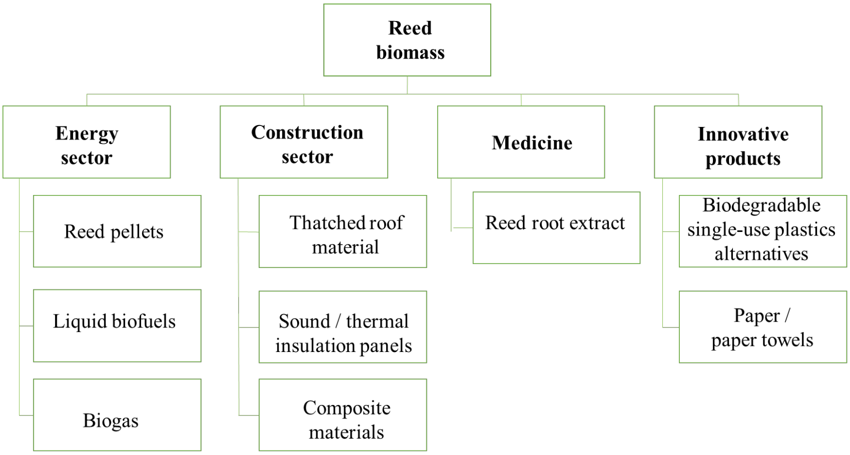


Fig. 4.2.1.1. Reed biomass use alternatives [created by the author].

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MCDM TOPSIS was applied to determine the most sustainable alternative for the use of reed. Complex problem assessment process requires comprehensive analysis of available solutions. Resource management is a complex system, therefore, all possible factors must be considered – effect on national economy, technical specifics and technology readiness, influence on society, and environmental impact. To evaluate the alternatives of reed biomass use, 11 criteria were chosen to define economic, technological, environmental and social indicators (see. Table 4.2.1.1).

Table 4.2.1.1

Indicators included in multi-criteria analysis [created by the author]

Economic factors	Technological factors	Environmental factors	Social factors
Product cost	Energy consumption in production process	Cleared reed stand area per year	Jobs created by starting production process
Production costs from biomass harvesting to finished product	Technology readiness level	Environmental pollution in production process	
Production start-up investments		Benefits to the environment	
Market availability for finished product		GHG emissions	

9 alternative products from reed biomass were analyzed using the TOPSIS MCDM method (see. Fig. 4.2.1.2). The best alternatives for reed biomass use were determined to be thatched roof material production, reed pellet production, sound or thermal insulation panel production, biogas production and biodegradable single-use plastics alternative production.

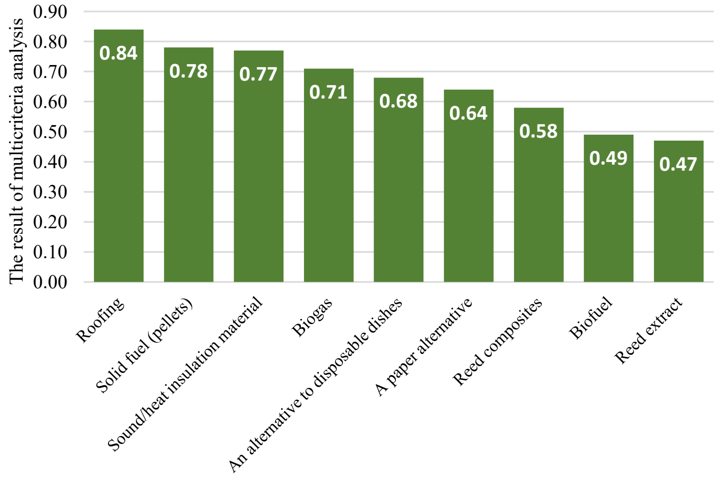

Fig. 4.2.1.2. TOPSIS MSDM analysis results [created by the author].

Sensitivity analysis was done to determine the elasticity of each alternative in changing environment. Therefore, technological and production process related indicators are considered more important for successful and sustainable reed use alternative. The least important are social and socio-economic factors (availability to social groups, jobs created and product market cost). The most promising alternatives are energy sector applications. Renewable energy is a growing industry, and each new renewable energy source can be introduced to the market relatively easily. Reed use in construction sector or innovative products should be developed to broaden the use of reed biomass. Energy sector applications can use only up to 3000 ha of reed biomass per year, leaving the opportunity for construction industry and innovators develop new products and reed applications.

4.2.2. Hemp use analysis

The aim of the research is to assess the sustainability of using hemp for energy production using an integrated set of methods including Multi-Criteria Decision Analysis (MCDA) and life cycle analysis (LCA). A methodology for the integrated application of MCDA and LCA methods was developed. The MCDA method was chosen for the evaluation of the eight selected hemp products, taking into account the six set criteria (see Fig. 4.2.2.1), which allows to evaluate not only environmental, but also economic and technological aspects. The application of MCDA allowed the sustainability of different hemp products to be assessed under crisis and non-crisis conditions taking into account six different criteria. In the next step, LCA was carried out for four different biomass energy resources, including energy production from hemp. The application of MCDA allowed the sustainability of different hemp products to be assessed under crisis and non-crisis conditions, taking into account six different criteria.

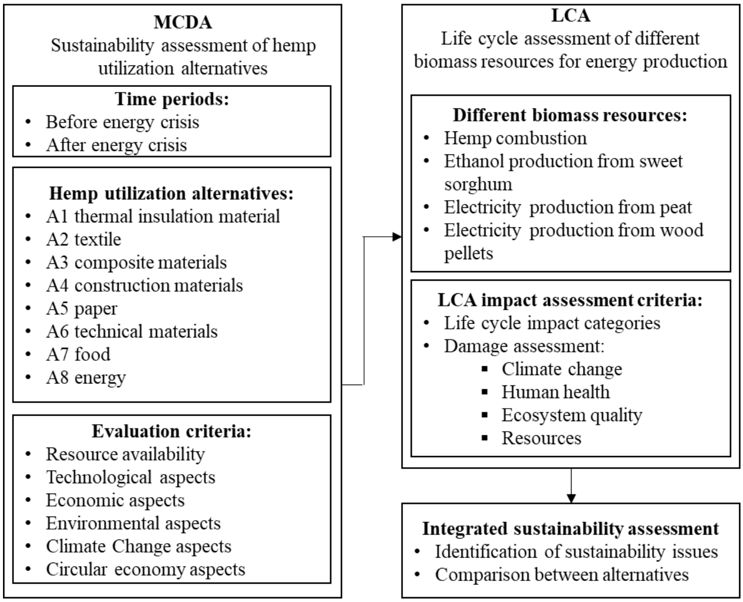

Fig.4.2.2.1. Visual representation of the methodology developed for the research [created by the author].

TOPSIS calculations to compare the eight hemp products under everyday conditions, using the method to determine the closest to the ideal solution, gave the results shown in Fig. 4.2.2.2. The closest to the ideal result is the production of building materials and thermal insulation, with values of 0.74 and 0.70, respectively. On the other hand, the poorest results are for energy and paper production, with 0.39 and 0.38, respectively. All eight products compared are far from the ideal positive solution, with the production of building materials only 0.24 units closer to the ideal. The best and second best performances differ by only 0.04 units. However, the sustainability performance of building materials is almost 50 % better than that of paper production from hemp. The best and second best performances differ by only 0.04 units. However, the sustainability performance of building materials is almost 50 % better than that of paper production from hemp.

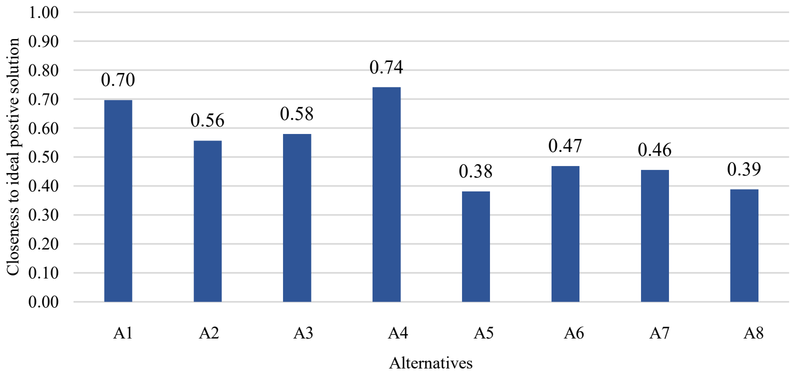

Fig. 4.2.2.2. Ranking of hemp use in everyday scenario under non-crisis conditions [created by the author].

A1 – thermal insulation in building sector; A2 – textile in different sectors; A3 – composite materials in different sectors; A4 – construction materials in different sectors; A5 – paper in industrial sector; A6 – technical materials in different sectors; A7 – food in agriculture sector; A8 – energy in energy sector.

The TOPSIS calculations to compare the eight hemp products under the conditions of energy and/or economic crisis, using the method to determine closest to the ideal solution, produced the results shown in Fig. 4.2.2.3. Energy and thermal insulation production are closest to the ideal positive solution, with values of 0.85 and 0.80, respectively. On the other hand, technical materials and paper production have the lowest results, with values of 0.25 and 0.17, respectively. Energy production has moved closer to the ideal by 0.35. Thermal insulation has also moved closer to the ideal, as it can reduce energy consumption in dwellings. The best and second best performances differ by only 0.05 units. The other six products compared are further away from the ideal solution. However, the sustainability performance of energy production is 4 times higher than paper production from hemp. This is a huge difference, which points to the need for additional analysis and adjustments in the priorities for hemp use in the context of an economic crisis.

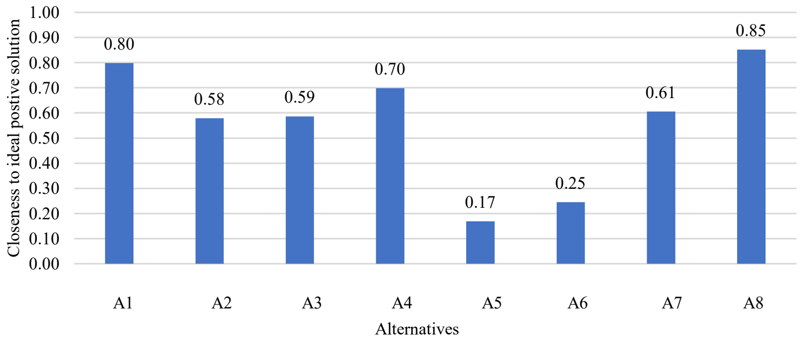

Fig. 4.2.2.3. Ranking of hemp under conditions of energy and/or economic crisis [created by the author].

A1 – thermal insulation in building sector; A2 – textile in different sectors; A3 – composite materials in different sectors; A4 – construction materials in different sectors; A5 – paper in industrial sector; A6 – technical materials in different sectors; A7 – food in agriculture sector; A8 – energy in energy sector.

In order to verify the results and evaluate the stability of the alternatives under changing conditions, a sensitivity analysis has been performed for all eight alternatives. The sensitivity analysis has been performed with the values of the single variation ratio βk = 0.01; 0.5; 1; 1.5; 2; 2.5. The sensitivity analysis was performed for all five criteria used in the TOPSIS analysis (see Figs. 4.2.2.7–4.2.2.11).

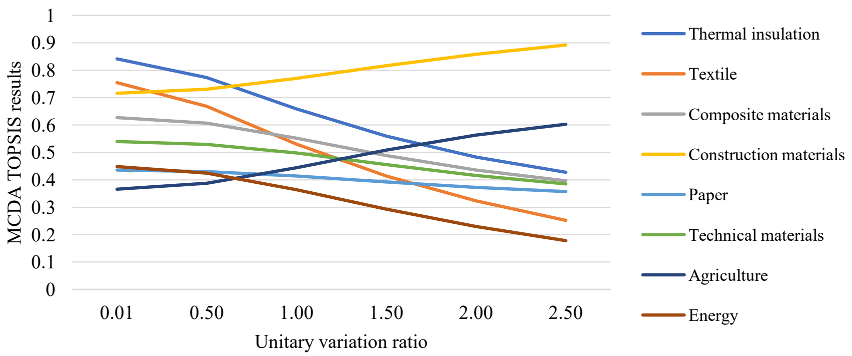

Fig. 4.2.2.7. Sensitivity analysis of the “Resource availability” criterion [created by the author].

Changes in the proportion of resource availability criterion of TOPSIS results have an adverse effect on industries where hemp fibers are mostly used as raw material (textiles, technical fabrics, composite materials, paper, thermal insulation). The most stable alternatives in terms of resource availability are the production of building materials and agricultural products, since all hemp components can be used for this purpose, and the requirements for the quality of raw materials for some products are not high. The use of hemp for energy production would not be useful

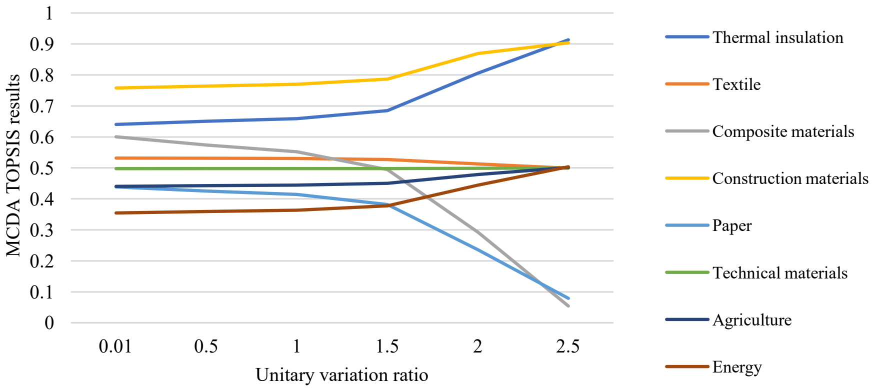

Fig. 4.2.2.8. Sensitivity analysis of the “Technological aspects” criterion [created by the author].

Changing the weight of technological aspects significantly affects the performance of paper and composites manufacturing alternatives in the TOPSIS analysis. The reason for this could be the complicated technological process of production. The increase in the proportion of the criterion has a favourable effect on the alternative of thermal insulation and construction material production, as the technologies are not complicated and are available. The other alternatives are not affected by the change in the criterion.

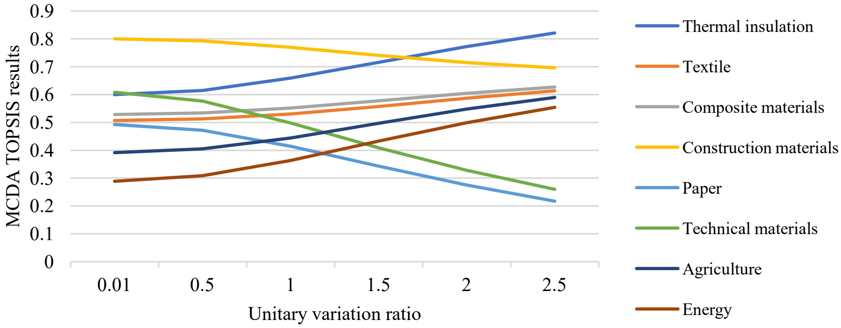

Fig. 4.2.2.9. Sensitivity analysis of the "Economic aspects" criterion [created by the author].

The change in the proportion of the criterion of economic aspects of TOPSIS results has a positive impact in the majority of sectors. The figure shows that the change in economic aspects has a significant impact on alternatives for the production of paper and technical materials. In the production of paper this can be explained by the high cost of production and raw materials, but in the production of technical materials hemp is a more expensive raw material than other raw materials.

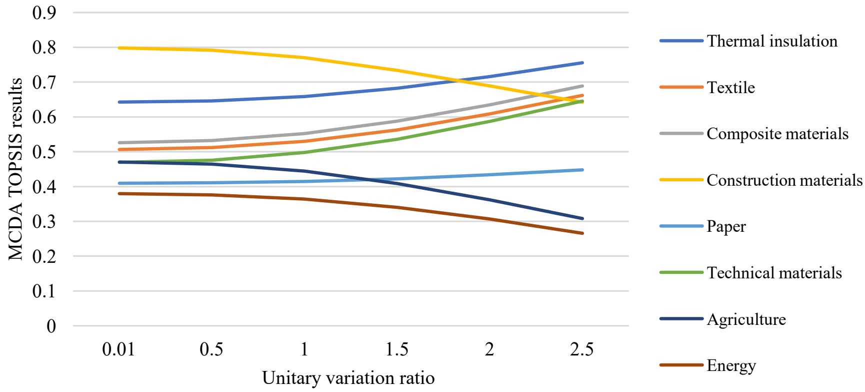

Fig. 4.2.2.10. Sensitivity analysis of the "Environmental aspects" criterion [created by the author].

Analyzing the impact of environmental aspects on the results of the TOPSIS analysis of alternatives of the use of hemp, the deterioration of the production results of construction materials, energy and agricultural products can be seen. The reason is the use of fossil resources and chemicals, as well as emissions into the environment during the production process. The other alternatives have a positive impact as hemp replaces fossil resources in many places.

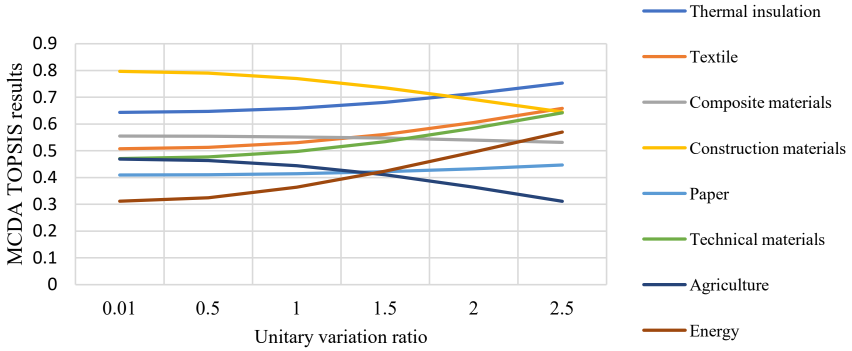

Fig. 4.2.2.11. Sensitivity analysis of the "Climate aspects" criterion [created by the author].

The analyzed alternatives for the use of hemp have a positive effect on energy production, since the use of hemp results in zero GHG emissions. The use of hemp as alternatives to various materials also has a positive effect, as fossil resources are replaced, for example, in the production of synthetic textile materials, technical materials, and thermal insulation materials. Only the use of hemp in agriculture and the production of building materials has a negative impact on the change in the proportion of the TOPSIS result criterion.

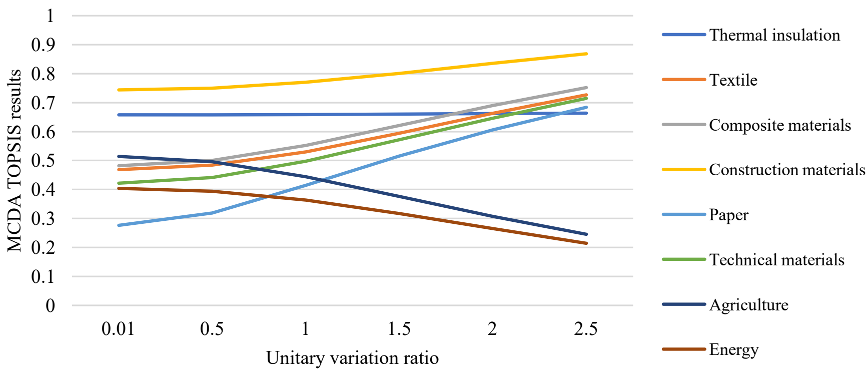

Fig. 4.2.2.12. Sensitivity analysis of the "Circular economy aspects" criterion [created by the author].

Changes in the weight of aspects of the circular economy have the most negative impact on the use of hemp in agriculture and energy production. The increase in the share of the criterion has a positive effect on the other alternatives. This confirms that hemp is an appropriate raw material for the requirements of the circular economy and has a future in the production of various types of products.

Life cycle impact assessment was conducted using characterization factors by using Sima Pro 9.3.0.3 IMPACT 2002+ methodology. The following impact categories were analyzed: carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion, respiratory organic, aquatic ecotoxicity, terrestrial acid, land consumption, aquatic acidification, aquatic eutrophication, global warming, non-renewable energy, and mineral extraction.

The life cycle performance of hemp combustion to produce 100 kWh electricity shows a high contribution (100 %) to all impact categories except land consumption, non-renewable energy, and global warming potential. Figure 4.2.2.4 shows the impact assessment results for hemp biomass, peat, wood pellets, and sweet sorghum. Electricity production from peat shows a high impact contribution to global warming and non-renewable energy, whereas ethanol production from sweet sorghum shows a high impact only on land consumption. Electricity production from wood pellets shows a 100 % contribution to the carcinogens and land consumption impact categories. In contrast, for non-carcinogens, aquatic ecotoxicity, terrestrial acid, and mineral extraction the contribution is between 65–80 %. Overall, the impact assessment result for hemp biomass shows negative results, i.e., the high-performance score for almost all impact categories compared to peat and sweet sorghum biomass. Wood pellet biomass also has the second highest impact contribution in the impact categories.

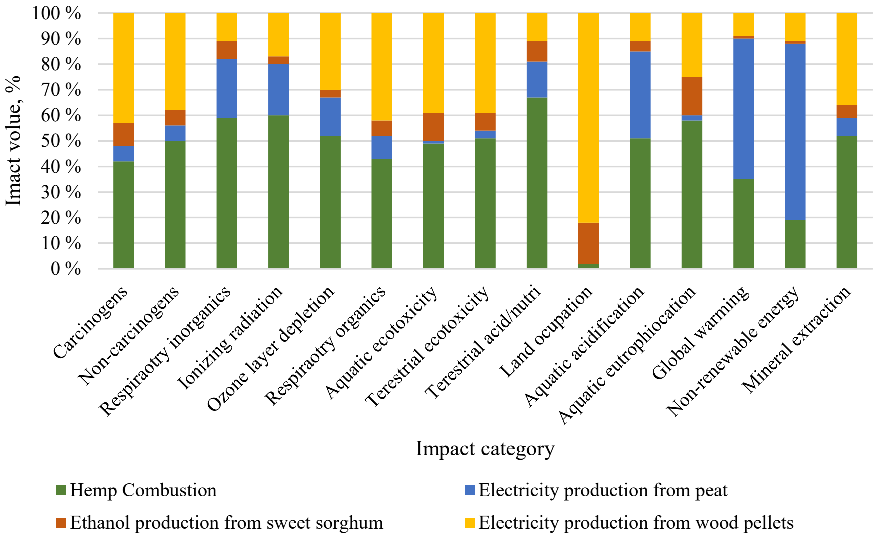

Fig. 4.2.2.4. Comparison of impact categories for hemp, peat, wood pellet, and sweet sorghum biomass [created by the author].

LCA concerns four categories of damage and indicates the largest significant negative impact on the environment. The identified damage categories are resources, human health, climate change, and ecosystem quality. A further definition of each damage category is as follows:

- resources account for the percentage of consumption of resources;
- climate change is the indicator of potential global warming due to the greenhouse gas emissions to air;
- ecosystem quality shows the protection zone which is related to impacts on the natural environment;
- human health shows the impact on human toxicity substances emitted to the environment.

The comparison of damage assessment between hemp combustion, electricity production from peat, ethanol production from sweet sorghum, and electricity production from wood pellets is presented in Fig. 4.2.2.5.

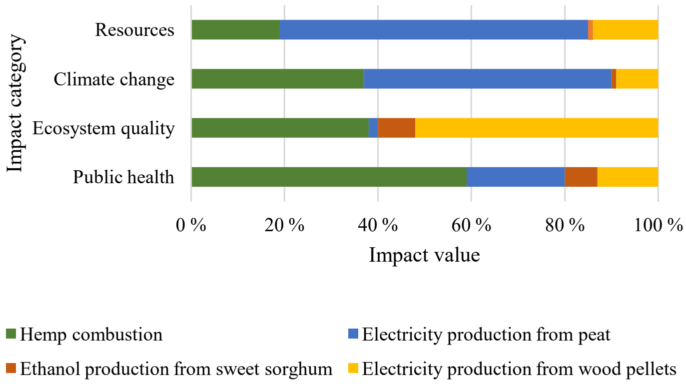

Fig.4.2.2.5. Comparison of damage assessment of hemp, peat, wood pellets and sweet sorghum biomass [created by the author].

The results show that peat and sweet sorghum biomasses have a lower score for human health and ecosystem quality than hemp biomass. The ethanol production from sweet sorghum has the lowest impact in all categories, whereas the contribution of hemp biomass has a significant contribution to the damage categories. Electricity production from wood biomass has a 100 % contribution to ecosystem quality, whereas human health, climate change, and resources have a 21 %, 15 %, and 16 % damage contribution, respectively. Overall, hemp combustion has a more significant damage impact than peat, wood pellets, and sweet sorghum biomasses.

The multidimensionality of sustainability is clearly evident when it comes to the use of hemp. On the one hand, there is the bioresource value pyramid, which defines the use of hemp resources for combustion and energy production. This type of use is close to the base of the pyramid, indicating low added value. On the other hand, the sustainability approach may lose priority and become an afterthought in specific circumstances, such as economic and/or energy crises.

The Russian war in Ukraine has led many countries to major problems, as they had to decide on the long-term development of the energy sector and change their long-term development policies. European countries urgently needed to move away from fossil fuels such as natural gas and find ways of replacing these fossil fuels with renewable energy sources. In this case, it is important to find criteria that cover the whole spectrum of sustainability.

The MCDA analysis for the everyday situation showed that the use of hemp in the energy sector scores low, meaning that it is far from the ideal solution. However, the situation changes in an energy crisis when the use of hemp in energy production comes first and is the best solution.

These results suggest that further research is needed to answer the question: Can a short-term solution also be considered a sustainable solution? The answer to this question is provided by the LCA of hemp pellet combustion compared to other biomass and indigenous fuels (peat) for energy production. Answers were sought on the impacts of different energy sources on human health, climate change, resources and ecosystem quality. The result was positive: the use of hemp in the energy sector for energy production is not sustainable and should be avoided even in times of economic crisis.

The developed sustainability assessment methodology showed that the MCDA methodology provides only a partial answer on the efficiency and effectiveness of the bio-based product. Only if the results obtained with MCDA are further analyzed with LCA, can a complete picture be obtained of whether the use of hemp in the energy sector is sustainable under all circumstances and could be a future solution for replacing fossil energy sources. The integrated sustainability assessment method is, therefore, expected to be widely used in the near future.

CONCLUSIONS

1. Under changing climatic conditions in Latvia, it is possible to cultivate hemp (*Cannabis sativa L.*) for the purpose of obtaining seeds as well as fibers and shives. The application of reduced sowing standards (for the extraction of fibers and shives from 40 to 60 kg/ha, whereas for the extraction of seeds – 50 kg/ha, or even less at a gap between rows from 12 to 15 cm) and additional nitrogen fertilizers (*N* 60 kg/ha) can result in invariably good harvests while at the same time reducing the environmental load.
2. In the conditions of East Latvia, cultivation of early varieties with a short vegetation period is better for the extraction of seeds. From the varieties studied, "Finola" may be recommended for seed growing. "Bialobrzesky" is suitable for fibers and shives. In general, the yields of hemp fibers and shives are varied; thus using all parts of the plant is economically more advantageous.
3. Empirical equations found in the research are applicable for calculation of the rate of additional nitrogen fertilizers and hemp sowing to produce a particular hemp product. Thus, by reducing the doses of additional nitrogen fertilizers, N_2O emissions from the agricultural sector can be reduced, contributing to the attainment of climate neutrality objectives in agriculture and to reducing eutrophication.
4. Hemp-based bio-products prototypes with improved properties and high added value have been developed – hemp-containing composite material and hemp concrete. Those are the basis for further development of the technologies and commercialization.
5. A methodology was developed to assess the sustainability of hemp use under changing environmental, economic and geopolitical conditions. The methodology includes agrotechnology and sustainability criteria and the combination of integrated data analysis methods for sustainable decision-making.
6. Given the growing global demand for energy and more ambitious climate objectives, the use of biomass (e.g., reed, hemp) for incineration will become even more important than it has been before. As wood is becoming scarcer due to increasing demand for wood products and energy production, there is a growing interest in the use of alternative solid biofuels in energy. Pelleting or briquetting of alternative biomass raw

materials is the best way to optimise the value of solid biomass fuels. Pellets have advantages such as high energy density, uniform physical properties, easy handling and efficient transportation. However, the use of biomass in energy production must be targeted and carefully selected. LCA shows that the hemp incineration causes more damaging effects than for other energy sources, such as peat or wood and other biomass.

7. The MCDA showed that hemp is a good raw material for the production of various products. However, the highest position in the ranking of products is taken by hemp products that can be used in the construction sector: building materials and thermal insulation materials. However, it should be noted that these results are limited to daily non-crisis conditions. During economic and energy crises, the situation is changing significantly, and the most near-perfect solution is the use of hemp for energy production or the production of material (in this case thermal insulation), which increases energy efficiency.
8. The results obtained in the research confirm that the cultivation of hemp (*Cannabis sativa L.)* for targeted production of hemp products with higher added value in Latvia is constituting the basis for replacing the rapeseed fields until 2030.

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