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UNCONVENTIONAL RESOURCES IN THE CONTEXT OF CLIMATE CHANGE: OPPORTUNITIES FOR THE DEVELOPMENT OF THE HEMP MARKET IN LITHUANIA

Vaida GRIŠKEVIČIENĖ*, Vaiva MICKEVIČIENĖ

Vilnius Gediminas Technical University, Vilnius, Lithuania

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Abstract. This article analyses the possibilities for developing non-traditional resources in Lithuania in the context of climate change, with a particular focus on bioeconomic resources such as hemp and their application in industry. Hemp, as an ecological raw material, remains a subject of scientific research that has not yet received sufficient attention, both in terms of assessing its impact on the environment during cultivation and exploring its potential for use in various industrial sectors. As one of the largest sources of pollution, industry can harness the potential of hemp, especially fibre hemp, to reduce the environmental impact of production and promote the creation of environmentally friendly products. An analysis of the processes currently underway in the European Union and Lithuania has identified several key areas: legal regulation, innovation and research, market demand, and service development. Lithuania has developed a comprehensive legal framework that facilitates the cultivation and use of hemp, but research institutions are still not sufficiently exploring the potential uses of fibre hemp in industry. Other industries, such as construction, food, and cosmetics, are already successfully using hemp products in their operations. The greatest potential is expected in segments where hemp products replace materials with a high carbon footprint, but development is limited by a lack of processing capacity, standardisation and regulatory clarity. The growing demand for organic products in Europe opens new opportunities for traditional Lithuanian hemp products. Cooperation with research institutions and innovation development can help farmers and manufacturers better understand the benefits of hemp cultivation and processing. In addition, services related to hemp processing could be developed. The article provides recommendations on how to integrate fibre hemp more effectively into industrial development.

Keywords: fibre hemp, climate change, bioeconomy, market development (Lithuania).

1. Introduction

Cannabis is increasingly being examined in the context of climate change due to the “double” impact of its cultivation and processing chains: energy-intensive indoor cultivation systems (here is used like contextual contrast) can create a significant environmental burden, but industrial hemp is considered to have the potential to contribute to climate change mitigation due to its carbon sequestration potential and bio-based products (Narayana Rao & Korres, 2024; Fernández-Quintanilla & Barroso, 2020). Understanding this balance is important because as hemp markets grow, the environmental significance of the sector increases, and with it the need for policy measures that balance environmental goals, economic efficiency, and social justice dimensions (Narayana Rao & Korres, 2024; Fernández-Quintanilla & Barroso, 2020). For Lithuania, as a member of the European Union (EU), aiming to achieve climate neutrality by 2050 and increasing its GHG reduction ambitions for 2030, measures to reduce emissions not only in energy but also in material and product value chains are becoming increasingly relevant (OECD, 2023; European Commission, 2024). In this context, non-traditional bioeconomy resources, including fibre hemp, are important because the knowledge-based circular bioeconomy in Lithuania is identified as a strategic direction that can increase resilience and create greater added value from biomass (Vitunskienė et al., 2023). Scientific literature emphasizes that quantitative assessment of the impact of hemp on the climate (especially the aspect of social sustainability, as well as data on the cultivation and processing chain) is still at an early stage, therefore there is a lack of comparable, context-reflective evidence and further research is needed (Kaur & Kaur, 2023). The practical industrial application of hemp fibre is also limited by technological maturity and a lack of innovative research in these areas (Zimniewska et al., 2022).

Purpose of the paper: to analyze the climate-change mitigation potential and market development prospects

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* Corresponding author. E-mail: *vaida.griskeviciene@vilniustech.lt*

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of fibre hemp in Lithuania through a LCA- based framework perspective, identifying priority value-chain segments based on climate benefit and implementation feasibility. **Methods** combine structured literature and policy synthesis; findings are secondary-data-based and context-limited. Where LCA concepts are invoked, estimates are contingent on the selected functional unit and system boundaries, co-product handling, and data gaps; without context-specific primary LCI, results should be treated as screening-level and interpreted cautiously.

2. Climate and best practices: fibre hemp as a resource for climate change mitigation and the circular bioeconomy

The European Union (EU) Green Deal sets out a transition to a climate-neutral economy, while circular economy actions emphasize the need to reduce resource use and pollution throughout the value chain (European Commission, 2020). Therefore, industrial decarbonisation is increasingly associated not only with energy efficiency, but also with material substitution: raw materials with a high carbon footprint are being replaced by bio-based alternatives, and products are being designed for durability, repair and recyclability (European Commission, 2020). At the same time, it is emphasized that a significant part of the impacts related to EU consumption and industry occur outside the EU, so climate and circularity goals inevitably include supply chain transparency and raw material selection (European Parliamentary Research Service, 2022). In this discourse, fibre hemp (*Cannabis sativa* L.) should be considered a bioeconomic "platform" resource, as its biomass can be used in several sectors: fibre for textiles and composites, shives for building materials (e.g., insulation, hemp-lime/hempcrete mixtures), and seeds and oil for food and cosmetic products (European Commission, 2018). However, biological origin alone does not guarantee climate benefits: the actual impact depends on decisions made throughout the entire life cycle – from cultivation (inputs, harvesting) and processing (energy, water, chemicals) to product use and end-of-life scenarios (reuse, recycling, biodegradation) (European Commission, 2020). Therefore, the EU Circular Economy Action Plan emphasizes systemic transformation through product design and material cycles, rather than individual "greener" raw materials (European Commission, 2020).

Scientific literature consistently shows that the LCA (Life Cycle Assessment) method is necessary to avoid "greenwashing" errors: in comparisons of textile fibres, hemp is often cited as a potentially lower-impact alternative, but the results are highly sensitive to assumptions about cultivation practices, yield, and fibre processing (La Rosa & Grammatikos, 2019). Similarly, in the construction sector, hemp-lime/hempcrete solutions are considered promising for reducing embodied emissions, but their climate impact depends on the recipe (the ratio of hemp to binder), transport distances, and the scope of the analysis (e.g., cradle-to-gate or cradle-to-grave), Therefore, LCA-based assessments are needed, rather than general assumptions about "carbon negativity" (Shanbhag et al., 2024). Thus, the greatest potential for fibre hemp in a climate-neutral economy is likely to be found where it actually replaces high-footprint materials and where the value chain is managed from raw material to standardized product (European Commission, 2018, 2020; Morgan et al., 2021; Mettu et al., 2023; Warren, 2021). In the Lithuanian context, this means prioritizing not only the expansion of cultivation, but also the creation of a processing-standardization-market structure that allows hemp fibre to be integrated into industrial flows, especially in textiles and construction (European Parliamentary Research Service, 2022).

3. The environmental footprint of hemp cultivation

The Transnational Institute (TNI) policy brief "Cannabis and Climate" from 2022 points out that environmental concerns often take a back seat in discussions about cannabis regulation. The environmental impact of cannabis cultivation is highly variable and depends on the cultivation model, technological base, and resource management decisions. In terms of energy consumption, indoor cultivation typically has the highest impact (see Figure 1): it is estimated that in the US, such cultivation can consume up to 595 PJ of energy per year and generate approximately 44 Mt of CO_2 equivalent emissions per year (roughly equivalent to the emissions of ~10 million cars), with lighting and heating, ventilation, and air conditioning (HVAC) systems having the greatest impact (McGrail et al., 2025; Morgan et al., 2021; Summers et al., 2021).

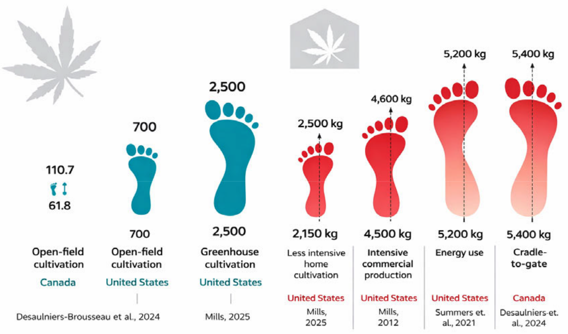

Figure 1. Carbon footprint of outdoor cannabis cultivation (kg of CO_{2e} produced per kg of dry flower) (source: United Nations Office on Drugs and Crime, 2025a)

In contrast, open-field cultivation typically has a significantly lower climate footprint: compared to indoor systems, emissions can be up to 76% lower and the carbon footprint up to 50 times smaller (Summers et al., 2021; Mettu et al., 2023). However, even in energy-intensive systems, it is possible to reduce the impact: more efficient LED lighting, optimized photoperiods, and advanced HVAC technologies (e.g., LDAC) reduce electricity demand and GHG emissions, while supplemental CO_2 supply, although promoting growth, can worsen the overall emissions balance; Therefore, the reuse of industrial CO_2 streams is being considered (Asiimwe et al., 2022; De Prato et al., 2022; Dillis et al., 2020). The water dimension is particularly sensitive in drought-prone or limited-access regions: hemp can require as much as 22.7 L of water per plant per day, so intensive cultivation increases competition for water resources (Fraser, 2019). Technological solutions can improve efficiency: supplemental lighting in greenhouses increases water use efficiency by about 35%, while underground drip irrigation in outdoor systems reduces water consumption by 18.6% and weed growth by up to 90%. In addition, indirect water consumption, embodied in energy production, is also important in indoor systems (Baier et al., 2022; Trancoso et al., 2022; McGrail et al., 2025; Summers et al., 2021).

In addition to energy and water, air quality is also an important consideration: hemp emits biogenic volatile organic compounds, whose emissions increase after harvesting and processing, deteriorate indoor air quality, and may contribute to ozone formation (Morgan et al., 2021; Dillis et al., 2020; Corredor-Perilla et al., 2025). The need for chemical inputs depends on practices: fertilizer use in outdoor systems can increase the risk of eutrophication, but innovations (e.g., hydroponics and recirculating systems) can increase resource use efficiency and improve yields (Zheng et al., 2021; Speer et al., 2025; Hahm et al., 2025). In summary, the greatest challenges are most often associated with indoor cultivation due to energy and indirect water costs, while outdoor and greenhouse systems are more likely to reduce impacts (McGrail et al., 2025; Morgan et al., 2021; Summers et al., 2021). However, progress is hampered by regulatory fragmentation and uneven environmental compliance, so sustainability policies (like energy efficiency requirements or promoting field cultivation) need to be developed in a context-sensitive way and integrate social goals, while in water management, data comparability remains an issue in many regions (Narayana Rao & Korres, 2024; Mills, 2025; McGrail et al., 2025; Yarnell et al., 2022; Firth et al., 2022; Jakka & Hammond, 2023; Jesmin et al., 2025; Danilova et al., 2025; Büser et al., 2025).

4. Hemp as a carbon sink and a resource for mitigating climate change

Climate change affects hemp cultivation through altered growing conditions, which influence yield, quality, and chemical compound profiles. Higher temperatures and higher humidity have been found to increase seed (grain) yield but reduce cannabidiol (CBD) concentration, while fibre yield is typically optimized under cooler and wetter conditions (Vernon et al., 2023). At extremely high temperatures (around 45 °C), cannabinoid biosynthesis genes are activated and CBD and cannabinol (CBN) levels increase, while high relative humidity is associated with lower cannabinoid concentrations and delayed flowering (Madden et al., 2022; Hahm et al., 2025). The literature emphasizes that environmental factors often have a greater influence on cannabinoid production than genetic differences, although the responses of different varieties may vary (Zipper et al., 2022; Kamminga & Me, 2025). At the same time, climate change is changing the pressure from pests and weeds, increasing the uncertainty of control (Hammami et al., 2022; Arehart et al., 2020). This makes adaptive practices (e.g., integrated pest management, ecologically based weed control, precision farming solutions) and selection are becoming increasingly important, as varieties differ in their sensitivity to heat and drought, which is reflected in biomass and cannabinoid yields (Duong et al., 2023; Vernon et al., 2023; Kamminga & Me, 2025; Nabila et al., 2025). Thus, climate change affects hemp agricultural performance through changes in growing conditions, variation in biochemical profiles, and dynamics of biopests, making it critical to increase resilience through management and breeding (Vernon et al., 2023; Denton et al., 2025; Madden et al., 2022).

Industrial hemp is also valued as a means of mitigating climate change due to carbon sequestration in biomass and soil and the possibility of "locking" carbon in long-lasting bioproducts. Empirical estimates show that hemp can sequester more carbon than it emits: capture rates are estimated at around 10–22 t CO_2/ha per year, and long-term soil organic carbon gains over 100 years could be around 25.8 t/ha (Wang et al., 2020). This potential is linked to adaptation to different soil and climate conditions and root system architecture, which increases underground carbon inputs (Speer et al., 2025; Mtewa et al., 2024). Hemp-based bioproducts are also an important direction: for example, hempcrete and hemp insulation materials can, in some estimates, achieve a negative life cycle CO_2 balance and outperform conventional building materials in terms of carbon footprint and energy savings, but the results depend on the boundaries and assumptions of the system (Warren, 2021; Dillis et al., 2023). In addition, bioplastics and composites are highlighted as more sustainable, (bio)degradable alternatives associated with an additional sequestration effect. Residue management (e.g., surface leaving, mulching) also significantly affects soil carbon accumulation, and root contributions are considered particularly important in literature. However, sequestration rates vary regionally, as they depend on soil type, climate, and farming practices (Urso et al., 2023; Mills, 2025). However, there is too little data to draw deeper insights. In summary, the climate change mitigation potential of industrial hemp stems from carbon accumulation in biomass and soil and carbon storage in long-lived bioproducts, but its realization depends on agronomic practices, residue management, and the scale of technological solutions.

5. The situation in the EU and Lithuania: regulation, innovation, market, and value chain

The EU political context creates favourable conditions for non-traditional bioeconomic raw materials: the updated EU bioeconomy strategy emphasizes the role of a sustainable bioeconomy in addressing climate change, ecosystem degradation, and dependence on non-renewable resources, while highlighting the importance of innovation, standards, and market confidence for bio-based products (European Commission, 2018). The green course and circular economy trends also signal that alternative fibres and materials gain an advantage when they meet regulatory and market criteria (e.g., eco-design, traceability, recyclability, quality requirements) (European Commission, 2020, 2022). In the case of fibre hemp, institutionalized separation from narcotic hemp is also important: at the EU level, cultivation is linked to Common Agricultural Policy (CAP) measures and clear requirements (certified seeds, THC limit), which reduces legal risks and facilitates the planning of investments in processing (European Commission, n.d.).

A legal framework has been established for the fibre hemp sector in Lithuania: The Fibre Hemp Law defines activities ranging from cultivation (selection of seeds, crops, etc.) to product harvesting, manufacturing, and market supply (Lietuvos Respublikos Seimas, 2013). There is no single public indicator for assessing the actual market volume, as the value chain covers different activities and is not consolidated into a single register. The closest public indicator covering the supply of products to the market is the list of fibre hemp product suppliers published by the State Plant Service: The list, updated on 4 December 2025, includes 316 entities (legal and natural persons), so this number reflects the volume of suppliers-entities rather than the number of "companies" in the narrow sense (Valstybinė augalininkystės tarnyba prie Žemės ūkio ministerijos [VATŽŪM], 2025). In addition, it is noted that 165 growers (economic entities) declared fibre hemp in 2022, but this indicator is not identical to the number of legal entities (VATŽŪM, 2022). According to the law, fibre hemp (*Cannabis sativa* L.) can only be grown in Lithuania in accordance with national regulations, and agronomically it grows best in fertile, well-drained soils; Therefore, in practice, it is important to manage moisture and nutrients according to the intensity of the farm (Lietuvos agrarinių ir miškų mokslų centras, 2023). Lithuanian hemp growers must comply with the following requirements: grow hemp only outdoors, in a single field; sow only varieties permitted by EU legislation; use only certified seeds; declare hemp crops; provide information on cultivation, areas, and flowering; declare warehouses, storage, retting, and overwintering sites; report on hemp grown for fibre and on the use of purchased seeds (Jonaitienė et al., 2016; Lietuvos Respublikos Seimas, 2013).

However, regulation alone does not guarantee industrial breakthrough if the weakest link remains processing, standardization, and innovation. This is also reflected in the priorities of the public sector: in 2024, the Ministry of Economy and Innovation presented initiatives aimed at promoting the processing of fibre hemp and increasing the competitiveness of the sector, which indirectly indicates that processing is considered a strategic "bottleneck" (Lietuvos Respublikos ekonomikos ir inovacijų ministerija, 2024). On a practical level, there are companies in Lithuania that declare the cultivation and processing of hemp fibre, but the scale of the industrial ecosystem, quality infrastructure, and standardization base remain key issues if systematic integration into the textile or construction industry is to be achieved (Natural Fibre, n.d.; European Commission, 2022).

In terms of research and innovation, it is appropriate to assess the situation in Lithuania through the prism of life cycle assessment (LCA) and value chains, identifying hot spots and data gaps (European Commission, 2020). Empirical studies emphasize that the impacts of outdoor systems have long been less studied than indoor production, and even with reduced direct energy intensity, issues of fertilizer and other input management remain significant; Therefore, LCA must cover the entire cycle (Desaulniers Brousseau et al., 2024).

The value chain can be conceptualized in five stages. (1) Cultivation and raw material preparation: the climate effect is determined by inputs (fertilizers, fuel), yield stability, and whether the raw material is directed to higher value segments (La Rosa & Grammatikos, 2019). (2) Primary processing: often becomes an infrastructural bottleneck due to the need for capital, technology, and economies of scale (Lietuvos Respublikos ekonomikos ir inovacijų ministerija, 2024). (3) Secondary processing and manufacturing: particularly important in textiles, where strict quality parameters and standardisation are required (European Commission, 2022). (4) Market entry: increasingly dependent on certification, traceability, and B2B buyer requirements, reinforced by the EU textile strategy and related policy signals (European Commission, 2022; European Parliamentary Research Service, 2022). (5) End of life: circular economy measures are increasing requirements for collection, reuse, and recycling (European Commission, 2020).

In summary, it can be said that EU policy creates targeted demand for sustainable materials and sets quality and traceability criteria, while Lithuania's legal framework allows the sector to function. However, the decisive factors for industrial development are processing capacities, standardisation and quality infrastructure, and a research and innovation agenda that would generate LCA data under Lithuanian conditions and create a "body of evidence" for industrial decisions (European Commission, 2018, 2020, 2022; Lietuvos Respublikos ekonomikos ir inovacijų ministerija, 2024).

6. Fibre hemp development cesses in Lithuania: current situation and factors

The results of the “climate value” of fibre hemp (*Cannabis sativa* L.) are particularly sensitive to regional conditions, product composition, and life cycle assessment (LCA) assumptions, so their impact cannot be assessed universally, in isolation from the specific context and chosen system boundaries (International Organization for Standardization [ISO], 2006a; Philp, 2018; Rivas-Aybar et al., 2023; Shanbhag et al., 2024). The development of the Lithuanian market is significantly dependent on regulatory limits: cultivated varieties must comply with the 0.3% THC limit and be certified (European Commission, n.d.). At the same time, the food segment is strongly influenced by the “novel food” regime, under which new products (including CBD) can only be placed on the market after authorization, and the practical application of the regulation is complicated by gaps in safety assessment data; National guidelines clearly emphasize the link between CBD/extracts and this regulation (European Parliament and the Council of the European Union, 2015; European Food Safety Authority, 2022; Valstybinė maisto ir veterinarijos tarnyba, 2025). However, hemp is not a new product on the Lithuanian market, and there is a wide range of uses and product types (see Figure 2).

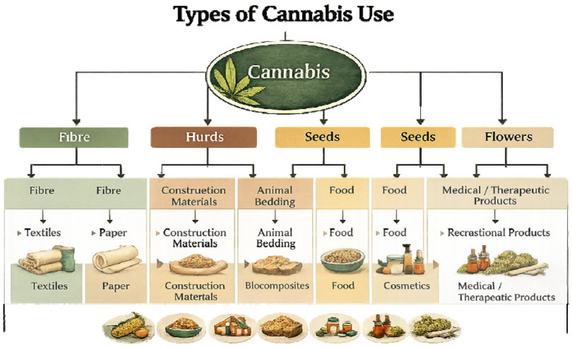

Figure 2. Map of hemp varieties and uses (source: compiled by the authors using MindMap software, based on MPortland (2017), EC (2026), etc.)

The wide range of uses and products made from fibre hemp increases the economic resilience of the sector, as it allows for diversification of demand and reduces dependence on a single, regulation-sensitive segment (e.g., the CBD food market). At the same time, it creates the conditions for cascading biomass use and higher added value, as different raw material streams (fibre, shives, seeds) are directed to different industries. Such multi-sector applicability facilitates the scaling up of processing infrastructure, as technological investments can be amortized across multiple markets and product categories. Finally, it provides more “entry points” to the market under different regulatory regimes, allowing expansion to continue in less restrictive directions while more complex segments undergo authorization and standardization processes. The article goes on to analyse the prospects for developing fibre hemp in Lithuania and whether its applications have potential under local conditions.

7. Historical significance and contemporary prevalence of hemp

Hemp is one of the oldest cultivated fibre crops. Archaeological and archaeobotanical evidence confirms its long-term cultivation in East Asia and subsequent spread to other regions, although early interpretations (e.g., ceramic “string impressions”) remain debated (Brand & Zhao, 2017; Dal Martello et al., 2023; The Power of Hemp, 2022). Chemical and laboratory analyses indicate ritual use in the Pamir region around 500 BC, while written and archaeological sources associate hemp with fibre production and early papermaking in China (Ren et al., 2019; Ma et al., 2025; Brand & Zhao, 2017).

In contemporary Europe, hemp cultivation has expanded significantly. The cultivated area in the EU increased from 20,540 ha in 2015 to 33,020 ha in 2022 (+60%), while fibre production rose from 97,130 t to 179,020 t (+84.3%) (European Commission, 2025). France accounts for more than 60% of EU production, followed by Germany (17%) and the Netherlands (5%). This growth reflects renewed interest in hemp as a bio-based raw material within circular economy and decarbonisation strategies.

Archaeological findings confirm the long-standing presence of hemp in Lithuania. Hemp grains discovered in Middle Neolithic (3500–3000 BC) Narva culture settlements in Šventoji, including hemp rope remains, demonstrate practical fibre use dating back at least 5,500 years (Petkevičius, 2017). This tradition was interrupted during the Soviet period due to regulatory restrictions.

Modern reintroduction is linked to evolving legal frameworks. International regulation of hemp fluctuated throughout the 20th century, institutionalising a distinction between industrial (low-THC) and narcotic forms. In Lithuania, separate regulation was established by the Law on Fibre Hemp (No. XII-336), effective 1 January 2014, defining cultivation, processing, and market supply procedures (Lietuvos Respublikos Seimas, 2013; Kanapės galia, 2022).

Thus, hemp’s “dual identity” is legally embedded, and reliable historical interpretation emerges where archaeobotanical, chemical, and legal sources converge (Brand & Zhao, 2017; Dal Martello et al., 2023; Ren et al., 2019; Petkevičius, 2017; Lietuvos Respublikos Seimas, 2013; Kanapės galia, 2022). From a market-development perspective, regulatory clarity is a key enabling condition for scaling production and integrating hemp into climate mitigation strategies.

8. Hemp characteristics and prospects in the Lithuanian context

Within the Cannabaceae family, the genera Cannabis and Humulus are recognised; taxonomic debate persists regarding species classification within Cannabis (Flores-Sanchez & Verpoorte, 2008; Hartsel et al., 2016). For regulatory and market purposes in the EU, industrial hemp is defined as *Cannabis sativa* L. varieties containing ≤0.3% tetrahydrocannabinol (THC) (Adhikary et al., 2021; Malayil et al., 2024; Lietuvos Respublikos Seimas, 2013).

Hemp is a short-day, photoperiod-sensitive annual crop (Meijer et al., 1995). Agronomically, planting density, harvest timing, and end-use orientation (fibre, seed, cannabinoids) determine biomass allocation and material properties. Dense sowing promotes stem elongation and reduces branching, producing longer and stronger fibres suitable for textile and construction applications (Amaducci et al., 2002).

From an industrial perspective, hemp stems yield three main fractions: long fibres, short fibres, and shives/hurds (Moulana, 2012). On average, stalks consist of approximately 25% fibre and 75% shives (Kolodziej et al., 2012). This multiproduct structure is particularly relevant in LCA modelling, as allocation choices influence environmental results and substitution credits.

Hemp seeds contain approximately 30% protein (including essential amino acids), ~30% oil, and ~25% carbohydrates, making them comparable to soybeans in nutritional value (Callaway, 2004). Female inflorescences produce cannabinoids such as CBD; commercial CBD production often relies on cloned female plants (Dingha et al., 2019). While relevant for market diversification, cannabinoid-oriented systems differ significantly from fibre-based production in input intensity and environmental profile.

Harvest timing varies across European countries depending on end use (Jonaitienė et al., 2016). For fibre production, harvesting at or shortly after flowering generally optimises fibre quality. In Lithuania, hemp is cultivated for both seed and fibre, but sector development remains limited. According to the Hemp Growers and Processors Association (2025), knowledge gaps and regulatory stringency may constrain expansion.

From a climate mitigation and LCA perspective, the most relevant characteristics of hemp in Lithuania are:

- high biomass productivity under temperate conditions,
- dual-output potential (fibre and shives),
- substitution capacity in carbon-intensive sectors (textiles, construction),
- compatibility with EU low-THC regulatory standards.

Therefore, botanical and agronomic characteristics are not treated here descriptively, but analytically — as determinants of yield stability, material performance, allocation modelling, greenhouse gas balance, and economic feasibility within Lithuanian bioeconomy development.

9. Analysis of the life cycle of fibre hemp in Lithuania

After reviewing the scientific literature, this section formulates recommendations and assesses the prospects for hemp cultivation and use in Lithuania through a life-cycle perspective. The analysis is summarized in the Figure 3 below.

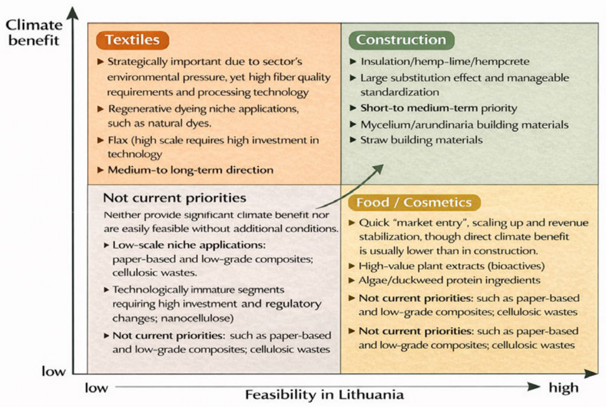

Figure 3. Logic behind the selection of priorities for the development of the Lithuanian hemp market in the context of its impact on the climate (source: created by the authors using MindMap software)

The Figure 3 explains why construction can be treated as a short- to medium-term priority (high climate-benefit potential combined with comparatively high feasibility), why textiles remain strategically important but typically require longer implementation horizons due to stricter quality and processing requirements, and why food/cosmetics may function as a high-feasibility market channel that can support farm-level economics and scale while other value-chain segments mature. As can be seen, Figure 4 explains all the LCA stages.

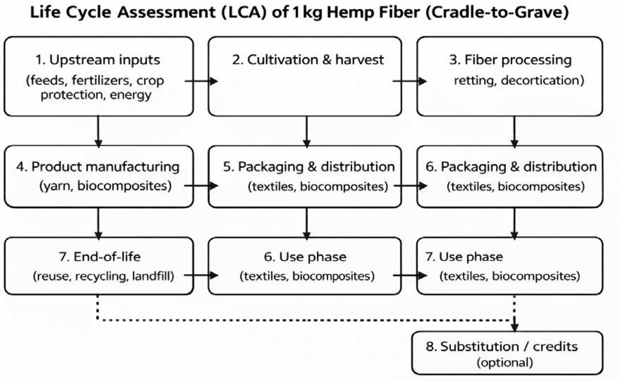

Figure 4. Life Cycle Assessment (LCA) of 1 kg Hemp Fibre (Cradle-to-Grave) (source: created by the authors using MindMap software)

Figure 4 presents a cradle-to-grave life cycle assessment (LCA) logic for 1 kg of hemp fibre, covering inputs (e.g., seeds, fertilizers, energy) and cultivation through pre-processing, processing, logistics, use, and end-of-life pathways. At each stage, the key inputs (energy, water, materials, transport) and outputs (emissions, wastewater, waste) are identified to enable calculation of climate-change impacts (kg CO_2e) and other environmental indicators. Because the hemp value chain typically produces multiple outputs (most importantly fibre and hurds, and in some chains also seeds), the LCA must explicitly state how co-products are handled—either via an allocation rule or via system expansion—since this choice can materially change results and comparability. A separate "substitution/credits" block is included to reflect that hemp-based products may replace higher-footprint alternatives; however, any "avoided impacts" must be supported by a transparent scenario and consistent methodological choices (system boundaries, functional equivalence, and data quality). This framing follows general LCA principles and is consistent with literature emphasizing the importance of well-defined boundaries, comparable inventory data, and harmonized methods when assessing hemp systems (Zheng et al., 2021; Wartenberg et al., 2021; Vance et al., 2022; Shen et al., 2022; Kamminga & Me, 2025).

This structure is consistent with ISO LCA methodology, which requires a clearly defined functional unit, system boundaries, life-cycle inventory (LCI), impact assessment, and interpretation, rather than conclusions drawn solely from the biological characteristics of the crop (ISO, 2006a, 2006b). In practical terms, the table serves as a "roadmap" linking climate-benefit mechanisms with potential hotspots, Lithuania-specific data priorities, and actionable interventions—thereby reducing uncertainty for research planning, policy design, and investment decisions.

Thus, without Lithuania-specific LCI data, reliable LCA comparisons remain limited and sensitive to methodological choices (ISO, 2006a, 2006b).

10. Conclusions

The climate benefits of fibre hemp as a non-traditional bioeconomy resource are primarily realised through substituting higher-carbon materials and through decisions made across the full life cycle; therefore, impacts are contextual and depend on regional conditions, product composition, and assessment boundaries. In Lithuania, development should concentrate on pathways where substitution can be demonstrated and products can be standardised and integrated into industrial value chains within a realistic timeframe. Building materials (insulation, hemp-lime/hempcrete) represent the most immediate priority due to their potential to reduce embodied emissions, provided that engineering-grade quality control and standardisation are established. Textiles and technical textiles remain strategically important under tightening supply-chain requirements, but progress is constrained by demanding fibre-quality specifications and processing technology barriers. Food and cosmetics can support farm-level revenue diversification and scale, yet their substitution-based climate effect is typically lower than in construction or textile applications.

Sector development is currently limited by regulatory uncertainty, insufficient processing infrastructure, immature standardisation and quality-assurance systems, and weak demand channels. Accordingly, priority should be given to an enabling environment that reduces investment uncertainty: clear rules, testing and certification capacity, targeted support for processing infrastructure, and pilot implementation (including public procurement where feasible). Businesses should pursue value-chain integration through clusters, long-term feedstock contracts, and harmonised quality specifications and traceability to meet B2B requirements. Scientific institutions should generate Lithuania-specific LCA data, run demonstration projects with industry, and support technology transfer into practice. Together, these measures would reduce investment risk, enable economies of scale, and accelerate credible market uptake of hemp-based solutions, especially in construction and, in the longer term, textiles.

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