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BIOTRANSFORM
TRANSITION PATHWAYS TO CIRCULAR BIO-ECONOMY

Circular bioeconomy transformation for regions by enabling resource and governance networks

D3.2 Transition roadmaps from linear fossil-based to a circular bioeconomy of our case-studies

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Authors

First Name	Last Name	Beneficiary
Johannes	Kisser	CluBE
Regional case study contribution by		
Janne	Keränen	VTT
Eetu	Nissinen	VTT
Marta	Macías Aragonés	CTA
Carmen	Ronchel Barreno	CTA
Theodora	Kalea	CluBE
Brena	Gaspar	CluBE
Anastasia Zafeiroula	Perouli	BioEastHUB
Peter	Stoffels	CLIB
Tatjana	Schwabe-Marković	CLIB
Johannes	Kisser	CluBE
Content contribution by		
Astrid	Stalmans	VITO
Annelies	De Meyer	VITO
Ruben	Guisson	VITO
Gitanjali	Thakur	LIST

Quality Reviewers

First Name	Last Name	Beneficiary
Peter	Stoffels	CLIB
Tatjana	Schwabe-Marković	CLIB
Kirsi	Kataja	VTT

In case you want any additional information, or you want to consult with the authors of this document, please send your inquiries to: johanneskisser.circular@gmail.com

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Table 1: Terms and Definitions

Abbreviation	Definition
aws	Austrian Wirtschaftsservice
CAP	Common Agriculture Policy
CBE JU	Circular Bio-based Europe Joint Undertaking
CCRI	Circular Cities and Regions Initiative
CO_2	Carbon dioxide
DEC	Dissemination and Exploitation Activities
ECBF	European Circular Bioeconomy Fund
ERDF	European Regional Development Fund
FDCA	2,5-Furandicarboxylic acid
FFG	Austrian Research Promotion Agency
GDP	Gross Domestic Products
GHG	Greenhouse gas
H2	Hydrogen
IAT	Impact assessment tool
JRC	Joint Research Centre - European Commission
KEM	Climate and Energy Model Regions in Austria
KLAR	Climate Change Adaptation Regions in Austria
KPC	Kommunalkredit Public Consulting Austria
LA/ PLA	Lactic acid/poly-lactic acid
MAA	Multi-actor approach
MCA	Multi-Criteria Assessment
MDF	Medium-density fibre board
MooV	Logistics optimization tool, provided by VITO
NRW	North Rhine-Westphalia
OFMSW	Organic fraction of municipal solid waste
PHA	Polyhydroxyalkanoate
PPPP	Public-Private-People Partnership
RFA	Resource flow analysis
RUI-S	Rural-urban-industrial symbiosis
SBP	Sugar beet pulp
SDGs	Sustainable Development Goals by the United Nations
SME	Small and medium enterprise

1. Executive Summary

This Deliverable D3.2 presents detailed, actionable transition roadmaps for six European case-study regions of the BIOTRANSFORM project - Andalusia (Spain), Northern Burgenland (Austria), Western Macedonia (Greece), Finland, Charles Spa Region (Czech Republic), and North Rhine-Westphalia (Germany) - supporting their shift from linear fossil-based systems to circular bio-based systems.

Building on BIOTRANSFORM's integrated assessment package (resource flow analysis, sustainability assessment, and logistics optimisation), the project co-created optimal regional pathways using a multi-actor approach. Stakeholders were actively engaged in co-definition, validation, and capacity-building workshops to ensure ownership and long-term applicability. The resulting roadmaps outline milestones, governance models, and policy recommendations tailored to local contexts, while identifying high-potential bio-based conversion routes and resource synergies.

The regional roadmaps are aligned with the EU Bioeconomy Strategy (2018), the Circular Economy Action Plan (2020), and national/regional S3 and S4 strategies. They contribute to strategic goals under the Green Deal, Just Transition Mechanism, and the Circular Bio-based Europe Joint Undertaking (CBE JU) by enabling systemic transformations in key regional sectors.

In addition to supporting EU policymakers with replicable models, D3.2 also feeds into the development of easily accessible guidance materials for public authorities, as delivered in D3.3 (a transition guideline overview as DEC), D4.1 (methodology on governance and financing), D4.3 (final joint policy brief), and supported by dissemination activities under WP5. The combined efforts aim to catalyse a pan-European transition towards regenerative, resilient, and place-based circular bioeconomies.

2. Introduction

The BIOTRANSFORM project supports the transition from linear fossil-based to circular bio-based systems by equipping European policymakers and regional stakeholders with practical tools, methodologies, and co-created solutions. Operating at the intersection of circular economy and bioeconomy transitions, the project facilitates systemic change across six diverse case-study regions: Andalusia (ES), Northern Burgenland (AT), Western Macedonia (EL), North Rhine-Westphalia (DE), the Charles Spa Region (CZ), and Finland. These regions represent a spectrum of sectors including agri-food, forestry, water ecosystems, chemical industry, and energy production. All these sectors need to transition towards circular bio-bioeconomy to become (more) sustainable.

Deliverable D3.2 presents detailed transition roadmaps developed collaboratively with regional stakeholders in each of the case-study regions. These roadmaps synthesise the findings of WP3 tasks T3.2 and T3.3 and apply BIOTRANSFORM's assessment package to real-world transformation pathways. The deliverable also reflects the iterative feedback processes and capacity-building workshops that were carried out to ensure practical relevance, ownership, and local applicability of the proposed transitions.

Aligned with the EU Bioeconomy Strategy, the Circular Economy Action Plan, the Green Deal, and the CCRI framework, these roadmaps aim to contribute actionable insights and models for wider replication. The BIOTRANSFORM project wants to provide local and regional actors with assistance in an easy-to-use format, which is the key to joint implementation. The objective is to pave the way for regional partnerships, supported by multi-level governance, which apply bioeconomy principles and achieve the necessary economic, social, and environmental transition.

2.1 Background and objectives

The shift towards a sustainable and regenerative European economy demands that regions become active agents in the transformation process. Building on the findings from Tasks 3.1, 3.2, and aligned with Task 3.3 of the BIOTRANSFORM project, this deliverable outlines tailored regional roadmaps as core instruments to operationalise the bio-based transition.

The objectives of this deliverable are to:

- Present region-specific transition pathways co-developed with local stakeholders and tested through BIOTRANSFORM's assessment tools.
- Define actionable milestones and circular economy strategies for each case study area, emphasising rural-urban-industrial symbiosis and value cycle optimisation.
- Strengthen the policy-relevance of transition pathways by linking them to existing strategies, infrastructure, and investment plans at regional and EU level.
- Provide a replicable structure for other regions aiming to develop similar roadmaps.

The roadmaps consider future trends, resource availability, stakeholder readiness, and economic feasibility, integrating feedback from capacity-building workshops and co-creation sessions held during the implementation phase. Through this approach, BIOTRANSFORM seeks not only to test transition models, but also to empower regions with the necessary frameworks, skills, and governance tools to navigate and lead their own circular bioeconomy transition.

2.2 Methodology

The methodology for developing regional transition roadmaps within BIOTRANSFORM is grounded in a participatory, data-informed, and iterative process. It combines qualitative and quantitative assessments to co-create feasible and tailored circular bioeconomy pathways with regional stakeholders. The overall methodological approach follows five core phases:

2.2.1 Mapping of secondary resource streams

The first step consisted in identifying and mapping locally available secondary biogenic resource streams, such as agricultural residues, food waste, or biomass by-products (e.g. olive or vine processing residues, lake resources, lignin). This involved data collection from public datasets, regional statistics, expert interviews, an info day with relevant stakeholders, and earlier project results (WP1), enabling the first outline of several possible resource uses and their conversion routes. This step was guided by existing frameworks on resource assessment and circular bioeconomy indicators [1].

2.2.2 Stakeholder co-creation and pathway selection

In each of the six BIOTRANSFORM case studies, multi-stakeholder workshops were organised to identify challenges, refine use cases, and collaboratively select promising transformation pathways. This participatory phase ensured that the proposed bio-based solutions were not only technically feasible but also aligned with regional priorities, policy contexts, and stakeholder capabilities. Several potential conversion routes were identified per region, which were gradually narrowed down to three key conversion pathways for further analysis with a qualitative colour-coded multicriteria analysis including three potential levels of impact (high, medium, low). In two regions, the final pathways were already selected in this step as clear priorities were pre-given. The individual adaptation of the methodology is described in more detail in D3.1.

2.2.3 Assessment using BIOTRANSFORM tools

The selected pathways were evaluated using the BIOTRANSFORM **assessment package**, composed of three core tools:

- **Resource Flow Analysis Tool**: visualisation and quantification of current and future resource streams in a Sankey diagram to visualise supply, use, losses of current and potential flows;
- **Socio-economic and environmental assessment**: based on multi-criteria analysis (MCA), stakeholder surveys, and LCA where enough data was available. This assessment covered jobs, health, environmental impact, governance, and investment needs;
- **Logistics and scaling tool**: assessing decentralised versus centralised approaches, infrastructure needs, and distribution systems.

[1] Beate El-Chichakli and others, 'Policy: Five Cornerstones of a Global Bioeconomy', *Nature*, 535.7611 (2016), pp. 221–23, doi:10.1038/535221a; Sara Lago-Olveira and others, 'Monitoring the Bioeconomy: Value Chains under the Framework of Life Cycle Assessment Indicators', *Cleaner and Circular Bioeconomy*, 7 (2024), p. 100072, doi:10.1016/j.clcb.2024.100072.

This step enabled a comparative evaluation of the benefits, trade-offs, and implementation needs of each pathway that supported decision-making.

2.2.4 Governance and financing exploration

In parallel, as part of WP4 activities, each region explored the necessary **governance and financing conditions** to enable implementation. This included co-creating potential governance models (e.g. transition broker roles, inter-municipal cooperation, PPPPs), identifying suitable funding instruments (e.g. CAP, ERDF, national circular economy funds), and highlighting institutional and regulatory barriers. These findings are also reflected in this document.

2.2.5 Roadmap formulation and validation

Finally, the preferred pathway per region was consolidated into a **transition roadmap** with milestones, outcomes, and next steps. These were validated in a second round of stakeholder discussions and documented in this deliverable. Where feasible, short- and long-term projections on job creation, investment volumes, and resource substitution were included. The roadmaps are aligned with the overall needs and possibilities of the six case studies and the ambitions of the **Circular Cities and Regions Initiative (CCRI)**.
The figure below illustrates the sequence of steps undertaken, showing how data collection, expert inputs, and participatory validation are interwoven throughout the roadmap development process.

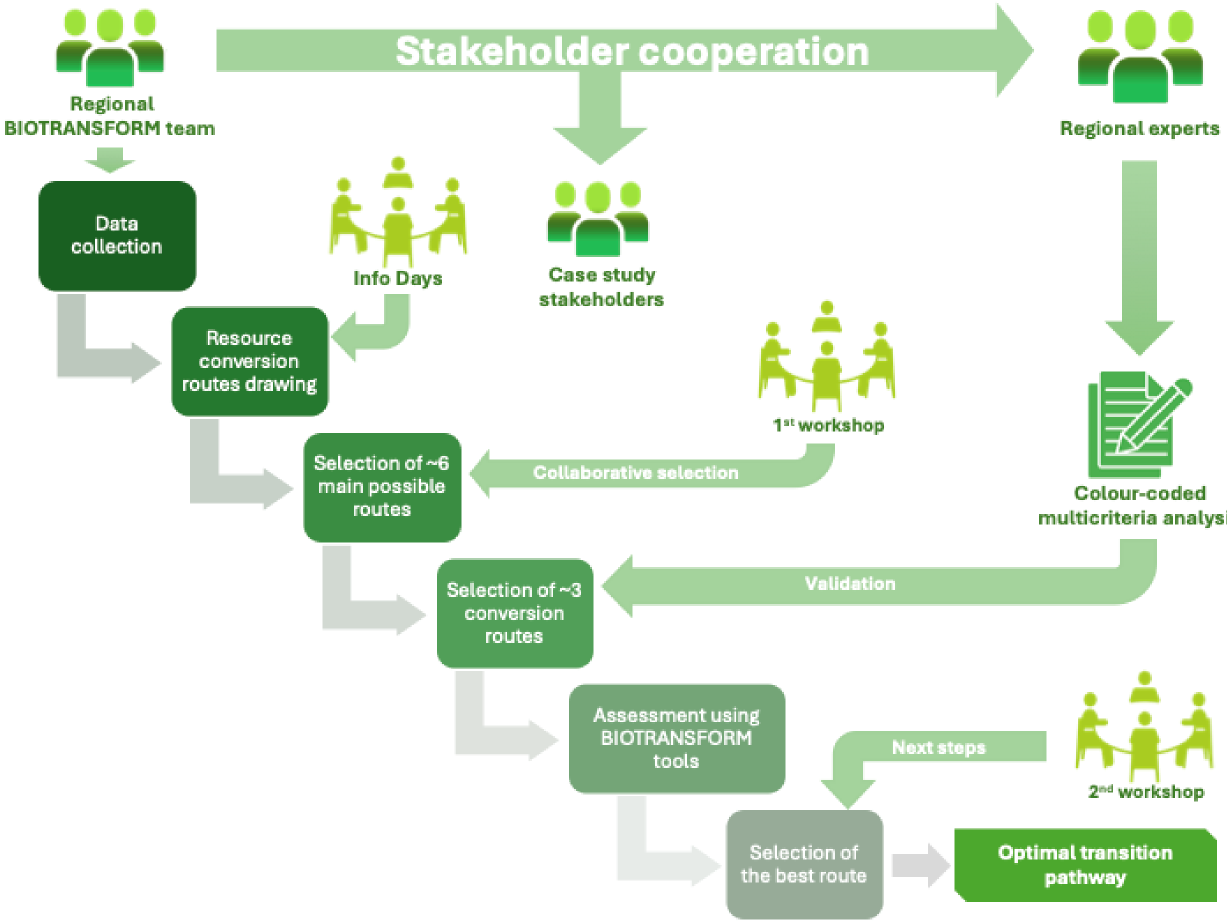

Figure 1: General stakeholder interaction methodology overview

3. Framework for roadmap development

To support regional transitions from fossil-based and linear systems towards circular bio-based economies, BIOTRANSFORM developed a replicable and structured roadmap development framework. This framework guides regions in selecting, evaluating, and implementing transformation pathways based on local realities, stakeholder input, and systemic sustainability principles. Grounded in co-creation, it builds on resource flow mapping, multi-criteria analysis, stakeholder engagement, and policy-financing alignment. The methodology ensures that both regional and European priorities are considered, while enabling long-term systemic change through circularity, resilience, and socio-economic inclusion.

3.1 Core components of the roadmaps

The development of regional transition roadmaps in BIOTRANSFORM followed a structured multi-step methodology, grounded in a **multi-actor approach (MAA)** to ensure legitimacy, feasibility, and regional relevance of proposed bio-based transition pathways (see chapter 1.2). The approach aimed to combine stakeholder knowledge with quantitative assessment tools to co-create actionable and tailored circular bioeconomy strategies.

The following core components were essential in this process:

- **Criteria for pathway selection.** The selection of optimal transition pathways (details in D3.1, selection following WP2 assessments) was based on a set of criteria jointly developed with stakeholders and aligned with regional strategies. These included circularity potential, environmental performance, socio-economic impact (e.g., job creation, skills alignment), technical feasibility, and economic viability. The BIOTRANSFORM multi-criteria analysis (MCA) matrix served as the backbone for comparing pathways.
- **Stakeholder co-creation and engagement.** A structured stakeholder engagement process ensured that the roadmaps were built on local knowledge, needs, and aspirations. Workshops, bilateral meetings, and feedback rounds brought together representatives from policy, business, civil society, academia, and utilities. These interactions allowed regions to define relevant resource flows, assess barriers and enablers, and co-define the most promising pathways. The use of MAA fostered co-ownership and enhanced acceptance of the proposed strategies.
- **Definition of transformation pathways.** Based on a review of regional resource availability (as mapped in WP1), technology options, and existing infrastructure, longlists of potential resource conversion routes were created. These included both high-value and bulk applications (e.g., biocomposites, fertilisers, bioenergy) for secondary resources such as reed, sediments, lignin, olive pomace, and food waste. Stakeholders supported the prioritisation and refinement of these routes.
- **Use of assessment tools.** The three BIOTRANSFORM tools (resource flow analysis, environmental & socio-economic assessment, logistics modelling) were applied to assess the proposed pathways in terms of impacts, costs, and practical implementation conditions. These tools provided a comparative evidence base to select optimal pathways. The assessment process required disaggregated data (e.g., on flow volumes, process efficiencies, logistics distances), co-created with stakeholders where needed.
- **Case-specific adaptability.** Each region adapted the overall roadmap methodology to fit its specific context, including institutional capacity, sectoral focus, and stakeholder maturity. While the steps

followed a common logic, flexibility in implementation allowed each case study to integrate local realities and knowledge systems. This ensured robustness across diverse regional contexts (e.g., rural–urban dynamics, water scarcity, industrial legacies).

- **Milestones and implementation trajectories.** The resulting roadmaps present sequenced implementation milestones, allowing regional actors to plan actions over time. Milestones were informed by the assessment findings, existing governance structures, and funding timelines. The roadmaps also include estimated timelines for pilot actions, infrastructure development, and scaling-up usually in the time horizon until 2050.
- **Circular economy guidance.** The deliverable provides **region-specific circular economy guides** that embed circularity principles (e.g., cascading use, the 10Rs framework, rural–urban–industrial symbiosis). These guides aim to support stakeholders in aligning local strategies with broader EU initiatives such as the Circular Economy Action Plan and the updated EU Bioeconomy Strategy.

Together, these components ensured that the transition pathways developed under BIOTRANSFORM are not only desirable and impactful but also realistic and ready for implementation.

3.2 Integration of Rural-Urban-Industrial Symbiosis

Rural-urban-industrial symbiosis (RUI-S) can be a key enabler of circular bioeconomy transitions, by linking different sectors and geographical regions to enhance resource efficiency. By fostering interconnections between agriculture, urban systems, and industry, RUI-S enables the circular use of materials, energy, and waste, reducing environmental impact and creating economic synergies.

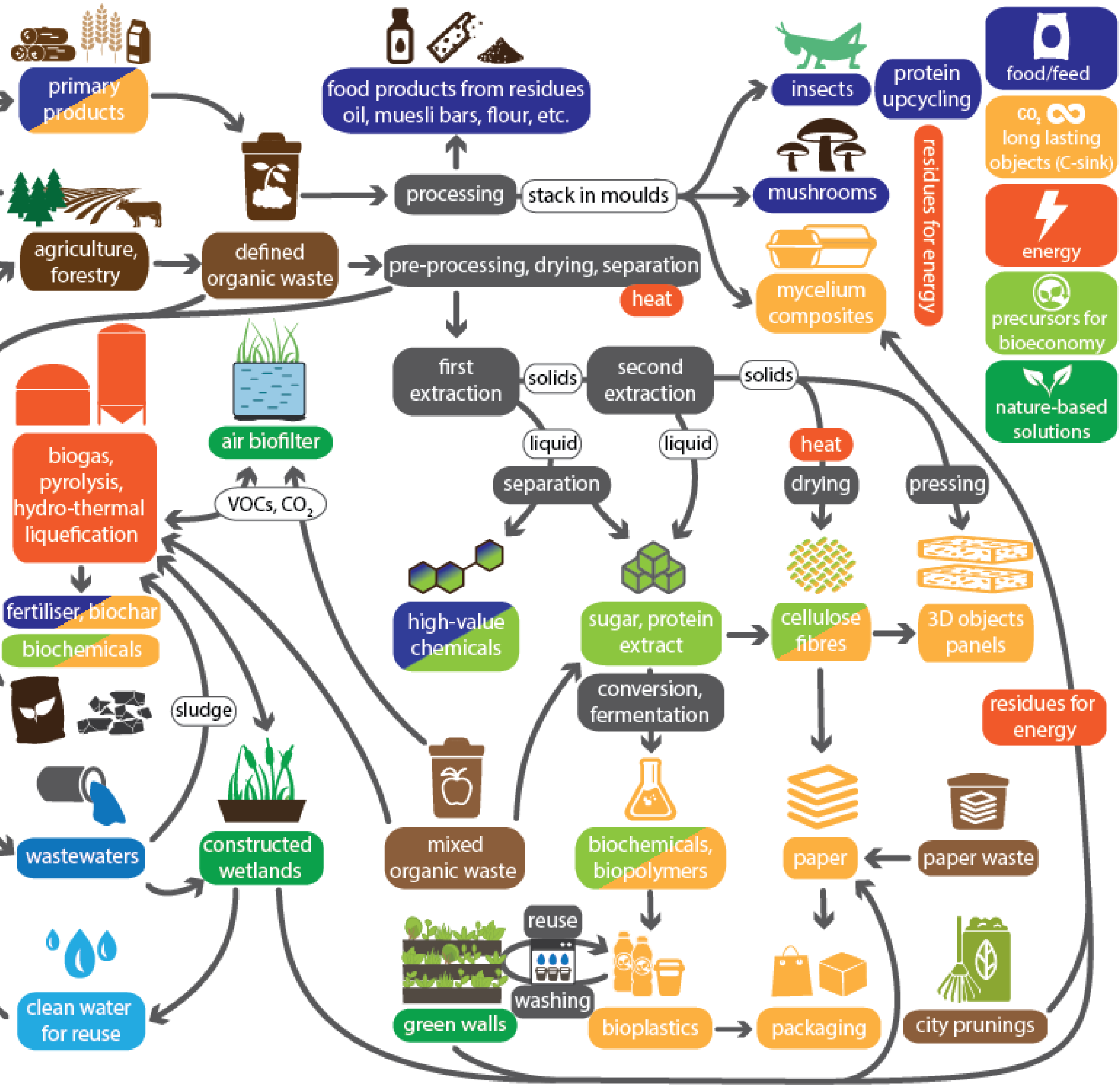

Figure 2: Scheme of process flow integration in symbiosis with agricultural, industrial, and municipal resources

RUI-S has a range of benefits, which were also included in the roadmaps designed in the project:

- Enhancing resource efficiency: Utilisation of agricultural, urban, and industrial byproducts reduces dependency on virgin materials [2].

[2] Ellen MacArthur Foundation, *Completing the Picture - How the Circular Economy Tackles Climate Change*, 2019 <https://www.ellenmacarthurfoundation.org/completing-the-picture>.

- Reducing waste: Encouraging cascading use of bioresources prevents landfilling and open burning [3].
- Fostering innovation: Development of new bio-based solutions through cross-sector collaboration [4].
- Boosting regional economies: Strengthening local value chains and creating employment opportunities in rural and urban settings [5].

The different case-study regions in BIOTRANSFORM provide a range of examples for these integrated value networks and synergies:

Agricultural-industrial synergies

- Utilisation of vineyard prunings and grape pomace for high-value chemicals production and soil improvement [6] as elaborated in the Austrian case.
- Conversion of lake sediments into construction materials and agricultural soil enhancers [7], see details in the Austrian case.

Urban-agricultural linkages

- Recovery of urban organic waste (food scraps, green waste) for composting and soil fertility management in surrounding rural areas [8] (partially developed in Czech case).
- Use of wastewater sludge in controlled applications for soil restoration [9] (wastewater is dealt with in the Greek case).

Industrial-waste utilisation

- Industrial byproducts from wood processing and paper industries used in bio-based panel manufacturing [10] (a possible pathway was developed in the Greek case).
- Integration of biogas production from organic waste streams with district heating and local power grids [11] (see Czech case for example).

Circular logistics & digital platforms

[3] European Commission, *A New Circular Economy Action Plan For a Cleaner and More Competitive Europe*, 2020 <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN>.
[4] OECD, *Meeting Policy Challenges for a Sustainable Bioeconomy* (OECD Publishing, 2018) <https://www.oecd-ilibrary.org/science-and-technology/policy-challenges-facing-a-sustainable-bioeconomy_9789264292345-en>.
[5] CBE-JU, *Strategic Research and Innovation Agenda*, June 2022 <https://www.cbe.europa.eu/system/files/2022-06/cbeju-sria.pdf>.
[6] Nicolae Scarlat and others, 'The Role of Biomass and Bioenergy in a Future Bioeconomy: Policies and Facts', *Environmental Development*, 15 (2015), pp. 3–34, doi:10.1016/j.envdev.2015.03.006.
[7] Audrey Maria Noemi Martellotta and others, 'Reuse of Lake Sediments in Sustainable Mortar', *Environments*, 10.9 (2023), p. 149, doi:10.3390/environments10090149.
[8] Julian Kirchherr, Denise Reike, and Marko Hekkert, 'Conceptualizing the Circular Economy: An Analysis of 114 Definitions', *Resources, Conservation and Recycling*, 127 (2017), pp. 221–32, doi:10.1016/j.resconrec.2017.09.005.
[9] European Environment Agency, 'Briefing. Urban Waste Water Treatment for 21st Century Challenges', *Publications*, 2021 <https://www.eea.europa.eu/publications/urban-waste-water-treatment-for/urban-waste-water-treatment>.
[10] Rosilei Garcia and others, 'Sustainability, Circularity, and Innovation in Wood-Based Panel Manufacturing in the 2020s: Opportunities and Challenges', *Current Forestry Reports*, 10.6 (2024), pp. 420–41, doi:10.1007/s40725-024-00229-1.
[11] IEA Bioenergy, 'Annual Reports – Bioenergy', 2023 <https://www.ieabioenergy.com/blog/document-category/annual-reports/>.

- Establishing regional bio-hubs that facilitate the collection, sorting, and redistribution of bioresources [12] (can be recommended for all cases and is elaborated in the Czech and Austrian case).
- Smart logistics systems for connecting decentralised biomass collection with industrial-scale valorisation [13] (as looked into the Spain case).

3.3 Integration of 10Rs in BIOTRANSFORM

The 10Rs methodology provides a structured approach to maximise resource efficiency in circular bioeconomy strategies. Within BIOTRANSFORM, this framework serves as a foundation for developing sustainable pathways by ensuring that biomass, agricultural residues, and bio-based materials are optimally utilised, minimising waste and enhancing value retention throughout their lifecycle.
The integration of 10Rs within BIOTRANSFORM focuses on:

- Creating systemic connections between different bioeconomy sectors (agriculture, forestry, food, energy, and bioprocessing).
- Designing cascading and closed-loop systems to prevent losses and enhance efficiency.
- Ensuring alignment with EU policies on circularity, waste reduction, and bio-based product sustainability.

The following list summarises the 10Rs framework in a circular bioeconomy context, refining and adapting each step to BIOTRANSFORM's objectives:

1. Refuse - Avoid unnecessary resource extraction by prioritising local, small-scale cycles over extended supply chains [14]. This includes preventing the generation of agricultural and food waste as well as packaging (waste) and also ensuring that bio-based materials originate from by-products whenever possible. Emphasis on local production can reduce transportation emissions and enhance small-scale cycles to cut CO_2 emissions [15].
2. Rethink - Shift towards regenerative agriculture and holistic land management to improve soil health, water quality, and biodiversity [16]. Encourage alternative business models, such as sharing economies and cascading biomass use. Systemic approaches focus on designing out waste and reconfiguring value chains so that nutrients and resources circulate optimally.
3. Reduce - Minimise material inputs, process inefficiencies, and food losses at all stages - from farm to consumer [17]. This includes optimising biomass valorisation while preventing unnecessary extraction of

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[12] Marian R. Chertow, '"Uncovering" Industrial Symbiosis', *Journal of Industrial Ecology*, 11.1 (2007), pp. 11–30, doi:10.1162/jiec.2007.1110.
[13] Henrik Hvid Jensen, 'Why Digitalization Is Critical to Creating a Global Circular Economy', *World Economic Forum*, 6 August 2021 <https://www.weforum.org/stories/2021/08/digitalization-critical-creating-global-circular-economy/>.
[14] Ellen MacArthur Foundation, *Cities and Circular Economy for Food* (Ellen MacArthur Foundation, 2019), p. 66 <https://emf.thirdlight.com/link/7ztxaa89xl5c-d30so/@/preview/1?o>; European Commission, *A New Circular Economy Action Plan For a Cleaner and More Competitive Europe*.
[15] European Commission, *The European Green Deal*, 2019 <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM:2019:640:FIN>.
[16] European Commission, *A Farm to Fork Strategy for a Fair, Healthy and Environmentally-Friendly Food System*, 2020 <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381>; FAO, *The State of the World's Land and Water Resources for Food and Agriculture – Systems at Breaking Point*, Synthesis Report (FAO, 2021), doi:10.4060/cb7654en.
[17] European Commission, *A New Circular Economy Action Plan For a Cleaner and More Competitive Europe, 2020.*

virgin resources. A reduction-centric mindset extends to packaging, energy use, and transport logistics.

4. Reuse - Cascade biomass through multiple lifecycles before disposal [18]. Zero-waste approaches - such as food sharing, reusable bio-packaging, and high-quality composting - enable nutrient recovery and reduce the environmental footprint of the bioeconomy [19]. Well-designed reuse systems can further align with local community initiatives and circular business models.
5. Repair - Focus on restoring and maintaining natural capital, including degraded soils, forests, and aquatic systems [20]. By implementing practices like agroforestry, cover cropping, and soil amendments, agricultural landscapes can be revitalised and kept productive for future generations. Such measures also extend the lifecycle of bio-based products through refurbishment or remanufacturing.
6. Refurbish - Improve or enhance bio-based materials to extend their functionality and market value. This may involve biochemical treatments (e.g., extractions of high-value biochemicals or converting biomass into biochar) or refining by-products for secondary applications [21]. Effective refurbishment programmes strengthen local value chains and reduce dependency on fossil-based inputs.
7. Remanufacture - Utilise bioconversion processes - such as fermentation and enzymatic treatment - to create new, high-value products from organic waste [22]. This stage capitalises on emerging biotech solutions, reducing the need for virgin resources and reinforcing the closed-loop potential of biomass valorisation.
8. Repurpose - Direct organic residues and by-products into alternative applications, including upcycled materials for packaging or industrial purposes [23]. By designing products with biodegradability in mind, repurposed materials can be reintegrated into natural cycles at the end of their lifecycle.
9. Recycle - Close the loop on organic waste via anaerobic digestion, composting, and biogas production [24]. Ensuring that nutrients return to agricultural soils supports ecosystem functions and reduces reliance on synthetic fertilisers. These processes also mitigate greenhouse gas emissions by diverting organic residues from landfill.
10. Recover - Extract residual energy and value from end-of-life bio-based materials through biogas or other valorisation pathways, incorporating final nutrient recycling where feasible [25]. This ensures that even the last stages of the circular bioeconomy generate benefits—providing energy, heat, or feedstock for further processes—and ultimately reintegrate nutrients back into the environment.

[18] Kirchherr, Reike, and Hekkert, 'Conceptualizing the Circular Economy'.
[19] European Commission, *A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment. Updated Bioeconomy Strategy* (Publications Office of the European Union, 2018).
[20] CBE-JU, *Strategic Research and Innovation Agenda*.
[21] OECD, *Meeting Policy Challenges for a Sustainable Bioeconomy*.
[22] IEA Bioenergy, 'Annual Reports – Bioenergy'.
[23] European Union, 'Best Practices in Bioeconomy', *European Circular Economy Stakeholder Platform*, 2 April 2025 <https://circulareconomy.europa.eu/platform/en>.
[24] Scarlat and others, 'The Role of Biomass and Bioenergy in a Future Bioeconomy'.
[25] IEA, *Net Zero by 2050 – Analysis*, 18 May 2021 <https://www.iea.org/reports/net-zero-by-2050>.

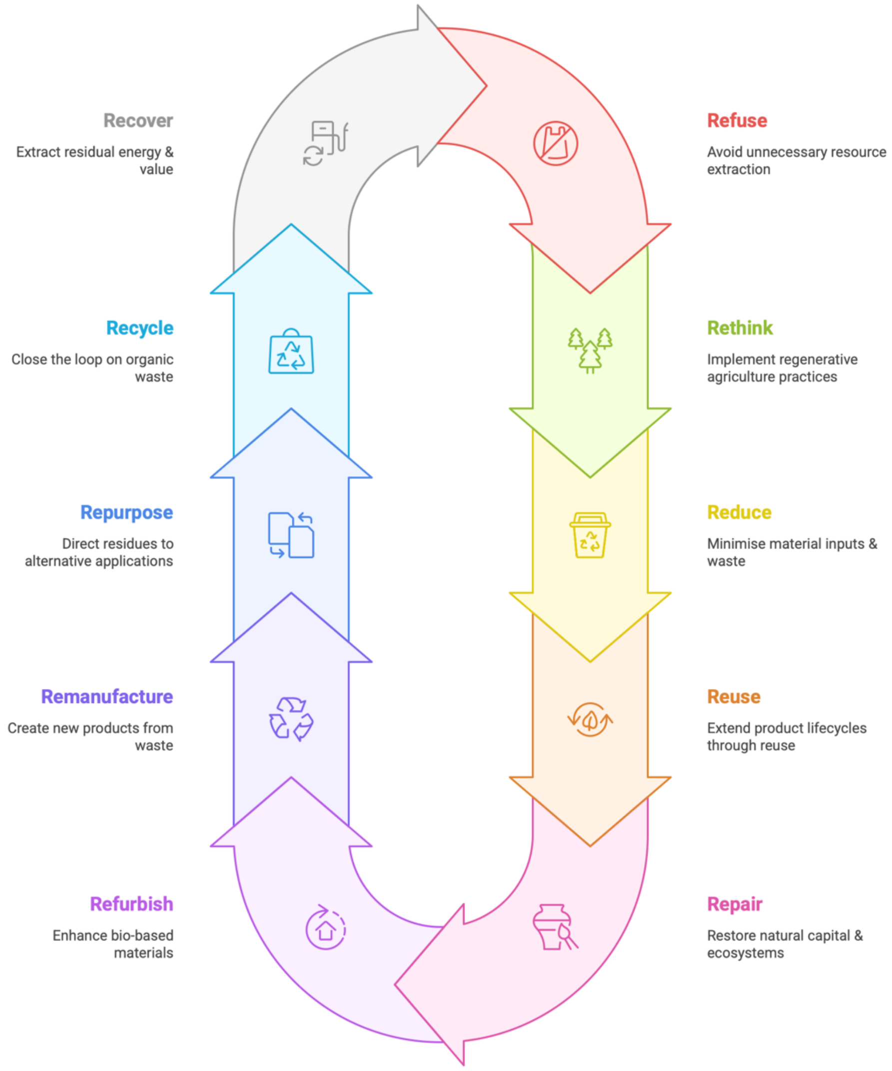

Figure 3: 10R strategies for circular bioeconomy, created with napkin.ai

3.4 MOOV addressing logistic challenges in the shift to a circular bioeconomy

Within BIOTRANSFORM, **MOOV offers decision support for supply chain and logistics network design and optimisation** (more info). MOOV is developed by a dedicated research team within VITO and:

- **Finds the optimal supply chain configuration**
  - From an economic, environmental or social viewpoint
  - Customise for specific client needs, conditions and goals
  - Applicable to existing, changing or new supply chains
  - Focus on sustainable, circular and biobased strategies
  - Considers all key conditions - including location, costs, quantity, quality, and planning
  - Considers all key activities - including resource collection, treatment, storage, processing and transport – in an integrated manner (Figure 4).
- **Provides decision support and impact assessment**

- Comparative assessment of multiple supply chain scenarios, encompassing both current setups and potential future configurations.
- The impact of each scenario is evaluated against a consistent set of Key Logistic Performance Indicators such as logistic costs/benefits, transport distances, loading rates and efficiencies, number of vehicle movements…
- Clear customised decision support is provided to clients on the optimal supply chain design for their specific case and needs

Investigated scenarios include, for example:

- Identifying optimal locations for new infrastructure or activities,
- Integrating innovative processes or products into existing supply chains,
- Selecting suitable transport modalities and determining fleet composition,
- Evaluating new planning strategies for optimizing feedstock delivery and storage capacity.

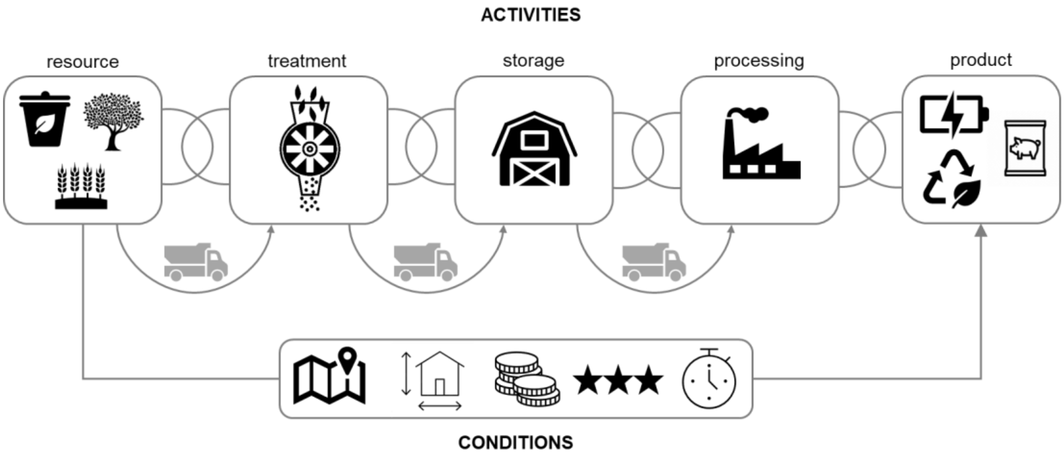

Figure 4: MOOV – supply chain concept

The MOOV team initiated a screening of logistic challenges in collaboration with representatives from all six **BIOTRANSFORM regions**, aiming to identify those regions **requiring support in tackling logistic challenges in transforming toward a circular bioeconomy**. This process led to the selection of two BIOTRANSFORM regions, whose logistic cases are discussed in the sections below:

- Spain (Andalusia): valorisation of prunings from olive groves (Section 4.1)
- Czechia (Charles Spa): valorisation of food waste (Section 4.3)

4. Regional Transition Roadmaps

This section presents the transition roadmaps developed for each BIOTRANSFORM case study regions. These roadmaps are the result of a co-creative and iterative process involving regional stakeholders and experts, building on resource flow mapping, pathway evaluation, and application of the BIOTRANSFORM assessment package. Each roadmap identifies a set of actionable and regionally appropriate circular bioeconomy transition pathways, accompanied by implementation milestones, pointing out stakeholder roles, as well as enabling governance and financing conditions. The transition plans also consider synergies across rural, urban, and industrial settings, supporting systemic integration, and resource efficiency. Anticipated impacts include improved material valorisation, greenhouse gas reductions, new value chains, and socio-economic benefits such as job creation and rural development.

4.1 Andalusia (Spain)

Andalusia, a leading agri-food region in southern Spain, offers a high potential for circular bioeconomy solutions based on its abundant biomass residues, especially from olive oil production. The regional roadmap focuses on unlocking value from olive pruning and pomace, currently used in low-value applications, by exploring innovative conversion pathways such as biocomposites, polymers, and antioxidant extraction. The roadmap was co-developed with local stakeholders and builds on existing policy momentum to position Andalusia as a frontrunner in sustainable resource valorisation and rural-industrial symbiosis.

4.1.1 Challenges

Andalusia, traditionally an agricultural region, has experienced significant economic transformation, with the service sector now leading, especially in tourism, retail, and transportation. However, agriculture continues to play a central role in the region's identity and economy. The region was one of the first in Europe to adopt a Circular Bioeconomy Strategy in 2018 [26], followed by the passing of a Circular Economy Regulation in 2021 [27], which focuses on industrial symbiosis, waste management, and a public database on product life cycle assessments (LCA).

In 2025, the Andalusian government approved the First Andalusian Olive Sector Strategy (Horizon 2027) [28] with a €986 million budget, aimed at enhancing competitiveness, employment, and rural development in the olive sector. The strategy includes sustainable production techniques, the establishment of the Olive Oil Quality Reference Centre, irrigation improvements, and circular bioeconomy projects such as carbon credit opportunities from olive groves.

Agricultural Potential for Circular Bioeconomy

Andalusia is a major producer of crops like olives, vineyards, citrus, and berries, with a growing focus on organic farming, mainly for export to European markets. The region is also a leader in biomass production, a vital resource for the circular bioeconomy.

Key Economic Data and Exports

In 2020, Andalusia exported €26.8 billion, making it Spain's fourth-largest exporter. Virgin olive oil accounted for €1.65 billion of this. In 2024, agri-food exports represented 32% of Andalusia's total exports, positioning it as the second-largest exporter in Spain, behind Catalonia.

Challenges in Circular Bioeconomy Transition

Andalusia faces several challenges in its transition to a circular bioeconomy:

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[26] MINISTRY OF ECONOMY AND KNOWLEDGE, *The Andalusian Circular Bioeconomy Strategy*, 2018 <https://circulareconomy.europa.eu/platform/sites/default/files/resumen_ejecutivo._estrategia_andaluza_de_bioeconomia_circular_0.pdf>.

[27] Parliament of Andalusia, *Circular Economy of Andalusia*, *Boletín Oficial Del Estado*, 2023, NO. 98, pp. 57418–75 <https://www.juntadeandalucia.es/boja/2023/67/1>.

[28] Agricultura, Pesca, Agua y Desarrollo Rural, *Primera Estrategia Andaluza para el Sector del Olivar Horizonte 2027 - Planes y programas - Junta de Andalucía*, 2025 <https://www.juntadeandalucia.es/organismos/agriculturapescaaguaydesarrolloru ral/consejeria/transparencia/planificacion-evaluacion-estadistica/planes/detalle/560761.html>.

1. The region has one of the highest unemployment rates in the EU, around 20%
2. The industrial sector is less developed compared to other Spanish regions, presenting challenges for circular economy integration
3. SMEs face difficulties accessing funding, and there is a disconnect between businesses and the regional knowledge system
4. Administrative barriers hinder the start-up and development of innovative circular bioeconomy projects

Despite these challenges, Andalusia has a strong agricultural base and a solid foundation for integrating circular bioeconomy models. The region's agri-food sector and biomass production offer significant potential for the development of circular bioeconomy pathways, which could create new economic opportunities and jobs.

4.1.2 Proposed pathways

As previously depicted in D3.1, the top 3 routes that were selected as proposed pathways are:

- Reinforcement of polymeric materials from olive pruning debris (Route 1)
- Polymeric production and antioxidants production from olive pruning debris (Route 2)
- Antioxidants production from olive pomaces (Route 7, renamed as Route 3 from now on)

The following pictures provides some insights about how these routes are identified among the olive value chain. The new high-value proposed valorisation routes are highlighted in red.

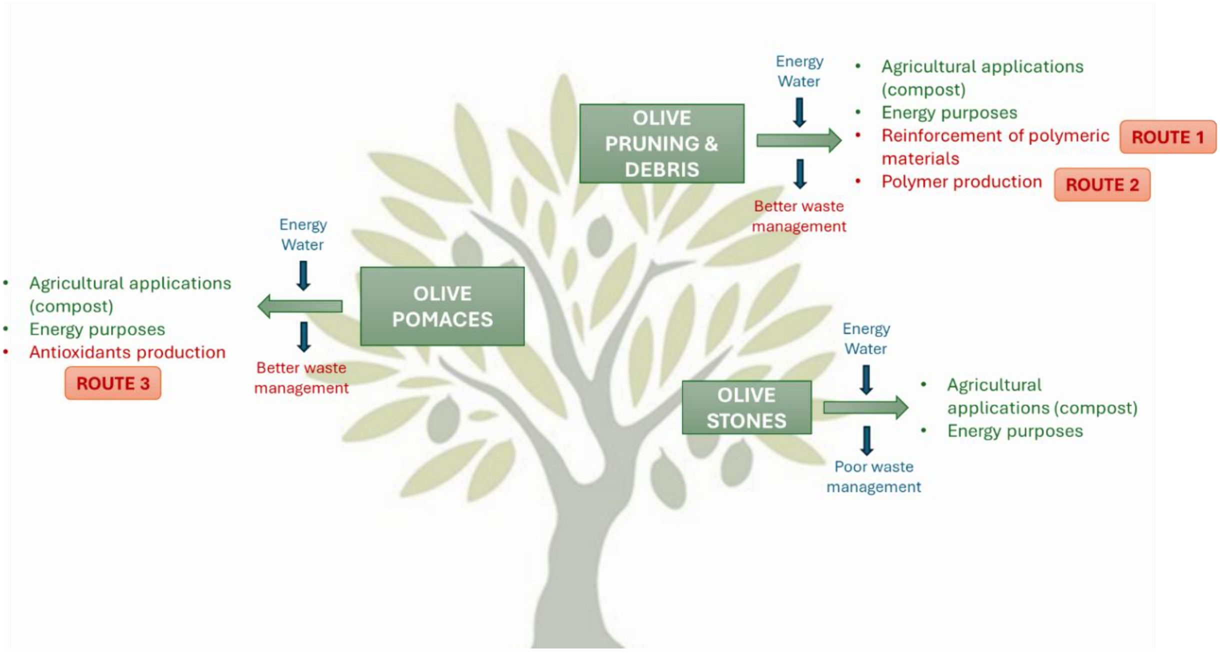

Figure 5. Top 3 pathways selected - Andalusian regional case [29]

As for these routes the following pieces of information were produced in order to draft a clear picture of all sustainability and circularity related aspects to be considered when analysing them: (1) Route current

[29] COMP0LIVE, 'COMPOLIVE – New Generation of bioCOMPosites Based on OLIVE Fibers for Industrial Application', 2025 <https://www.lifecompolive.eu/>.

development status and process block diagram; (2) Resource flow diagram – Sankey diagram; (3) Business model; and (4) Logistics strategy.

As for the Sankey diagrams, the one for the base scenario (current valorisation schemes for the olive value chain) is provided next. This has been elaborated using information provided in regional policy documents [30].

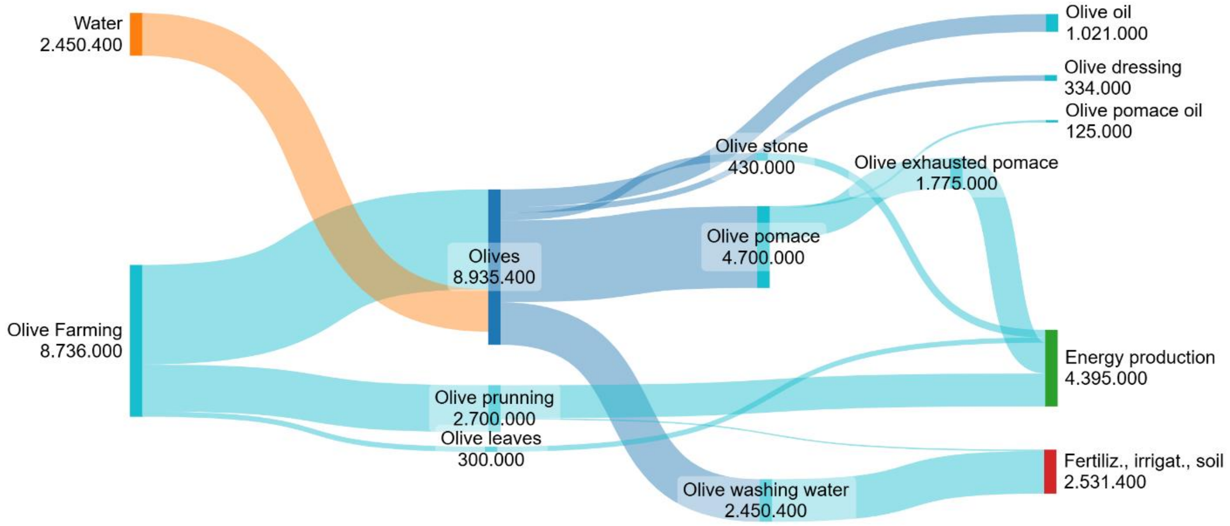

Figure 6. Andalusian regional case. Sankey diagram for current state (numbers refer to tons/year)

Route 1: Reinforcement of polymeric materials from olive pruning debris

This pathway aims to produce high-value biocomposites from olive pruning residues (as visualised process chart in Figure 5), primarily focused on recycled polypropylene materials. The process, developed by ANDALTEC, has reached a Technology Readiness Level (TRL) of 5-6, supported by the LIFE project COMPOlive [31]. The commercial production of biocomposites has strong market potential, particularly in the automotive and furniture industries, with an estimated annual revenue of over €3.5 billion. The process utilizes existing extrusion lines and injection molding machines, reducing capital expenditure (CAPEX) while facilitating smoother integration into conventional manufacturing setups.

Key Elements

- **CAPEX**: Investment is mainly in extrusion lines, biomass processing equipment, and reactors. Using existing machinery reduces capital costs and facilitates integration into current production systems.
- **OPEX**: Operational costs include raw materials, energy, and personnel. These costs are expected to be on par with conventional polymer production, ensuring market competitiveness.
- **Market Potential**: The process can produce up to 3.5 million tons of biocomposites annually, targeting the automotive, furniture, and construction sectors, with projected revenues of €3.5 billion.
- **Business Applications**: Applications in the automotive sector as lightweight biocomposites for car parts (e.g., bumpers, panels) or as durable, eco-friendly furniture. This flexibility allows for easier adoption and scalability across existing facilities, making the transition from laboratory to commercial production more efficient.
- Logistics Strategy:
    - **Collection**: Local collection and processing of pruning residues using shredders and balers, reducing transport costs.
    - **Intermediate Processing**: Material compression and basic treatments at strategically located centres.

[30] MINISTRY OF ECONOMY AND KNOWLEDGE, *The Andalusian Circular Bioeconomy Strategy*.
[31] COMP0LIVE, 'COMPOLIVE – New Generation of bioCOMPosites Based on OLIVE Fibers for Industrial Application'.

- Final Production: Partnership with industries such as automotive, furniture, and urban infrastructure to ensure diverse applications for the biocomposites.
- **Distribution**: Efficient supply chain management using digital platforms to optimise transport routes and return reusable materials to their points of origin, further enhancing the sustainability of the process.

- **Sankey Diagram**: Figure 7 illustrates the resource flow for this route, showing the mass balance of pruning residues through to biocomposite production.

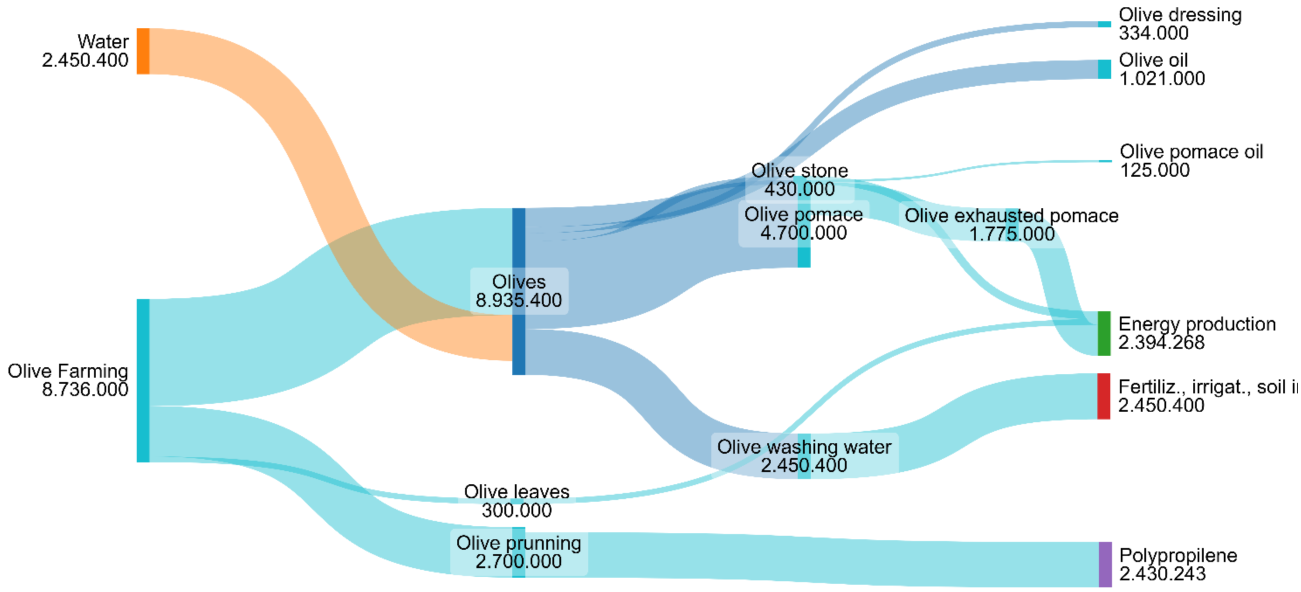

Figure 7. Andalusian regional case. Sankey diagram for route 1 (numbers refer to tons/year)

Route 2: Polymeric production and antioxidants from olive pruning debris

This route targets the production of nanocellulose crystals and cellulose acetate from olive pruning residues, with a TRL of 3-5. These materials have strong applications in the production of biofilms for sustainable food packaging and textiles. The market for cellulosic fibres and bioplastics is growing globally, and this process offers a potential pathway to meet the European demand for sustainable fibres while contributing to the circular bioeconomy.

<u>**Key Elements**</u>

- **CAPEX**: Investment in pulping equipment, chemical reactors, and fibre spinning machinery
- **OPEX**: Raw materials, energy consumption, and labour costs
- **Market Potential**: Significant growth in the global textile and bioplastic industries
- **Business Applications:** Applications include bioplastics for food packaging and eco-friendly textiles. The flexibility of the process supports scaling and adoption in various industries.
- **Logistics Strategy:** Focus on local collection and processing of pruning residues, optimising supply chains and minimising transport costs - same as described in Route 1.
- **Sankey Diagram**: The resource flow diagram for this route (Figure 8) illustrates the mass balance of pruning residues and fibre production.

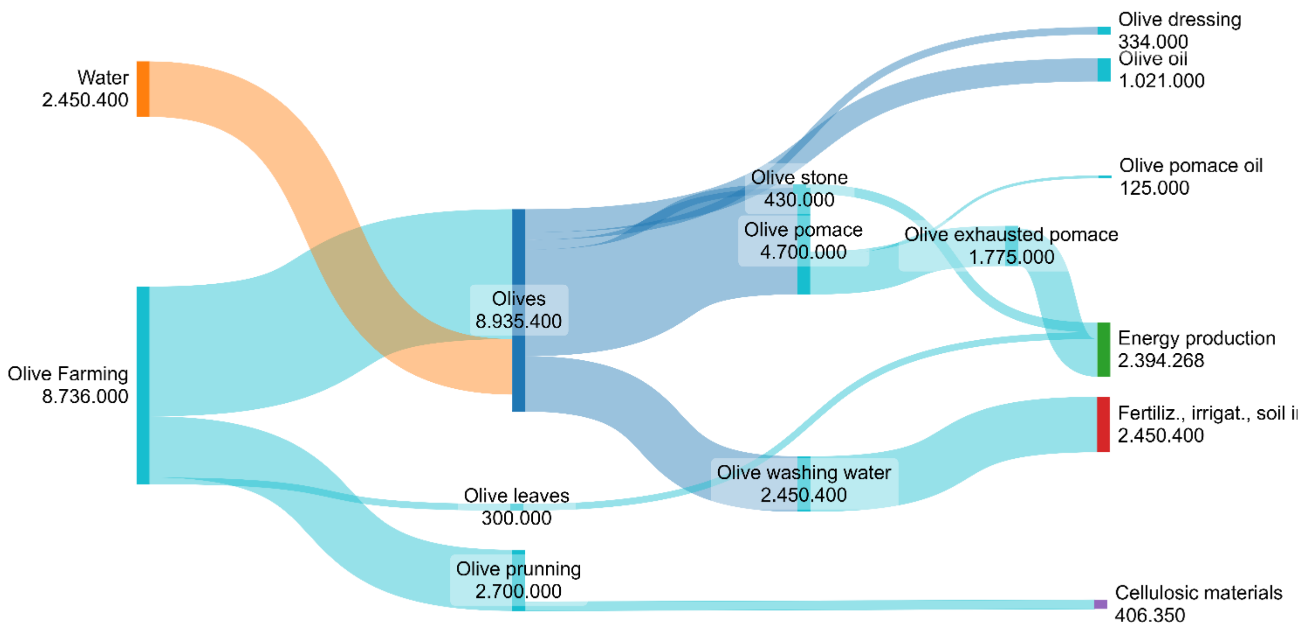

Figure 8. Andalusian regional case - Sankey diagram for route 2 (numbers refer to tons/year)

Route 3: Antioxidants production from olive pomaces

This pathway focuses on the extraction of valuable antioxidants like hydroxytyrosol from olive pomace, a byproduct of olive oil production. Several Andalusian actors, including Naturphenolive and Deretil Nature, are advancing this technology. The extraction of hydroxytyrosol is expected to be highly profitable, with the market for these antioxidants growing rapidly. The total potential of antioxidants from olive pomace in Spain is estimated at around 100,000 tons, including 75,000 tons of hydroxytyrosol. The product has various applications in the pharmaceutical, cosmetic, and nutraceutical industries, with the market for hydroxytyrosol projected to reach $73 billion by 2031.

Key Elements

- **CAPEX**: High-cost equipment such as High-Performance Liquid Chromatography (HPLC) systems for antioxidant extraction
- **OPEX**: Raw materials (olive pomace), energy, specialised labour costs
- **Market Potential**: The hydroxytyrosol market is expected to reach $73 billion by 2031
- **Regulation**: The regulatory environment for hydroxytyrosol is complex, requiring careful navigation and investments in compliance and certification processes.
- **Business Applications**: Nutraceuticals (growing demand for natural antioxidants in health products), cosmetics (hydroxytyrosol's anti-aging properties for high-end personal care products), food (antioxidant as a natural preservative and functional ingredient), and pharmaceuticals (hydroxytyrosol's health benefits)
- **Logistics Strategy**: Focus on the distribution of antioxidant products with minimal additional infrastructure
- **Sankey Diagram**: The resource flow diagram for this route (Figure 9) illustrates the mass balance and extraction process for antioxidants from olive pomace.

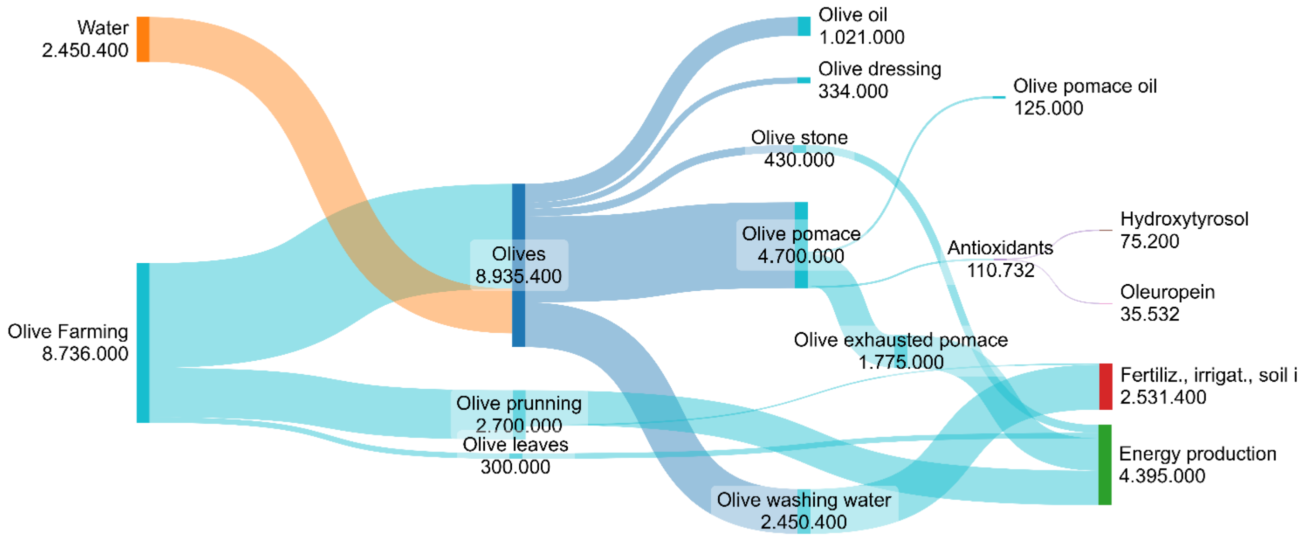

Figure 9. Andalusian regional case - Sankey diagram for route 3 (numbers refer to tons/year)

General insights for all routes

Sustainability: These pathways contribute to the valorisation of agricultural residues, promoting circularity by reducing waste and enhancing resource efficiency. Each pathway plays a role in minimising waste and promoting sustainable practices across multiple sectors.

Economic Impact: The commercial potential for all three routes is significant. The development of biocomposites, textiles, and antioxidants is expected to create substantial revenue streams while supporting regional job creation and economic growth in Andalusia.

Regional Benefits: By integrating these solutions, Andalusia stands to gain new business opportunities, reduce environmental impacts, and foster rural development. The scaling-up of these pathways could enhance regional self-sufficiency and contribute to Spain's broader circular economy objectives.

Results from the logistics assessment

This case investigates the **logistic feasibility of valorising olive tree prunings** (OTP) from Andalusia's extensive olive groves **as a feedstock for bioplastic production**.

The region, with over 1.16 million hectares of olive cultivation, generates large volumes of woody biomass that are often underutilised or burned. However, the seasonal nature of pruning, fragmented field distribution, high moisture content of fresh OTP, and lack of suitable infrastructure pose **significant logistical challenges** in valorising them. Efficient collection, storage, and transport in combination with optimal siting strategies are essential to enable the year-round operation of biorefineries and to unlock the economic potential of this biomass stream.

The **logistics chain** unfolds as follows: it begins with the in-field pruning of olive trees, with the prunings chipped into woodchips at the edge of the field. Due to the chipper's limited container capacity, the material is unloaded into a larger transport truck, which then either delivers the chips to a storage facility or transports them directly to the biorefinery (Figure 10**Error! Reference source not found.**).

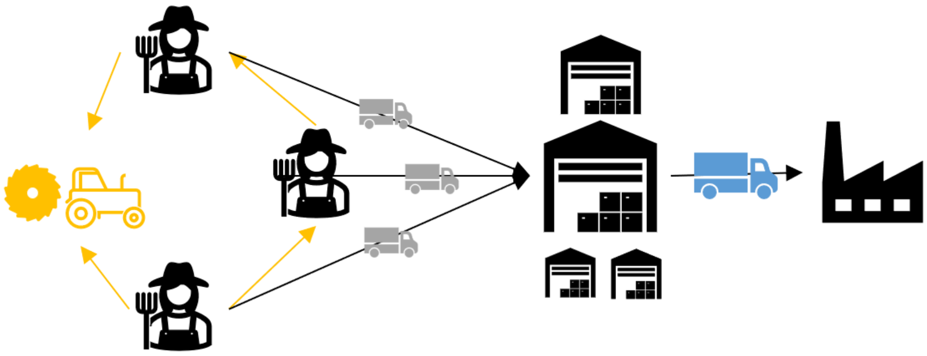

Figure 10: Network flow diagram

To address the supply chain challenges, **MOOV investigated a range of OTP collection, storage and transportation scenarios** in the Andalusian region.
The scenarios differ in terms of the **number, size, and location of storage facilities and biorefineries**, as well as the **impact of decentralised storage and processing**.

- **Scenario 1:** using only existing storage facilities.
- **Scenario 2:** 1 biorefinery with a 150 kton/year input capacity with on-site storage
    - **Sensitivity 2A:** Impact of multiple biorefineries
    - **Sensitivity 2B:** Impact of multiple off-site storage facilities
- **Scenario 3:** 1 biorefinery with a capacity for all available OTP with on-site storage
    - **Sensitivity 3A:** Impact of decentralisation of biorefineries
    - **Sensitivity 3B:** Impact of decentralisation of off-site storage

The analysis results demonstrate the impact of introducing alternative logistics scenarios on the performance indicators: **mobilisation cost** (Figure 11) and **transport distance** (Figure 12).
Mobilisation cost is defined as the sum of the costs for chipping, chipper transport, storage, and all transport between the field, storage facilities, and biorefinery.

Scenario results

In **Scenario 1**, the supply chain relies solely on the **existing storage infrastructure** within the region, offering a capacity of 15 kton distributed across approximately 20 locations. This enables a feedstock throughput to the biorefinery of 32 kton/year. Optimal utilisation of storage capacity and optimal selection of the biorefinery location result in a mobilisation cost at the biorefinery gate of 122 €/ton[32] of dry woodchips, with an average transport distance of 18 km/ton.
However, a techno-economic study on woody biorefineries[33] has demonstrated the positive impact of scale on economic feasibility, with a 150 kton/year capacity performing best. Consequently, **Scenario 2** investigates the scaling up to a **150 kton biorefinery** with on-site storage. The biorefinery location is optimally selected in view of minimising the mobilisation cost. This results in an increased mobilisation cost of 143 €/ton, with an average transport distance of 21 km/ton. As fresh woodchips, containing approximately 50% moisture, are transported directly to the refinery in this scenario, transport costs represent a significant fraction of the total mobilisation cost.

- A sensitivity analysis of this scenario shows that the region can supply sufficient OTP feedstock to support **multiple 150 kton/year biorefineries**, with a maximum of four - **Sensitivity 2A**. Mobilisation

[32] Dry woodchips
[33] BIOWOOD

costs increase by 2%, to 145 €/ton, when two biorefineries are established, and by 13%, to 162 €/ton, when four are operating. In the latter case transport distance rises to 28 km/ton. This can be logically explained by the fact that, as more biorefineries require servicing, feedstock must also be sourced from less optimally located fields, resulting in slightly increased transport distances.

- **Sensitivity 2B** explores the installation of one biorefinery while using **multiple off-site storage facilities** distributed across the region, instead of a centralised storage facility at the biorefinery. Important to note that during storing the fresh woodchips are air dried, resulting in a significant weight loss which positively affects transportation costs.

Storage facilities are also assumed A range of six storage capacities was investigated, from XXL-to-XXS. Results show that opting for extra-small (XS) off-site storage facilities are used, mobilisation costs are reduced by 13%, to 124 €/ton (compared to Scenario 2).
The cost reduction is primarily due to a 25% decrease in field-to-storage transport costs, as the storage facilities are now optimally located near the olive fields, reducing the average transport distance to 16 km/ton. Additionally, results show that opting for smaller (XXS) or larger (XXL) scale facilities is suboptimal compared to XS-facilities. This is because the benefits of decentralisation are determined by balancing field-to-storage and storage-to-refinery transport costs, as well as by balancing the number of required storage facilities against their associated investment costs.
Scenario 3 explores a more hypothetical situation in which **all available OTP** in the region is processed at a **single biorefinery with on-site storage**. This raises mobilisation costs to 219 €/ton, driven by high field-to-storage/refinery transport distances, reaching up to 54 km/ton.

- **Sensitivity 3A** explores the **decentralisation of the biorefineries** by introducing 10 smaller biorefineries with on-site storage. This reduces by -33% the overall mobilisation cost to 147 €/ton, and the transport distance to 21 km/ton (compared to Scenario 3). This positive impact is explained as refineries are now located closer to the fields. Note however that investment costs for a biorefinery are not included in this analysis and should be considered when interpreting overall economic feasibility.
- **Sensitivity 3B** investigates the decentralisation of storage facilities using medium-sized (M) storage units. Results show that the benefits are correlated with the degree of decentralisation of the biorefineries: the advantage of decentralised off-site storage diminishes as the decentralisation of the biorefineries increases.

For example, deploying off-site storage with a single central refinery reduces mobilisation costs by 23%, down to 172 €/ton vs. 219 €/ton - Sensitivity 3B(1) vs. Scenario 3. In contrast, when ten biorefineries are deployed, mobilisation costs slightly increase to 151 €/ton vs. 147 €/ton, when adopting off-site storage facilities - Sensitivity 3B(2) vs. Sensitivity 3A.
This suggests that when a higher number of biorefineries is already present, the system is sufficiently decentralised, and the additional benefits of off-site storage are reduced, while higher investment costs for these additional storage facilities are still incurred.

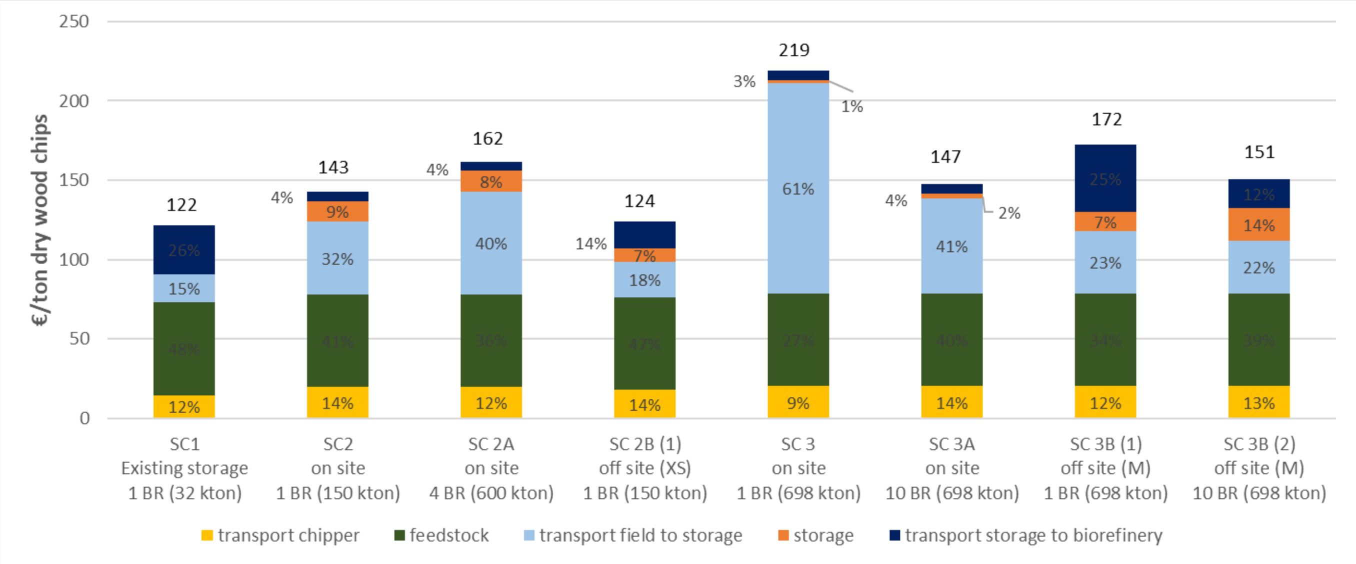

Figure 11: Mobilisation cost (€ per ton dry woodchips)

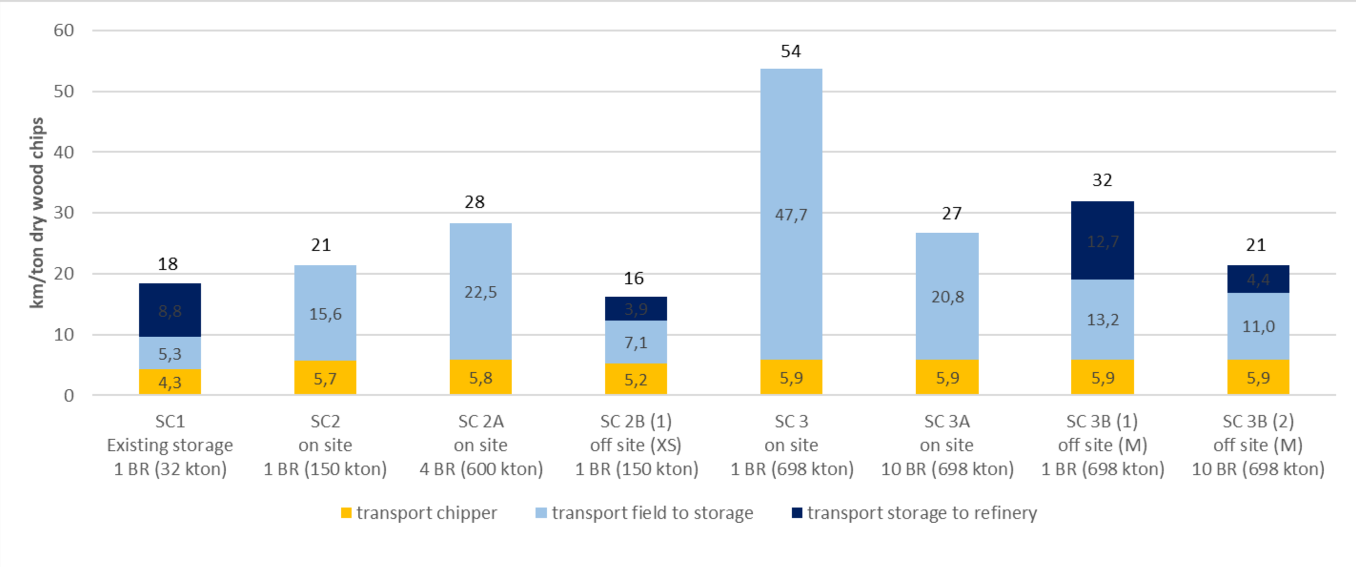

Figure 12: Transport distance (km per ton dry woodchips)

<u>In conclusion</u>

- **Decentralised systems are consistently more cost-effective.**

Scenarios involving multiple localised facilities - whether in the form of off-site storage near production zones or distributed biorefineries - outperform centralised configurations by significantly reducing transport distances and leveraging regional OTP availability. The XS off-site storage scenario (124 €/ton) and 10 biorefinery setup (147 €/ton) proved to be the most economically viable strategies, demonstrating that a decentralised network better matches the spatial reality of the OTP supply base. The benefits of decentralisation are determined by balancing field-to-storage and storage-to-refinery transport costs, as well as balancing the number of required storage facilities and related investment, which is influenced by economies of scale.

- **Transport of fresh chips from the field to storage facilities or biorefinery is the dominant cost driver.**

Fresh woodchips possess a high moisture content and low bulk density, leading to higher transport weights and increased transport costs. When direct transport to the biorefinery is used — without drying at storage facilities — transport accounts for between 30% (Scenario 2) and 60% (Scenario 3) of the total mobilisation cost. This underscores the importance of minimising the fresh transport leg to control costs, whether by drying near the source, decentralising storage capacity, or decentralising processing capacity.

- **Optimal design balances minimal field-to-storage transport with efficient storage sizing.**

While maintaining a single biorefinery, increasing the number of storage facilities reduces the transport distance for fresh chips but raises the required investment. For example, the XXS scenario achieved low transport distances but would require 48 facilities, resulting in a mobilisation cost of 134 €/ton. In contrast, the XS configuration required only 10 facilities and achieved a better balance between logistics efficiency and infrastructure investment, with a lower mobilisation cost of 124 €/ton.

- **Investment costs for a biorefinery were not included in this analysis and should be considered when interpreting overall economic feasibility.**

- **XS off-site storage with a 150 kton biorefinery is the best performing logistic configuration.**

Among all the reviewed scenarios, the XS off-site storage configuration combined with a 150 kton biorefinery proved to be the best-performing logistics setup. The XS scenario achieved the lowest mobilisation cost across all options, at 124 €/ton.
It effectively matched storage capacity to the spatial distribution of olive groves, reduced field-to-storage transport distances, and enabled air drying at the storage facility before transporting the lighter, drier chips to the biorefinery. Its modular and scalable design makes it particularly well-suited for incremental rollout and for adapting to future demand growth or processing capacity expansion.

4.1.3 Stakeholder roles

The following stakeholders have been identified as key actors in the deployment of the proposed transition routes. They have been grouped in the following Triple helix model.

Table 2. Andalusian stakeholders for the proposed transition pathways

Actor	Stakeholders	Route
Academia (Research & Development)	- Research and development centers	Route 1, Route 2, Route 3
Industry (Businesses & Producers)	- Agricultural service companies (olive pruning residue producers)	Route 1, Route 2
	- Farmers (olive pruning residue producers)	Route 1, Route 2
	- Cooperatives (olive pruning residue producers)	Route 1, Route 2
	- Waste collection and processing companies	Route 2
	- Polymeric material manufacturing companies	Route 1, Route 2
	- Polymeric material transformation companies	Route 1, Route 2
	- Industrial consumer sector	Route 1
	- Olive mills	Route 3
	- Pomace extractors	
	- Antioxidant producers	

	- Antioxidant-consuming industries	
	- Technology and machinery suppliers	Route 1, Route 2, Route 3
Government (Regulators & Policymakers)	- Regional ministries - Public agencies	Route 1, Route 2, Route 3

4.1.4 Regional governance and finance

Governance model

The governance of Andalusia's bioeconomy is led by the Regional Ministry of Agriculture, Fisheries, Water, and Rural Development, under the Andalusian Circular Bioeconomy Strategy (EABC). Key governance elements include:

- Monitoring Committee: Evaluates the implementation of strategic measures and tracks relevant indicators.
- Andalusian Circular Bioeconomy Cluster: Brings together business, research, public administration, and traditional sectors (agri-food, fisheries, etc.) in a collaborative effort.
- Ongoing Strategy Update: The Andalusian Circular Bioeconomy Strategy (ACBS) is currently being updated to reflect evolving priorities.
- Knowledge Platforms:
    - The Andalusian Biocircular Economy Observatory serves as a hub for the agri-food sector to foster collaboration and knowledge-sharing.
    - The Andalusian Bioeconomy Website supports awareness and engagement.
    - The Andalusian Institute for Research and Training in Agriculture, Fishery, Food and Ecological Production (IFAPA) comprises 47 Rural Development Groups, and 15 operational Research and Training centres in Andalusia.

Funding opportunities

The following set of funding opportunities have been identified at EU, national and regional level, being matched with the TRL stage. The details of the national funding opportunities are provided next:

CDTI Funding Instruments: Spanish government agency (Ministry of Science, Innovation and Universities) offering **grants and loans** for R&D&I projects across various technologies, including programs for early-stage tech companies (NEOTEC). **General Link:** https://www.cdti.es/en/; **Grants Section:** https://www.cdti.es/en/ayudas/tipo/grants
Tech Transfer Agrifood: Venture capital fund managed by Clave Capital, providing **equity investment** (pre-seed to pre-Series A) in agrifood startups with high impact. **Link:** https://techtransferagrifood.com/
ENISA: Publicly owned company (Ministry of Industry, Trade and Tourism) offering **participatory loans** (no personal guarantees usually required) to innovative Spanish SMEs and startups in different stages, including specific lines for young entrepreneurs, growth, and the agrifood sector (Agroinnpulso). **Link:** https://www.enisa.es/
Eatable Adventures: Global **foodtech accelerator** providing acceleration and incubation programs for agrifood startups. May include **investment** in promising startups through their programs (e.g., "Raíces"). **Link:** https://eatableadventures.com/

Fundación Biodiversidad: Public foundation (Ministry for Ecological Transition and the Demographic Challenge) offering **grants** for projects related to biodiversity conservation, sustainable use, ecological restoration, and the fight against desertification. **Link:** https://fundacion-biodiversidad.es/ (Look for "Convocatorias" or "Ayudas" for calls)
Spain Foodtech Start-up Ventures: This is an **ecosystem or community of investors** focused on Spanish foodtech startups rather than a single funding program. It could involve VC groups, events, or platforms connecting startups with investors.

At regional level, the Technological Corporation of Andalusia (CTA) primarily focuses on facilitating innovation and establishing connections between various stakeholders to access funding opportunities. In contrast, the IDEA Agency (Andalusian Agency for Innovation and Development) offers direct financial support, including grants and subsidies, aimed at a wide range of business activities within Andalusia. Lastly, the TRADE Agency (Andalusian Agency for Foreign Trade Promotion) concentrates on supporting the international expansion of Andalusian companies, potentially providing some forms of financial assistance related to their export endeavours. More information is provided below.
CTA - Corporación Tecnológica de Andalucía: A public-private foundation supporting **RDI projects** in Andalusia. They have their own funding programe (private) They don't usually offer direct grants in the same way as IDEA, but they guide companies to relevant funding opportunities and support the development of innovative projects. **Link:** https://www.corporaciontecnologica.com/en/
IDEA Agency (Agencia de Innovación y Desarrollo de Andalucía): The **Andalusian Agency for Innovation and Development**, part of the Regional Government of Andalusia. It offers a range of **grants, subsidies, and financial instruments** to support business creation, growth, innovation, internationalization, and other economic development activities in Andalusia. Their programs often target SMEs, entrepreneurs, and specific sectors. **Link:** https://www.agenciaidea.es/
TRADE Agency (Agencia Andaluza de Promoción Exterior - Andalucía TRADE): The **Andalusian Agency for Foreign Trade Promotion**. While their primary focus is on supporting the **internationalization of Andalusian companies** through services like market research, trade missions, and promotional activities, they may also offer **specific financial aid or grants** related to export and international expansion. **Link:** https://www.andalucia.org/en/trade

For the optimal pathway the most relevant funding would be the EIC Accelerator at EU level while at national level it would be a PID project application to be funded by CDTI (blend of grant and loan). At the Andalusian level, CTA own funding programme with private capital is the only one that finances higher TRL stages, i.e. is the only one that finances innovation rather than research and development, so this is deemed to be the most suitable one.

Figure 13: Different funding schemes suitable for Andalusia

4.1.5 Roadmap

This roadmap leverages Andalusia's strategic biomass potential - particularly olive pruning waste and supports the regional transition to a circular bioeconomy. It aligns with the **Quintuple Helix model** (academia, industry, government, civil society, environment) and promotes **Circular Systemic Solutions (CSS)** to overcome technological, regulatory, and market barriers. The focus is on scaling up the optimal pathway so it can reach the market and change the current regional landscape.

Selection of the optimal pathway

For the selection of the optimal pathway the overall methodology has already been reported in D3.1. The specific assessment methodology is described in D2.2. Here, only the results of this sustainability assessment are shown.

Figure 14. Andalusian case. Results from the optimal pathway selection

This way it can be concluded that the optimal pathway for the Andalusian region is route 1 (obtention of biocomposites from olive pruning and debris).
It is important to note that during the meetings with the stakeholders, new routes were identified and it was discussed another potential route that could be a merger of the three routes following a cascading approach for olive pomace valorisation through a thermos hydrolysis that would deliver 3 phases: oil phase for pomace olive oil production, liquid phase for antioxidants further extraction and purification and solid phase that could be processed following route 1 approach for biocomposite production.

Main goals

- By 2030: TRL 8–9, 15% reduction in olive pruning incineration, 1,200 new jobs created.
- By 2040: 30% bio-polypropylene market share across Spain and Portugal, 500k tons CO_2/year avoided.

This would allow the full deployment of the proposed optimal pathway, achieving regional transition from linear-fossil to circular-bio.

Proposed timeline

Short-Term (2025–2027) goals and actions – Piloting & Network Building

Technology Development

- Launch pilot biorefineries to convert olive pruning waste into bio-based polypropylene reinforcements, building on prototypes developed by ANDALTEC.
- TRL upgrade, paying attention to process optimisation, Safe and Sustainable by Design principles and integrating a techno-economic assessment during the whole process.

Stakeholder Engagement

- Create alliances with actors including olive cooperatives (e.g., Cooperativas Agro-alimentarias), private companies and the Junta de Andalucía. Other innovation agents (like CTA) are also to be included.
- Establish feedback loops to evaluate consumer acceptance of bio-based materials in sectors such as packaging and construction.

Policy and Funding

- Interact with the regional government to assess the alignment of olive pruning waste valorisation with waste and innovation policies.
- Apply for EU funding instruments (e.g., Horizon Europe, CCRI) for pilot plants and techno-economic feasibility studies.

Mid-Term (2027–2030) goals and actions – Scaling and Infrastructure Development

Industrial Scaling

- Build a First-of-a-Kind (FOAK) biorefinery with a processing capacity of 10,000 tons/year, located in provinces such as Jaén or Córdoba.
- Implement a circular logistics network in partnership with key operators for raw material collection and product distribution.

Market Development

- Foster B2B agreements linking biorefineries with regional plastics manufacturers.
- Develop circular business models, delve into incentives schemes for farmers and also for end-users.

Regulatory Adjustments

- Study and explore certification standards for composting and biodegradability of bio-based polypropylene.

- Compliance for the whole process and end-products.

Long-Term (2030-) goals and actions – Systemic Integration

Full-Scale Deployment

- Develop 3–5 regional biomass hubs capable of processing up to 500,000 tons/year of olive pruning residues.
- Integrate collection and processing into existing olive oil cooperatives, ensuring closed-loop biomass valorisation.

Education and Workforce Development

- Launch certified vocational training programs in biorefinery operations.
- Run regional campaigns to increase awareness of the benefits of circular bioeconomy.

Policy Mainstreaming

- Embed targets into the main Andalusian policy documents, aiming for 40% circularity in agriculture and plastics sectors by 2040.
- Align with EU directives by mandating 50% recycled content in plastic production.

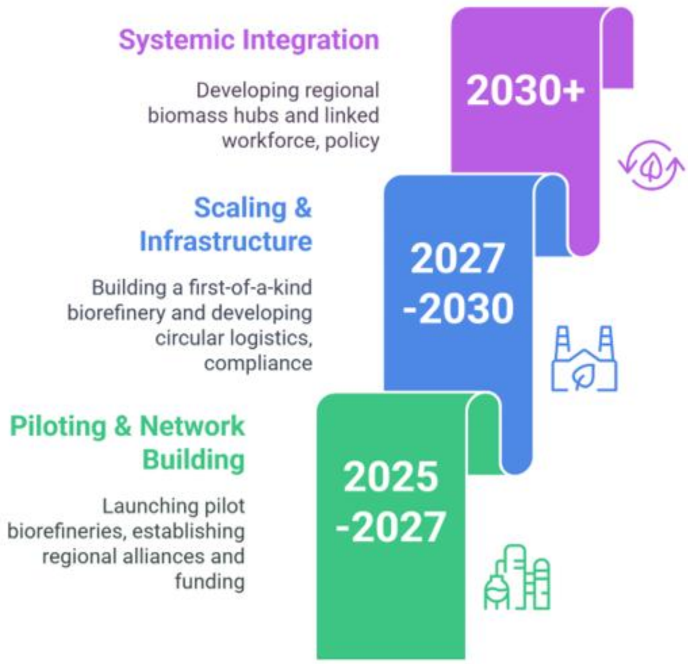

Figure 15. Andalusian case. Roadmap for regional transition through Route 1

Anticipated benefits

The following benefits can be identified:

Social level

- Training opportunities for local workers in circular bioeconomy technologies
- Promotion of circular bioeconomy principles and practices
- Enhancement of rural development and reduction of rural-urban migration
- Improvement of working conditions in the olive sector
- Increased awareness of sustainable practices among consumers and stakeholders
- Potential for collaboration between academia, industry, and local communities

Environmental level

- Significant reduction in olive industry waste

- Minimisation of CO_2 emissions associated with fossil-based plastic manufacturing
- Reduction of emissions caused by burning olive tree pruning waste. In the province of Jaén alone, more than 500,000 tons of CO_2 are generated annually from this practice
- Conservation of natural resources through the use of by-products
- Potential for soil improvement through the application of bio-based fertilizers
- Reduction of water pollution from olive mill wastewater
- Contribution to climate change mitigation efforts in the agricultural sector

Economic opportunities

The following economic opportunities can be pointed out:
- Job creation in transformation, logistics, and manufacturing sectors
- Increased revenue from bio-based products
- Access to new markets, particularly in the growing sustainable products sector
- Attraction of investments in circular bioeconomy initiatives
- Diversification of income streams for olive farmers and processors
- Potential for export of high-value bio-based products
- Reduction in waste management costs for olive oil producers

Value proposition for the identified stakeholders

The following value propositions have been defined for each group of actors that would be involved in the regional transition.

Table 3. Value proposition for Andalusian actors involved in the transition

Actor	Value proposition
Agricultural service companies, farmers, and cooperatives	- Increased income through waste valorization - Compliance with environmental regulations by reducing waste - Promotion of circular economy
Waste processing companies	- Job creation in the bioeconomy sector - Logistics cost savings - Expansion of target market
Industrial sector	- Job creation in the bioeconomy sector - Access to new markets (bio-based products) - Reduction of carbon footprint
Research centers	- Promotion of technological advancements - Encouragement of interdisciplinary projects - Training and education in the use of innovative materials and sustainable technologies
Technology and machinery suppliers	- Development of new technological applications based on agricultural resources - Increased revenue - Access to public incentives - Contribution to sustainability
Governmental and regulatory entities	- Alignment with EU sustainability objectives - Strategic collaborations

4.2 Northern Burgenland (Austria)

Northern Burgenland, a lakeside and wine-producing region in eastern Austria, presents a unique circular bioeconomy potential by combining aquatic, agricultural, and biomass resources. Within D3.1, the selected resources were straw, vineyard and soy residues. The valorisation of lake residues should have been developed within another project. However, in the further development of the specifics of the region and the non-availability of other projects, the Northern Burgenland team decided to shift focus to lake resources. The regional roadmap targets underutilised side streams such as lake reed, sediments, and vineyard residues to develop value-added applications in construction, soil enhancement, and bio-based materials. The roadmap integrates ecological restoration goals for Lake Neusiedl with industrial valorisation strategies, aiming to establish a decentralised bioeconomy model supported by local clusters and regional innovation agencies.

4.2.1 Challenges

Reed dieback and lake shallowing

Lake Neusiedl faces ecological imbalances due to sediment accumulation and reed degradation, negatively impacting biodiversity and water quality.

- Current reed harvesting: ~18 km^2 (of available 178 km^2 reed belt) ~13,000 t/year (used mainly for roof thatching and a very small amount for wall panels)
- Sediment removal: ~60,000 m^3/year currently extracted

Underutilisation of available resources and agricultural residues

Vineyard residues, lake biomass, and sediments remain largely unexploited, despite their high potential for value creation in construction, bio-based materials, and agriculture.

- Lake biomass (reed): ~30% of harvested reed classified as lower quality, only a small portion of harvestable reed is currently utilised.
- Lake sediments: ~10,000–15,000 t/year could be repurposed for construction materials (e.g., bricks, plasters), and ~5,000 t/year or more for agricultural applications (e.g., soil improvement).
- Vineyard residues: ~3,000–5,000 t/year of prunings available; ~40% could be used for biochar, composting, or mulching. ~2,000–3,000 t/year of pomace available; valorisation potential in grape seed oil, flour, animal feed, and biofertilisers.

Lack of integrated resource management

Currently, there is no established framework for connecting lake and vineyard biomass into a cohesive regional circular bioeconomy. Resource flows remain fragmented, preventing optimised valorisation and economic scaling of bio-based industries.

4.2.2 Proposed pathways

Lake biomass (reed) valorisation

- High-quality reed harvesting expansion for roof thatching and wall panels.
- Medium-quality reed utilisation for composite panels and bio-based construction materials.
- Transformation of low-quality reed into bioenergy, co-composting materials, and substrates for mycelium/mushroom cultivation.

Lake sediment valorisation

- Construction materials: Bricks, plasters, and fillers from stabilised sediments.
- Agricultural applications: Soil amendments and fertilisers for improved soil health and structure.

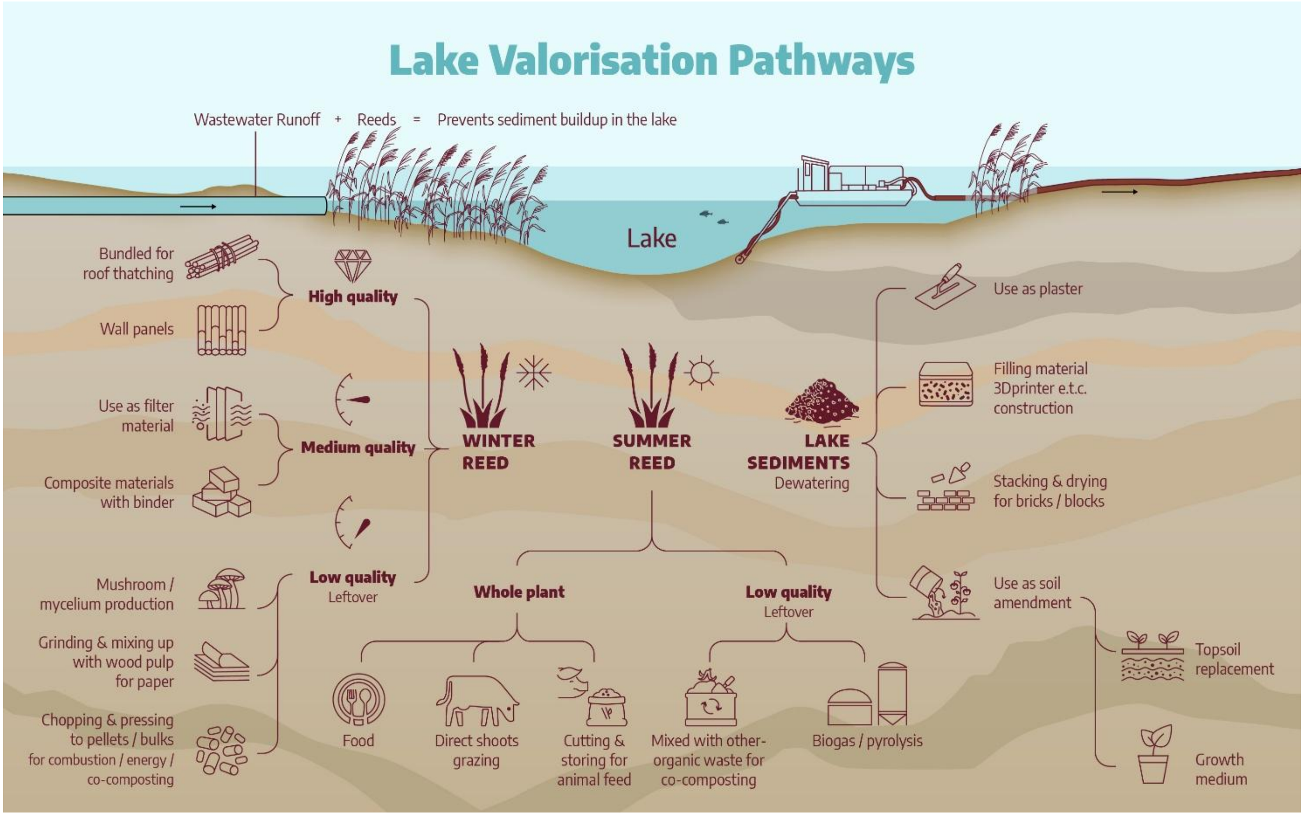

Figure 16: Infographics for lake valorisation pathways

Wine residue valorisation

- Grape pomace: Grape seed oil and flour for food applications, animal feed, and biofertiliser.
- Vine prunings: Mulching and composting for soil improvement, biochar production for carbon sequestration, soil bioengineering for erosion prevention.
- Intercropping in vineyards: Legumes for nitrogen fixation and flowering plants for pollinator biodiversity.
- Involvement of non-conventional water sources: soil amendments for water storage (increasing soil carbon), rainwater collection and natural wastewater treatment and reuse for sustainable irrigation.

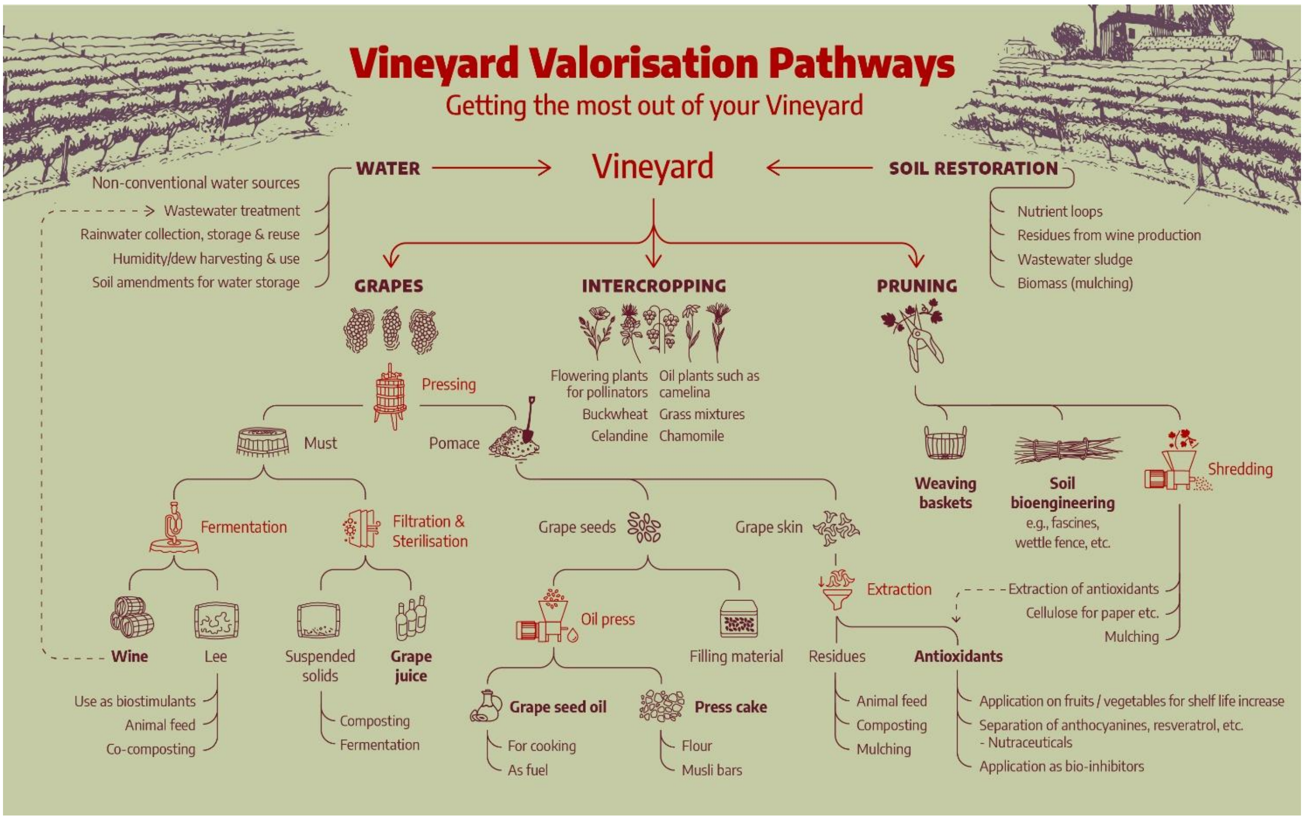

Figure 17: Infographic for vineyard valorisation pathways

4.2.3 Stakeholder roles

- Local industry: Construction sector, bio-based materials manufacturers, agricultural co-ops, biorefineries.
- Policymakers: Regional government, LEADER and other regional programme managers, transition brokers through business development agency.
- Research institutions: Fachhochschule Burgenland, environmental NGOs, bioeconomy clusters.
- Infrastructure providers: Biomass processing plants, composting facilities, logistics hubs for decentralised processing.

4.2.4 Regional governance & financing

Governance model

- Establishment of a regional bioeconomy coordination hub.
- Strengthening inter-agency collaboration between environmental and economic sectors.
- Capacity building through local training providers (BUZ, Wirtschaftsagentur Burgenland).

Funding opportunities

- EU-level: CBE JU, Horizon Europe, LIFE Programme, ECBF.
- National: Bioeconomy Austria (rather financing network activities - good for interaction with other stakeholders and experts), Austrian Wood Initiative (fund for material and energetic use of wood),

FFG (research and innovation projects), aws (intermediate step for business applications), KPC (structural funds for environmental savings).

- Regional: LEADER (dedicated regional development activities), KEM (climate and energy model region fund), KLAR! (climate adaptation fund), Wirtschaftsagentur Burgenland (regional business activities).

Figure 18: Funding opportunities for xBurgenland

The most applicable ones for this case study are follow-up FFG or Horizon Europe projects for innovation development and demonstration. Within this innovation follow-up project, the implementors should involve regional structural funds for infrastructure upgrades.

4.2.5 Roadmap

The goal of the Northern Burgenland circular bioeconomy roadmap is to establish a sustainable and scalable system that maximises the value derived from local bio-resources, with a focus on Lake Neusiedl's reed beds and sediments.

Main goals

This can be measurable achievements:

- Harvest up to 60 km² of reed, equating to 42,000 tonnes per year, to contribute not only to sustainable lake management and habitat renewal but also to the development of bio-based materials and energy solutions.
- Achieve the sustainable removal and utilisation of up to 90% of the lake sediments for applications such as construction materials and soil enhancement. A targeted removal rate of 100,000 m³ or more per year would help mitigate the sedimentation challenges currently affecting Lake Neusiedl.

Proposed timeline

Short-term (2025–2028): foundation and initial projects

Resource assessment & stakeholder engagement

- Assess local resources (reed, lake sediments, vineyard residues) - achieved within BIOTRANSFORM.
- Engage regional stakeholders (farmers, local businesses, researchers) - started engagement within BIOTRANSFORM.

Pilot projects & R&D

- Launch pilot projects focused on resource collection and processing.
- Collaborate with universities for innovative bioprocessing technologies.

Infrastructure & policy development

- Develop basic infrastructure for biomass collection and storage.
- Initiate planning for decentralised biomass hubs and drying facilities.
- Establish supportive local policies for bioeconomy initiatives.

Public awareness & market analysis

- Launch community education campaigns about circular bioeconomy.
- Conduct market analysis to identify potential biobased products.

Mid-term (2029–2035): scaling up and diversification

Scaling pilot projects & biobased product development

- Expand successful pilot projects into larger operations.
- Develop biobased products (e.g., bioplastics, biofuels, organic fertilisers).

Infrastructure investments

Estimated €10–15 million for key processing infrastructure:

- Decentralised collection hubs for biomass storage and pre-treatment.
- Drying facilities for reed and vineyard residues (~€0.2-1 million per facility).
- Bioprocessing plants for biochar, insulation materials, and composites (~€2-4 million per plant).

Diversification of resources

- Explore additional biomass sources (e.g., agricultural residues, organic waste).

Biorefinery development & training programs

- Establish biorefinery for local biomass valorisation.
- Deliver training programmes for sustainable bioeconomy skills.

Partnerships & funding

- Secure partnerships for commercialisation and scale-up.
- Leverage EU and national funding opportunities.

Long-term (2036–2050): consolidation and leadership

Sustainable ecosystem & biobased alternatives

- Substantially replace fossil-based inputs with biobased alternatives.
- Achieve a regionally integrated, sustainable bioeconomy ecosystem by 2050.

Policy review & international collaboration

- Regularly revise policies to reflect evolving needs and progress.
- Cooperate with European partners for mutual learning and replication.

Innovation hubs & market leadership

- Set up innovation hubs to stimulate research and entrepreneurship.
- Establish Northern Burgenland as a model region for circular bioeconomy in Europe.

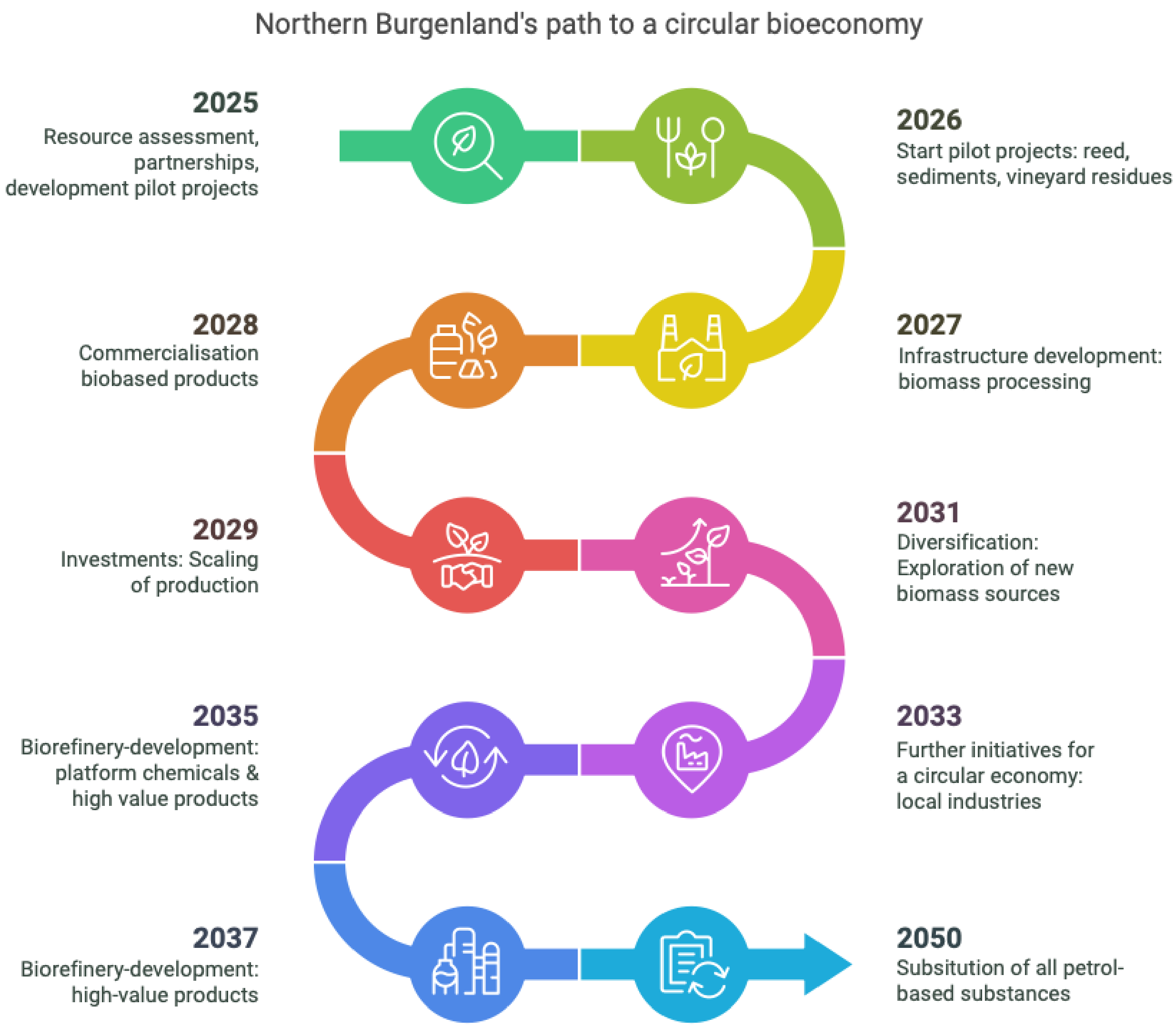

Figure 19: Northern Burgenland proposed transition timeline, created with napkin.ai

Anticipated benefits

Improved sediment, soil and water management

- Current sediment accumulation: ~60,000 m³/year.
- Planned sediment removal: Up to 15,000–20,000 m³/year for construction, soil enhancement, and remediation purposes.
- Expected reduction in sediment accumulation: ~25–30% over a 10-year period, helping maintain navigability, improve aquatic biodiversity, and prevent further lake shallowing.
- Water retention improvements: Sustainable sediment removal could increase water storage capacity in parts of Lake Neusiedl by 5–10%, reducing seasonal water shortages.
- Controlled sediment application could restore up to 100 ha of degraded farmland annually.

- Increased application of biochar and compost could enhance soil fertility across 500-1,000 ha of vineyards.

Carbon sequestration, emissions reduction and biodiversity conservation

- Utilisation of vineyard residues and lake biomass for biochar and composting could sequester 1,500-3,000 t CO_2/year.
- Sediment utilisation in construction could replace traditional materials, reducing cement-related CO_2 emissions by ~5,000 t/year.
- Current reed dieback affects 10–15% of reed-covered lake areas (~1,800-2,500 ha).
- Adaptive harvesting and management could stabilise or restore at least 30-40% of declining reed areas over the next decade (~500-1,000 ha restored).
- Improved reed bed management would enhance habitats for >200 bird species and promote overall lake biodiversity.

Strengthened regional identity through sustainable land use

- Integration of lake resources (reed, sediment) and vineyard residues into regional value chains enhances traditional industries like natural construction and ecological farming.
- Promotion of local bio-based businesses could improve community perception of bioeconomy and increase regional branding of "sustainable Burgenland" products.
- Better soil management (e.g., biochar from vine prunings, sediment-based fertilisers) could enhance drought resistance on 500-1,000 ha of farmland, increasing resilience to climate change impacts.

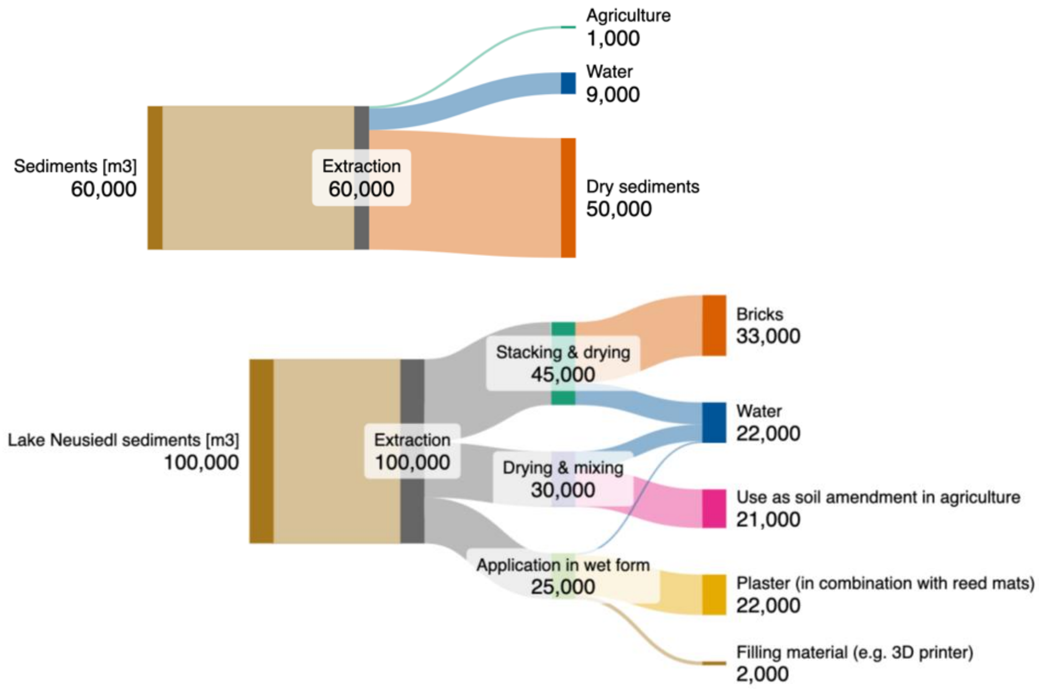

Figure 20: Lake sediments current pathways (top) & possible scenario (bottom)

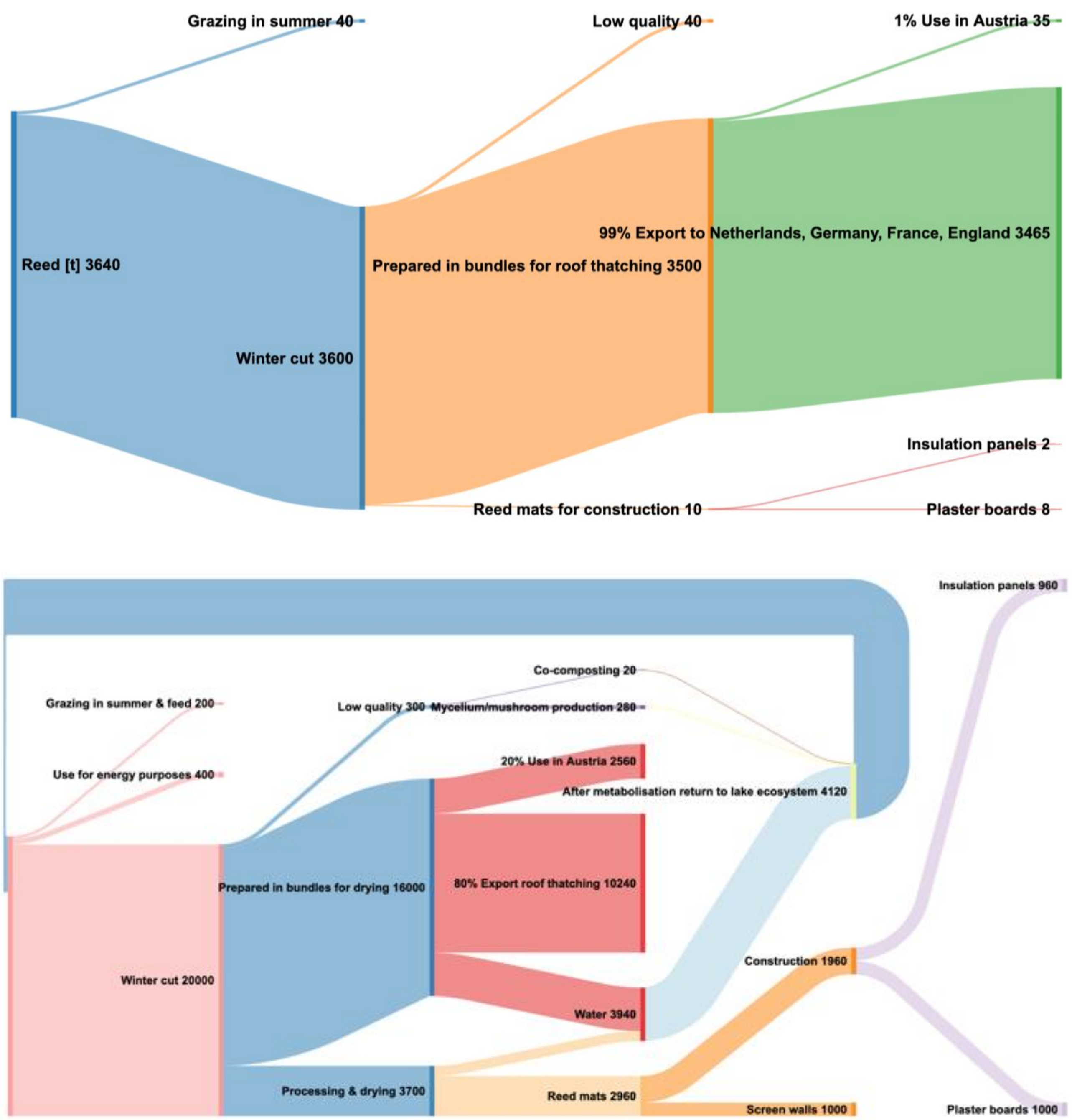

Figure 21: Lake reed current utilisation (top) & possible scenario (bottom) (numbers in tons/year)

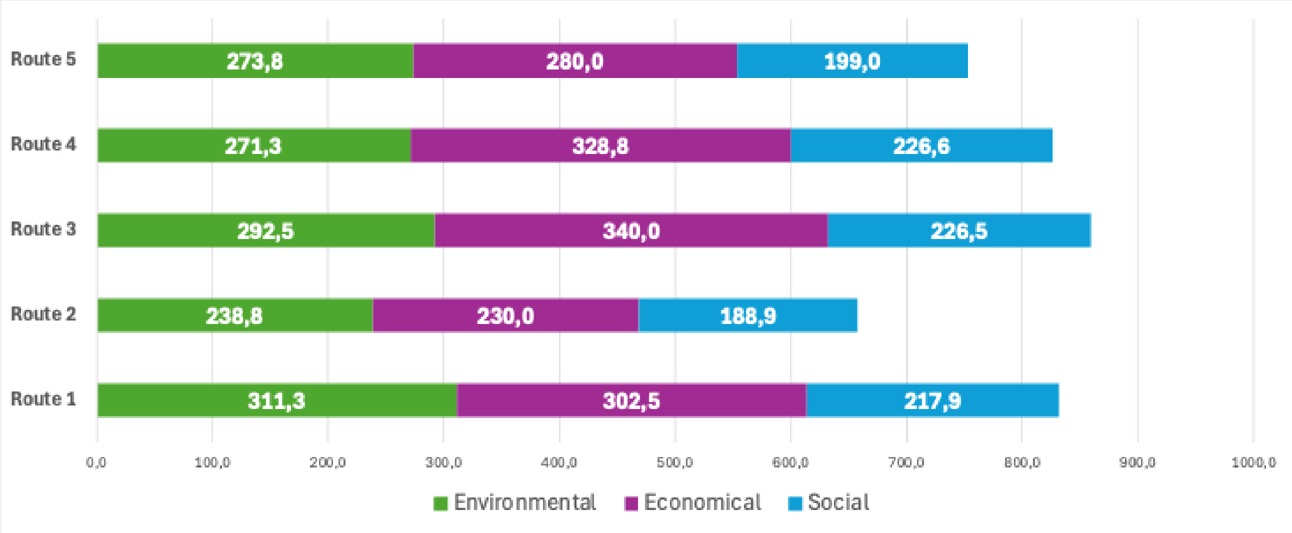

Figure 22: Evaluation of 5 different routes for lake resources valorisation

Explanation from Figure 22
Route 1: Sediments as construction materials
Route 2: Sediments in agriculture
Route 3: Reed as construction materials
Route 4: Reed for mycelia production
Route 5: Reed for energy

Economic opportunities

The development of these new bioeconomy sectors around biomass processing, material production, and logistics could generate 50–100 direct jobs, primarily in reed harvesting, vineyard residue processing, and sediment valorisation. For every 10 ha of optimised resource management, approximately 2-4 additional jobs could be created.

Revenue generation

- Reed-based construction materials: ~€3-5 million market potential/year; ~€7,000-12,000/ha for roof thatching depending on processing efficiency and product quality; ~€3,000-6,000/ha for reed panels and bio-based materials.
- Sediment-based products: Potential to generate €2-4 million/year, assuming utilisation in construction materials and agricultural soil amendments. €100–200/t for construction materials (e.g., bricks, plasters); €50–100/t for agricultural applications (e.g., soil enhancement); ~€1-2 million revenue per 10,000 m^3.
- Wine residue valorisation: Up to €1 million/year from grape seed oil, feed and fertiliser applications; ~per 10 ha of vineyard residues processed: €4,000-6,000 for grape seed oil & flour, €2,000-3,500 for biochar & soil amendments, €1,500-2,500 for pomace-based animal feed.

4.3 Charles Spa Region (Czech Republic)

The Charles Spa Region (Karlovy Vary) in western Czech Republic, traditionally reliant on tourism and coal-based industry, is navigating a dual transition: economic revitalisation and energy system transformation. With limited agricultural land and industrial activity, the regional bioeconomy roadmap focuses on valorising urban food waste through decentralised biogas and fertiliser production. This approach aligns with regional energy transition plans and leverages tourism-driven organic waste streams, while addressing demographic challenges through public engagement and the emergence of local transition brokers.

4.3.1 Challenges

Sectorial economic challenges and energy shift

The Charles Spa Region (or Karlovy Vary), nestled in the northwest of the Czech Republic along the German border, is facing a tough economic transition. Known for its rich natural assets - like mineral springs and spa tourism in some areas—it also has a legacy of mining and manufacturing in others. Traditional industries such as glassmaking, porcelain, textiles, and instrument production have been in steady decline over the past couple of decades for various reasons like: High energy and material demand, along with a shrinking and aging workforce, and a notable exodus of younger, educated people.

Additionally, Charles Spa's dependency on brown coal mining sets transitional challenges in shifting the energy mix toward more sustainable options. This is addressed in local action plans [34].

Limited agricultural resources

Agriculture isn't much of a fallback either. The region's mountainous terrain and poor soil quality limit farming, which only employs a tiny fraction of the population. Crop production is modest—mostly potatoes, cereals, and oilseed rape—and livestock farming plays a small supporting role.

Human capacity limitations

Demographics do not favour Charles Spa which is facing a gradual aging of the workforce, accompanied by difficulty in developing new skills. In parallel younger people migrate to other parts of the Czech Republic in search of more promising working opportunities. The absence of universities and educational institutions in the region is amplifying the problem.

Now, the region stands at a crossroads. With its economic foundations eroding and limited access to biomass, it's being pushed to find innovative ways to shift toward a circular bioeconomy. But that's easier said than done. The real challenge lies in building something sustainable and future-proof from limited natural and human resources.

[34] *Just Transformation Plan 2021-2030*, 2021 <https://www.rskkvk.cz/assets/uploads/1622794512-7170416232830507911024522135.pdf>.

4.3.2 Proposed Pathways

Figure 23: Biogas and fertilizer production from food waste with all stakeholders involved

In Charles Spa (Karlovy Vary and Mariánské Lázně cities) - known for their spa tourism - the decision **to turn food waste into biogas and fertilizer** came down to a mix of practical need and strategic alignment. With hotels, restaurants, and spas generating large volumes of food waste daily, it made sense to treat that waste as a local resource rather than a problem. The proposal was discussed with local stakeholders and with experts in the field.

Given the region's high tourist traffic and small resident population (about 300,000), central food waste collection from hospitality services provides a steady, manageable supply. Add to that a well-established national waste-sorting system with strong public participation.

The Czech Republic's broader energy transition strategies also push for more circular, local solutions. In what concerns regional strategies, biogas, and fertilizer production is in line with the Energy concept of Karlovy Vary region (2017-2042) and the Regional Development Programme 2014-2020 of Karlovy Vary region.

Biogas production fits that narrative—cutting emissions, creating local energy, and reducing reliance on fossil fuels [35]. Plus, it aligns with EU food waste and sustainability goals, turning unavoidable waste into something useful instead of letting it rot in landfills.

Results from the logistics assessment

The **Charles Spa Region in the Czech Republic** is a key centre for tourism and related industries, leading to substantial **food waste** generation during peak seasons. The cities of Karlovy Vary and Mariánské Lázně are in focus.

[35] Eurostat, 'Food Waste and Food Waste Prevention - Estimates', 2022 <https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates>.

Through its **MOOV service, VITO analysed the region's existing food waste collection and processing system from a logistics perspective, aiming to identify opportunities for reducing costs and transport distances.** Alternatively, improvement scenarios (TO BE) are explored with a focus on introducing alternative processing methods such as anaerobic digestion, centralising the treatment process, combining composting with anaerobic digestion, and bypassing transfer collection points (Figure 24).

This case study explores the **impact of introducing alternative logistic and processing scenarios** on the **transport distance** (Figure 25) and **mobilisation cost** (Figure 26).

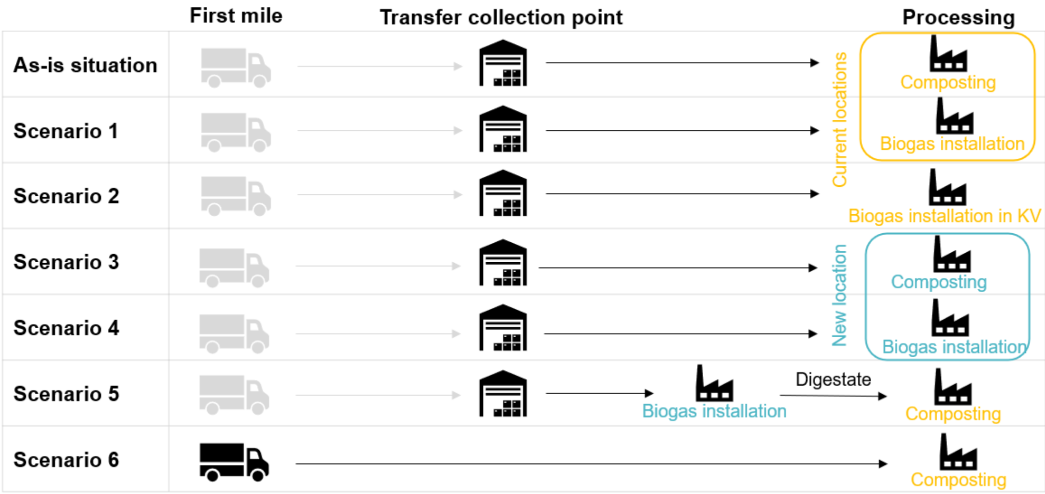

Figure 24: Scenario overview

Currently (AS IS), food waste from both cities is collected via first-mile pick-up and brought to intermediate transfer collection points (TCPs), from where it is transported to their respective composting facility. In total, 1,689 tons of food waste are processed annually, resulting in a transport distance of ca. 15.000 km a total annual logistic cost of €286.726—equating to roughly 9 km and €170 per processed ton. Of the total cost, 37% is attributed to the first-mile collection and transport to the TCPs, 56% to transport from TCPs to the composting facility, and only 6% to the composting OPEX costs.

Scenario results

Scenario 1 retains the existing two processing locations but shifts the treatment method from composting to AD. Since the locations remain unchanged, transport costs are unaffected; however, a 12% increase in total costs is observed, driven by higher operational expenses associated with AD.

Scenario 2 shifts treatment method from composting to AD while centralising processing at the Karlovy Vary plant. This increases transport distance by 8% and total costs by 14%. However, the additional transport cost is expected to be offset resulting from the consolidation of activities into a single end-processing facility, rather than the two facilities currently in operation.

Scenario 3 proposes the **establishment of a new centralised composting facility, with the flexibility to select the optimal location within the region.** This approach results in a 39% reduction in total transport distance and a 48% decrease in overall costs, highlighting the efficiency gains from strategic centralisation.

Scenario 4 builds upon Scenario 3 by introducing an anaerobic digester in place of a composting installation. Despite the higher OPEX costs associated with anaerobic digestion, the scenario still achieves a 37% overall cost reduction, owing to lower transport costs.

Scenario 5 builds on Scenario 4 by further processing the digestate from the AD facility at the existing composting sites, while both TCPs remain operational. This introduces an additional transport leg, increasing the overall transport distance by 19%. However, when considering the mass balance, the transport distance per processed ton decreases by 31%. The transport cost per processed ton decreases by 39% in Scenario 5, due to a higher total processed volume compared to the AS-IS scenario

To end, **Scenario 6 eliminates the TCPs, directly transferring food waste to a centralised composting facility**, reducing the total transport distance by 46% and cutting overall costs by 50%.

<u>In conclusion</u>

As this case study focused on minimising mobilisation costs, the results demonstrate that the **greatest cost savings are achieved by consolidating operations at a centralised facility, particularly when the location is optimised to minimise transport distances.**

To further refine the results towards a robust business case, the following aspects require additional attention:

- **CAPEX Costs**: The capital expenditure (CAPEX) associated with new installations was excluded from this analysis. Future evaluations should incorporate these costs to provide a complete financial picture.
- **OPEX Costs**: Operational expenditure (OPEX) was assumed to remain unchanged within the current study scope. However, consolidation scenarios — merging two operational sites into a single optimally located site — could potentially reduce OPEX through efficiency gains and should be assessed.
- **Revenues**: No additional revenues were considered from biogas production or digestate valorisation. Exploring potential revenue streams could improve the business case.
- **Policy Framework**: The potential impact of regulatory and policy developments, particularly government incentives for biogas, needs to be evaluated to understand financial and operational implications.
- **Social Framework**: Stakeholder consultations are recommended to assess the feasibility of transitioning to a centralised facility and to evaluate its potential effects on local communities.
- **Additional Scenarios**: Based on the current findings, a combined scenario could be explored where: i) Direct transport is organised to an optimally located composting site (Scenario 6), ii) Anaerobic digestion (AD) is integrated at this location (Scenario 2), iii) Composting of digestate occurs on-site, eliminating the need for additional transport (Scenario 5).
- **Phased CAPEX Investments**: To ease financial planning, CAPEX investments for the new composting and AD facilities could be staggered over time, allowing depreciation of the first facility before investing in the second

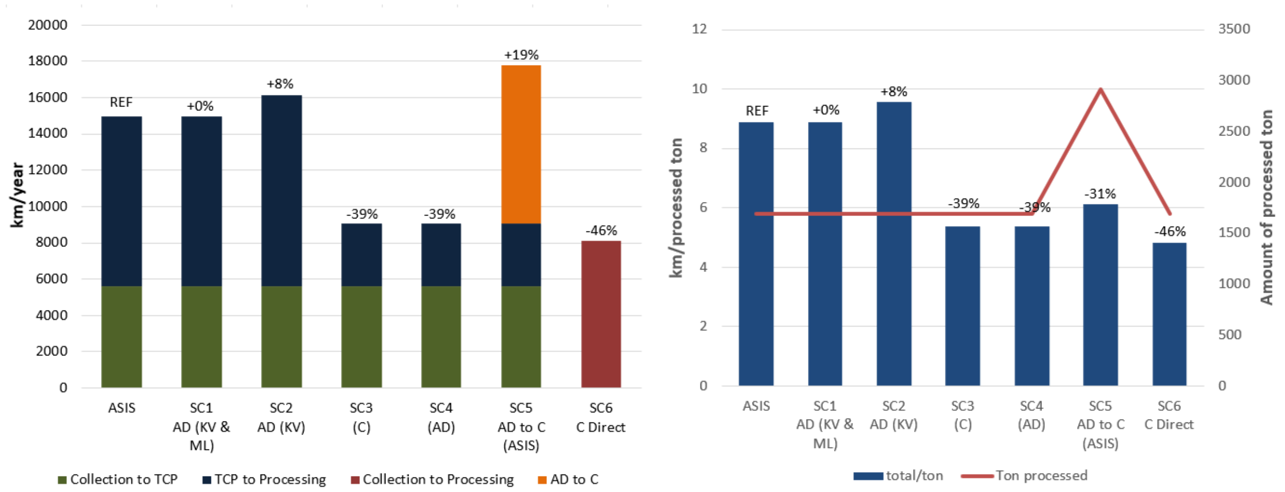

Figure 25: Transport distance in km/year (left) and €/ton (right)

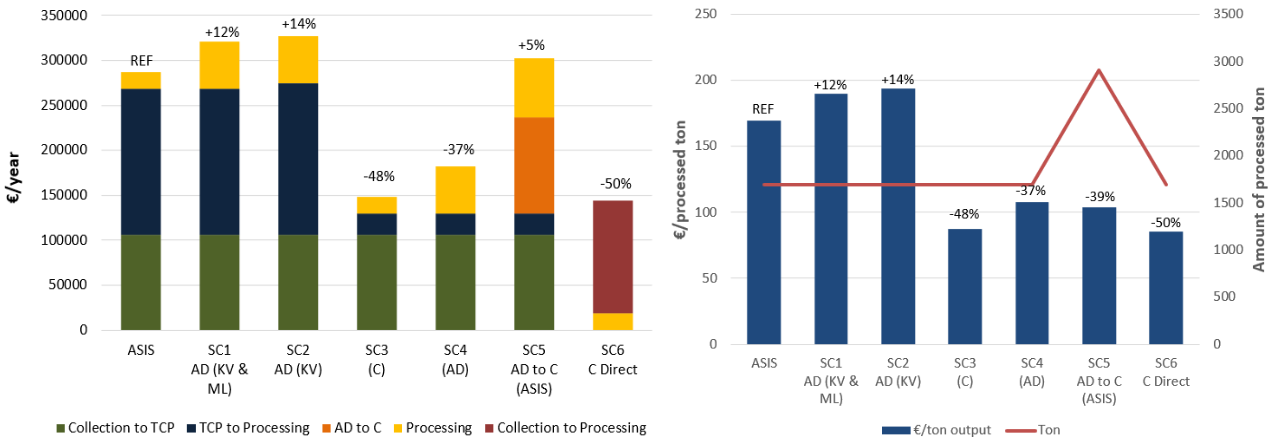

Figure 26: Mobilisation cost in €/year (left) and €/ton (right)

4.3.3 Stakeholder roles

Relevant stakeholders involved include local authorities, biogas and fertilizer production companies, waste management companies, restaurants and hotel owners, general public and local researchers. Despite biogas and fertilizer production being a familiar concept for the region, and the collection processes being in place, finding knowledgeable and influential stakeholders that can act as "transition brokers" is challenging due to limited expertise.

A **transition broker** plays a crucial role in connecting the dots between diverse stakeholders. Ideally, this person (or organization) should have credibility, neutrality, and strong communication and facilitation skills. In the Karlovy Vary case, this could be:

Regional Development Agency (RDA)[36]

KARP (Karlovarská agentura rozvoje podnikání - Karlovy Vary Business Development Agency) plays an important role as a regional innovation broker by connecting local businesses with research institutions and helping them bring new ideas to life. It supports companies in adopting innovations, while also focusing on

[36] Business Development Agency of Karlovy Vary Region, 'About Business Development Agency of Karlovy Vary Region', 2025 <https://www.karp-kv.cz/en>.

education—organizing workshops, seminars, and working with schools to develop the next generation of talent. KARP listens to the needs of the local business community, offers guidance on funding opportunities, and shares real-world entrepreneurial experiences with students and young people. By promoting the Karlovy Vary Region through marketing events and international projects, and by mapping key industrial areas, KARP helps shape a vibrant, forward-looking business environment that attracts investment and supports sustainable growth.

Appointed Liaison from the Municipality or Regional Council

Local authorities have legitimacy and access to key decision-makers all while focusing on alignment with existing policies and action plans. Proper involvement can generate interest and create policy incentives all while coordinating across departments (waste, tourism, environment).

Independent Sustainability Consultant or NGO – BIOEAST HUB CZ

The BIOEAST HUB CZ, working to establish working relationships with local stakeholders works as a credible outside voice with experience in circular economy awareness raising, all while networking sectors without internal bias.

4.3.4 Regional governance and financing

Regional governance faces a lot of structural problems related to the region's economic stability and development, with energy efficiency and transition being one of the issues. Energy however is one of the priorities as reflected in regional documents followed by a few available funding schemes:

Just Transition Fund (JTF): The Operational Programme Just Transition is a European initiative designed to support coal-reliant areas in the Czech Republic — specifically Karlovy Vary, Ústí nad Labem, and Moravian-Silesian. Between 2021 and 2027, around CZK 41 billion is available to help retrain workers, modernize businesses, invest in clean energy, and restore landscapes damaged by mining. For biogas and fertilizer producers, this opens real opportunities. Projects that promote clean energy, circular economy practices, and land restoration can apply for funding. Both individual companies and larger regional initiatives can join calls for strategic or thematic projects.

RE:START Programme: The RE:START initiative, led by the Czech government, focuses on revitalizing regions hurt by the mining industry's decline — mainly Ústecký, Karlovarský, and Moravskoslezský. Rather than offering direct funding, it links projects to existing national and EU financial resources, with a strong emphasis on business growth, innovation, the environment, and especially the shift to clean energy. For biogas and fertilizer sectors, RE:START is a great gateway. It connects them to funding for renewable energy, sustainable waste management, and agriculture projects through programmes like OPE and JTF.

Operational Programme Environment (OPE): OPE is another important funding channel in the Czech Republic, focused on promoting energy savings, renewables, climate adaptation, water management, the circular economy, and pollution control. About €2.4 billion is available for the 2021–2027 period. For biogas and fertilizer initiatives, OPE offers strong backing — whether it's building biogas plants that turn waste into energy or using byproducts to produce sustainable fertilizers. Municipalities, small businesses, and research institutions can all apply, with support available through the State Environmental Fund.

Private Investment:

Alongside public programmes, private investment in clean energy is picking up pace across the Czech Republic.

Renewable energy projects, energy efficiency improvements, and sustainable infrastructure developments are all drawing interest. Some of the key players include:

- ČEZ Group, the largest Czech energy company, investing heavily in renewables.
- EPH **(Energetický a průmyslový holding)**, a major European energy group moving away from coal into cleaner technologies and hydrogen.
- **Sev.en** Energy, expanding into innovative and transitional energy technologies, including biogas and waste-to-energy solutions.

4.3.5 Roadmap

Main goals

These are the main goals for the roadmap of the Charles Spa region in Czechia:

- Harvest local food and gastro waste, contributing to efficient waste management and renewable energy production, and supporting the development of local bioeconomy industries.
- Repurpose former lignite mining sites for bio-based applications, aiming to create new opportunities for biogas production and renewable energy solutions, while revitalizing areas previously dependent on coal mining.
- Invest in local innovation hubs and educational initiatives, including a new university focused on bioeconomy-related disciplines, to foster skills development and attract youth to support the region's transition towards a sustainable, circular bioeconomy.

Proposed transition timeline

Karlovy Vary has formulated a Territorial Just Transition Plan (TJTP) to address the social, economic, and environmental impacts of this transition. Following the Operational Programme Just Transition 2021-2027, which aims to support regions like Karlovy Vary in transitioning towards climate neutrality by minimizing the transitional effects, the proposed timeline aligns accordingly:

Short-term (2025-2027) goals and actions

Enhance research and data availability

Further research on the regional capacities in terms of biomass used, especially food waste. This will feed the development of digital and innovation hubs and support new solutions and efficient system designs.

Further engagement of local biogas production industries to build trust in data sharing and valorizing potential through dedicated business days and open discussions.

Mid-term (2027-2030) goals and actions

Seeking investment

Investment for repurposing former lignite mining sites. National studies are already mapping gaps in infrastructure regarding biogas production, setting the scene for further investment in covering local needs. The repurposing of former lignite mining sites can valorise upon heavily exploited areas that are set to be progressively abandoned.

Raising awareness for renewable energy projects

Promoting renewable energy projects through involving local stakeholders is key in building synergies and using available funds on-time. As energy efficiency initiatives for cities are highlighted and supported in the TJTP. Charles Spa has identified the need for energy transition. Yet, synergy building is often difficult because of the limited companies operating in the field and low innovation rates. Actions can include info days, personal outreach, tighter cooperation with KARP on local conferences, presentation of opportunities to participate in international projects.

Long-term (2030-2050) goals and actions

Enhancing public participation

Public participation has been a key component in the development of the TJTP. The Karlovy Vary Region was the first among Czech coal regions to hold public consultations on their Just Transition Plan [37], aiming to involve citizens and various stakeholders in shaping the region's sustainable future. Despite this promising initial engagement, public acknowledgement of bioeconomy related opportunities remains low. More sources of biomass should be researched (like food waste) and widely communicated, hopefully leading into discussions for cascading use valorisation.

Building skills

Skills building through education and making the energy sector an attractive work opportunity is key for the development and an ongoing effort that will allow more advanced applications in the future. Only recently, the decision to create the first local university was adopted yet more remains to be decided in terms of the disciplines to be included. The measure is promising in attracting youth and creating local opportunities for innovation and development. Actions would be to research in co-creation with locals and advocate for university disciplines that can actively support local innovation and bioeconomy development.

Anticipated benefits

When comparing the two value chains, biogas production (Route 1) comes out slightly ahead overall, even though the competition is fairly close.

From an environmental perspective, Route 1 scored 211.25 compared to 163.57 for Route 2. This suggests a stronger alignment between biogas production and the region's long-term sustainability ambitions. The local push toward renewable energy solutions makes biogas a more future-oriented choice, fitting well with broader environmental strategies.

On the social front, the two routes are almost neck-and-neck: Route 1 earned 189.66 while Route 2 scored 166.33. This close result reflects a deeper reality — that neither path will dramatically shift daily life in the region. Improving social outcomes seems to require broader political efforts. However, there's an opportunity: better tapping into food waste as a resource could not only strengthen Route 1 but also raise local awareness about the hidden value in waste management.

Economically, the difference is again modest. Route 1 edges out with a score of 104.26 versus 93.56 for Route 2. Biogas production could bring slightly better wages, although these jobs might not be enough to keep younger generations from leaving for bigger cities. Fertilizer production, meanwhile, plays a stronger role in supporting local agriculture by adding value where it's most needed. Yet, given the region's deep-rooted economic issues, neither pathway alone seems likely to spark a major turnaround — though both would offer meaningful, if incremental, benefits.

In short, while both routes have their merits, biogas production offers a more future-proof, environmentally aligned path forward, even if the social and economic impacts remain modest for now.

[37] CEE Bankwatch Network, 'Territorial Just Transition Plan for the Czech Karlovy Vary Region Finally Opened for Public Participation : Just Transition', 2021 <https://www.just-transition.info/territorial-just-transition-plan-for-the-czech-karlovy-vary-region-finally-opened-for-public-participation/>.

Table 4: Expected benefits for both suggested value chains

Environmental Benefits	Social Benefits	Economic Benefits
Efficient management of food and gastro waste	Job creation and skills advancement	Added value by valorising waste for the production of biogas and fertilizer
Contributing to local energy efficiency	Awareness raising among involved actors	Investments in infrastructure and repurposing older facilities
Efficient use of existing waste transport systems	Creating a model for other regions with heavy tourism industry to use biowaste resources locally	Slight benefit on wages and job creation

Through the assessment, several benefits were identified for both of the value chains applying in the environmental, social and economic aspects. These are presented in the table above, where we can highlight the efficient waste management and local energy efficiency.

Based on the overall assessment between the two pathways, a comparative analysis is presented below showcasing the score received for each category.

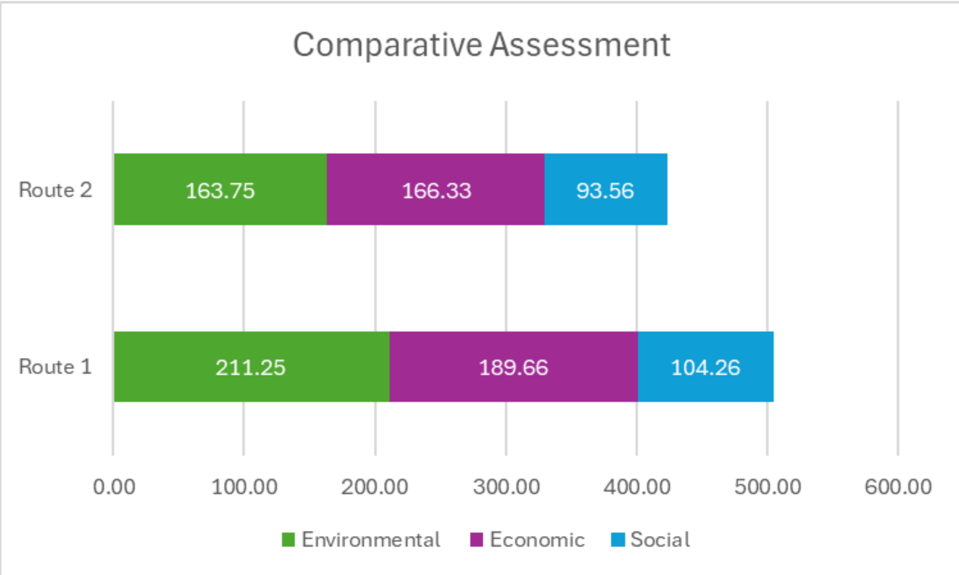

Figure 27: Comparative assessment between Route 1 (biogas production) vs Route 2 (Fertilizer production)

Economic opportunities

- Added value by valorising waste for the production of biogas and fertilizer
- Investments in infrastructure and repurposing older facilities
- Slight benefit on wages and job creation

4.4 Finland

The Finnish case study focuses on forestry-rich regions, where side streams from the pulp and paper industry—particularly lignin—are explored for higher-value applications in bio-based chemicals, adhesives, and battery materials. The roadmap proposes an integrated industrial transformation strategy that leverages Finland's strong bioeconomy policies, R&D infrastructure, and global leadership in sustainable forestry. Through stakeholder co-creation and cross-sectoral integration, the roadmap highlights cascading lignin valorisation pathways and emphasises the importance of industrial decarbonisation in achieving circular bioeconomy goals.

4.4.1 Challenges

Challenge today is to maximise forestry residues utilisation into products. Lignin is an underutilized stream from pulp industry and is being incinerated into electricity currently. Lignin amount is approximately 20% of wood matter. Potential material products of lignin are in anode material production, adhesives and plasticisers. Other streams identified in the forest industry were green liquor dregs (64 kt), bark & sawdust (5.5 Mm3), hemicellulose (20% of wood), ash (from forest industry, 545 kt) and post-consumer wood (225 kt).

4.4.2 Proposed pathways

Pathway was selected by researchers based on discussions with stakeholders in workshops backed up by literature survey that first identified several possible secondary streams that were: lignin, green liquor dregs, bark and sawdust, hemicellulose, ash and post-consumer wood. Based on these, lignin was selected and from lignin three different utilisation options were selected. Proposed pathways are in integration of forestry by-products into existing value chains from pulp production.

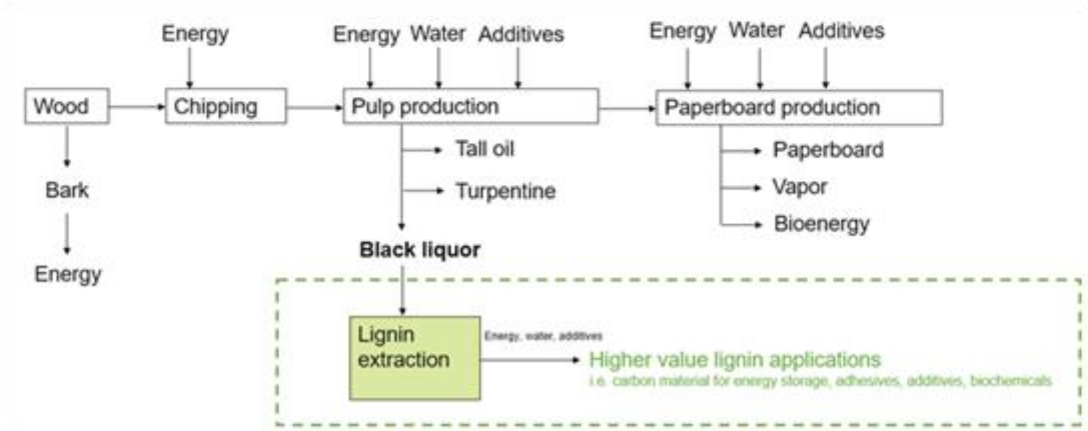

Figure 28. Simplified lignin extraction process from pulp mill.

Extraction from existing pulp mills is possible with relatively small investments without additional logistics needed from forests harvesting. Several piloting facilities are built for pre-commercial purposes aiming for commercial scale investments.
The current use of lignin is incineration (Figure 29). It's been proposed that some other material products could be made out of it instead (Figure 30).

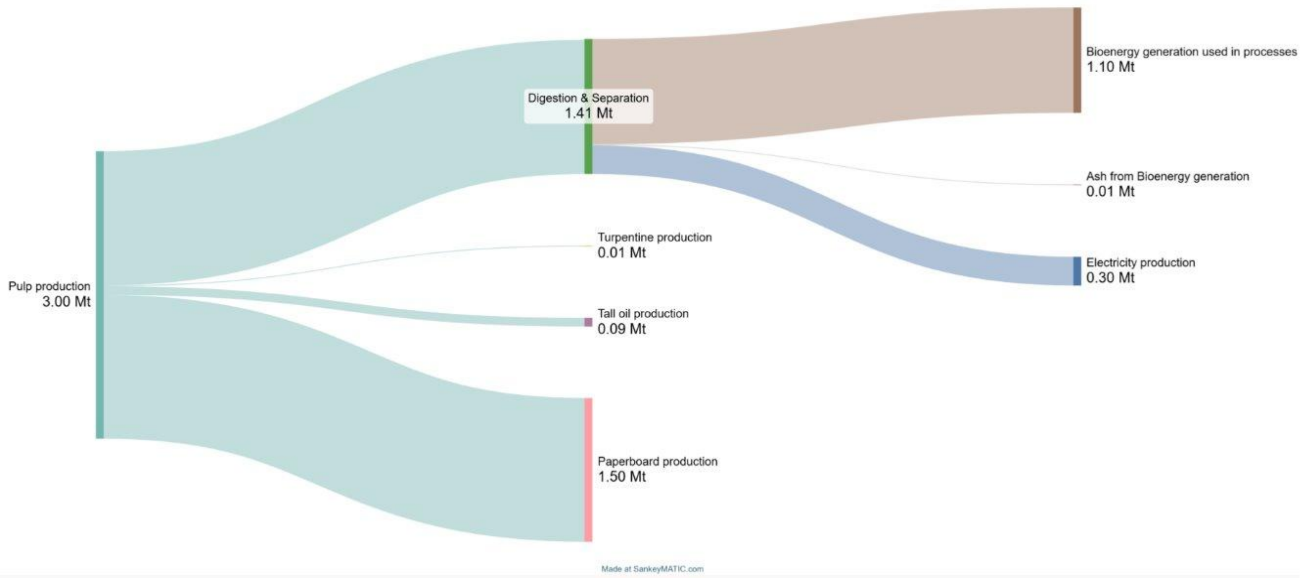

Figure 29. Current use of lignin from black liquor - electricity production.

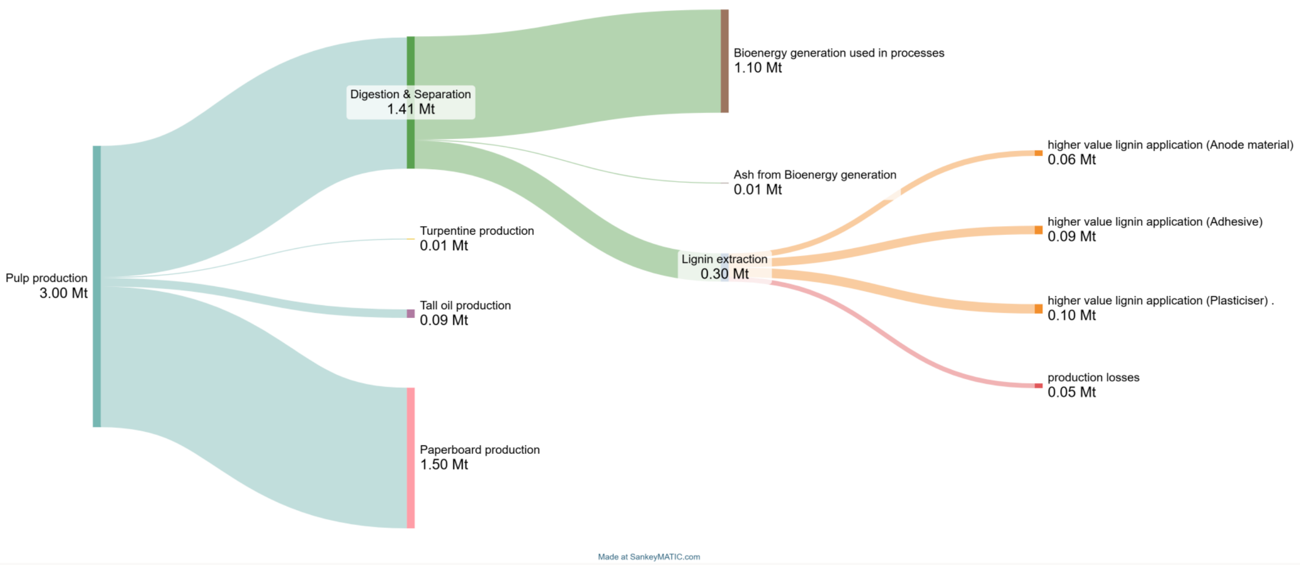

Figure 30. Proposed use of lignin into plasticisers, anode material and adhesives.

4.4.3 Stakeholder roles

Stakeholder roles identified were forestry industries, research institutions, industry involvement, government and regional authorities.

4.4.4 Regional governance & financing

Regional governance & financing is already at good level as Circular bioeconomy strategy of Finland 2023 aiming for carbon neutrality by 2035 as well as Climate Change Policy Plan aiming for climate neutrality 2035 are in place. Company-driven financing methods are based on earlier works financed on a national and EU-level. Main national research support actions are from Business Finland[38] offering services for SMEs, startups, large companies, research organisations and public sector. Regional support actions are mainly from the European Regional Development Fund (ERDF)[39] and basic research actions are funded by Finnish academy[40] All of these can be used to finance the selected pathway.

4.4.5 Roadmap

Main goals

These are main goals for the Finnish roadmap:

- More than 1 commercial lignin separation unit operational in a pulp mill.
- Produce high-value products from lignin to replace fossil-based alternatives, contributing to the development of a sustainable bioproduct industry and enhancing Finland's position as a leader in circular bioeconomy.
- Develop and scale up lignin processing technologies, aiming to utilize up to 200,000 tonnes of lignin per year, enhancing its market potential and supporting the transition to a circular bioeconomy in Finland's pulp and paper industry.
- Integrate lignin-based products into key industries, such as batteries, construction, and packaging, to diversify Finland's bio-based product offerings and create new economic opportunities, while reducing reliance on fossil resources.

Proposed transition timeline

Short term goals and actions of the roadmap (2025-2027)

- Building lignin separation pilot factories for at least 1 of the proposed pathways

Mid-term goals and actions of the roadmap (2028-2030)

- Building lignin separation pilot factories for second of the proposed pathway
- Starting the commercialisation of the first pilot factory products via selected market launch in a proposed product, 1st investment decision
- Prepare market incentive and investment support introduction in a pilot case

Long-term goals and actions of the roadmap (2030-2050)

- Commercialising more than one of the proposed pathway.
- Market incentives introduced
- Investment support scheme piloted and launched
- Bioeconomy included in curriculum after secondary school -level
- Over 500 new jobs created in lignin factories and several thousands in the value chain
- EU level regulation updated regarding fossil material use

[38] https://www.businessfinland.fi/en/for-finnish-customers/home
[39] https://www.europarl.europa.eu/factsheets/en/sheet/95/euroopan-aluekehitysrahasto-eakr-
[40] https://www.aka.fi/en/

Visual Roadmap

Roadmap of forestry side-stream utilization was constructed based on expert and researcher views (Figure 31). It separates PESTEL-elements. It is an external factor evaluation used often in strategic management. PESTEL is an acronym from words Political, Economical, Social, Technological, Environmental and Legal.

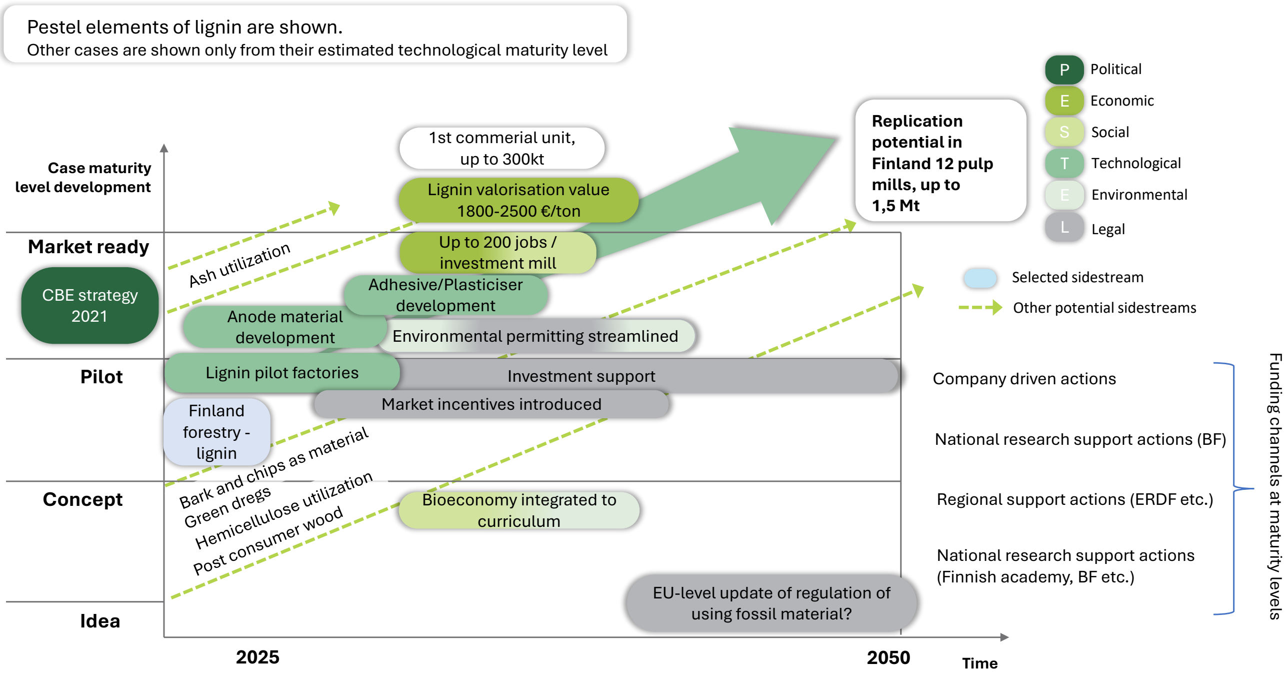

Figure 31. Forestry sidestream utilisation roadmap in Finland.

The roadmap includes side streams mentioned in the interviews and as selection was made for lignin, it was analysed more deeply. It also is mature enough from pilot onwards. E.g., forest ash utilisation is already in market-ready phase and needed research and legal changes are already made. Bark, green dregs, hemicelluloses utilization and post-consumer wood are all preparing for piloting to increase their maturity. Timeline in the roadmap is relatively flexible, but it's estimated that first commercial scale installation could take place in few years followed by several other after it. Some of the potential can only be reached if regulatory framework supports use of renewable materials instead of fossil ones, when available.

Anticipated benefits

Outcomes are in the proposed transition timeline and anticipated impacts (incl. socio-economic, env., financial), innovation potential, enhanced bio-based materials production.

The summary of different impact categories is shown in Figure 32. It weighs equally each category. The impacts with higher bar is better, and from the selected cases anode and adhesive is found to have almost equal sustainability followed by plasticizer with marginally lower overall sustainability.

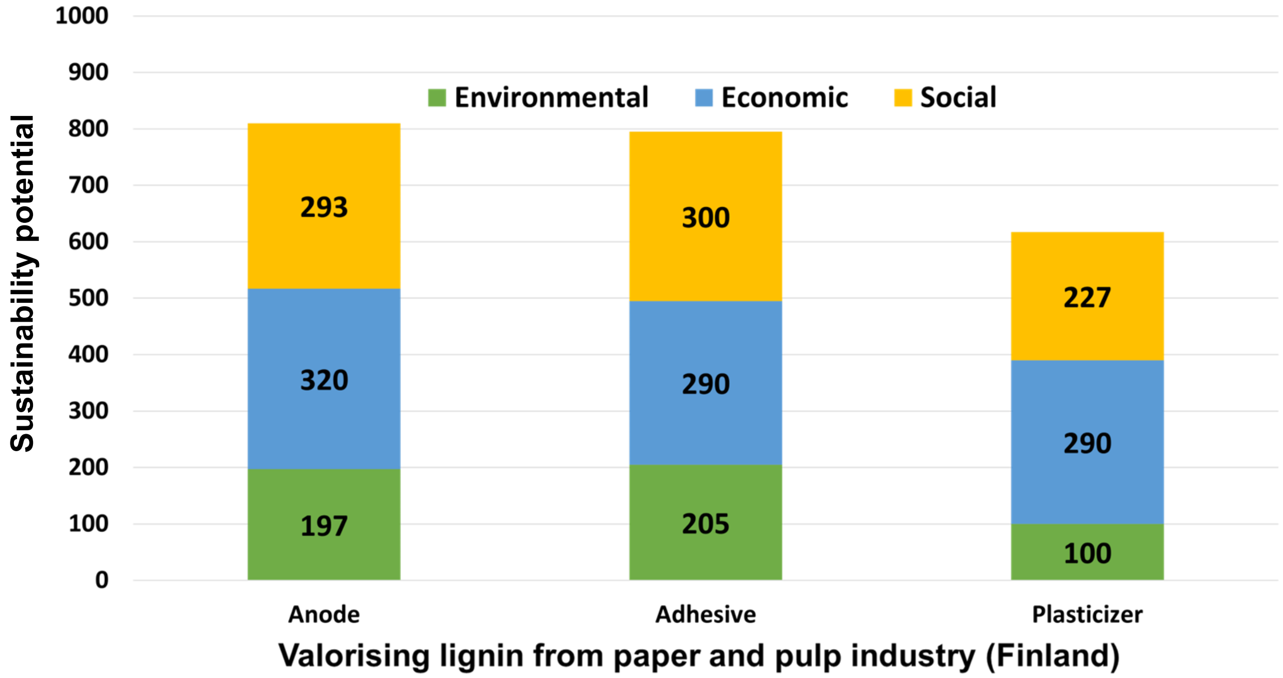

Figure 32. Summary of environmental, economic and social impacts

4.5 North Rhine-Westphalia (Germany)

North Rhine-Westphalia (NRW), one of Germany's most industrialised regions, holds substantial potential for circular bioeconomy solutions by valorising agri-industrial sides treams. The regional roadmap centres around two innovative pathways: using sugar beet pulp (SBP) for lactic acid production and rearing black soldier flies for organic waste treatment and protein production. These pathways combine technological maturity with strong regional expertise and infrastructure, fostering industrial symbiosis between food production, biotechnology, and material processing. NRW's roadmap exemplifies how established industrial clusters can integrate bio-based circularity into mainstream operations.

4.5.1 Challenges

The North Rhine-Westphalia region is in the process of transitioning to a circular bioeconomy. The end of coal mining creates the need for a transformation process in a large area, which has great potential, but also needs to be carefully managed in terms of ecological, economic and social aspects. This change is being addressed strategically in a number of areas. On the level of the former mining region, the Rheinisches Revier, initiatives and funding frameworks have been established that work towards shaping a region built upon bioeconomy principles. To this end, universities, industrial companies, clusters and networks, municipalities and city administrations and other stakeholders are working closely together so that this transition can succeed. In addition, North Rhine-Westphalia is working on its own bioeconomy strategy, for which the Bioeconomy Council, made up of experts from industry and academia, has been appointed. This body now has the task of developing a suitable strategy together with the NRW state government based on industrial and societal needs. Initial guidelines include a reorientation of the raw material base towards renewable resources. Along the lines of the National Bioeconomy Strategy and the Biomass Strategy, this will likely include the use of biogenic residues and side streams. For the chemical industry this is an opportunity and a challenge at the same time. On the one hand, the chemical industry is strongly dependent on reliable carbon sources, on the other hand they have to move away from fossil feedstocks to achieve EU´s climate goals [41]. While there won´t be enough regional biomass to replace the carbon demands of the chemical industry, future scenarios depict scenarios that combine carbon sources from highly efficient recycling strategies, carbon capture and utilisation (CCU), and from biomass to meet the needs of the industry [42]. It will be a major task to develop suitable and economically feasible processes, a supporting legislature and framework to work towards biobased competitiveness. Together with technologies and processes that allow cascading valorisation, resources have to be used in the most efficient way.

In this case study, efforts were made to create a higher valorisation for sugar beet pulp. The concept of an integrated lactic acid production at a sugar production side could create an efficient processing of local feedstock without the need of long transport routes. Thus, creating a diversification of income for local farmers and sugar producers and providing a base chemical for the local industry.

4.5.2 Proposed pathways

Following the process of pathway definition through desk research, expert interviews, and the multi actor approach described in deliverable 3.1, two pathways were identified to be promising for further analysis.

The valorisation of biogenic side streams through insects (such as Black Soldier Fly, *Hermetia illucens*) and the use of sugar beet pulp as a feedstock for the production of lactic acid.

Valorisation of biogenic side streams via the black soldier fly

The development of the transformation path for the utilisation of side streams by black soldier fly was carried out with the help of industry representatives from NRW. The structure of the process and the estimation of the necessary inputs and outputs were assumed on the basis of existing plants and existing literature. The potential of the technical utilization of insect oil (and proteins) should be clearly emphasized here, as this could create an additional, value-added option for the producing insect breeders. However, there are regulatory hurdles for feeding waste streams to animals which hinder several potential business cases.

The approximate material flows of an insect farm for the production of the insect oil and insect protein shown in Figure 33 were calculated on the basis of exemplary production capacities. While literature data suggests a main use of water by process steps and washing steps (about 95 % of water consumption) [43], the available data suggests an increased water consumption for the preparation of larval feed. This imprecision is due to contradictory data and is strongly dependent on the type of feed and its water content. If crop residues or food waste are used, an increased inherent water content can be assumed, so that additional fresh water is unnecessary. The step of food preparation is therefore very much dependent on the available feedstock,

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[41] Manfred Kircher, 'Chemical Production Based on Biomass—Potential and Limits', *Biomass*, 5.1 (2025), p. 8, doi:10.3390/biomass5010008.

[42] Carus, M. and others, *Is There Enough Biomass to Defossilise the Chemicals and Derived Materials Sector by 2050* (nova-Institut GmbH, February 2025) <https://biconsortium.eu/sites/biconsortium.eu/files/publications/Is%20there%20enough%20biomass%20to%20defossilise%20the%20chemicals%20and%20derived%20materials%20sector%20by%202050.pdf>.

[43] Sergiy Smetana, Eric Schmitt, and Alexander Mathys, 'Sustainable Use of *Hermetia Illucens* Insect Biomass for Feed and Food: Attributional and Consequential Life Cycle Assessment', *Resources, Conservation and Recycling*, 144 (2019), pp. 285–96, doi:10.1016/j.resconrec.2019.01.042.

however a water content of 75 % dry matter (DM) [44] can be assumed as a rule of thumb. Water flows in the process can be recycled, increasing the efficiency of the process.

The further use of insect oil in technical applications, such as lubricating oil, has the potential to save fossil raw materials. Research in this area shows that although the composition of black soldier fly oil is fundamentally suitable for this application, the composition can vary with the composition of the feed [45]. The fattening of non-food grade side streams and waste to insects poses a valorisation option besides the processing via industrial composting or as feedstock in biogas production. However regulatory hurdles remain.

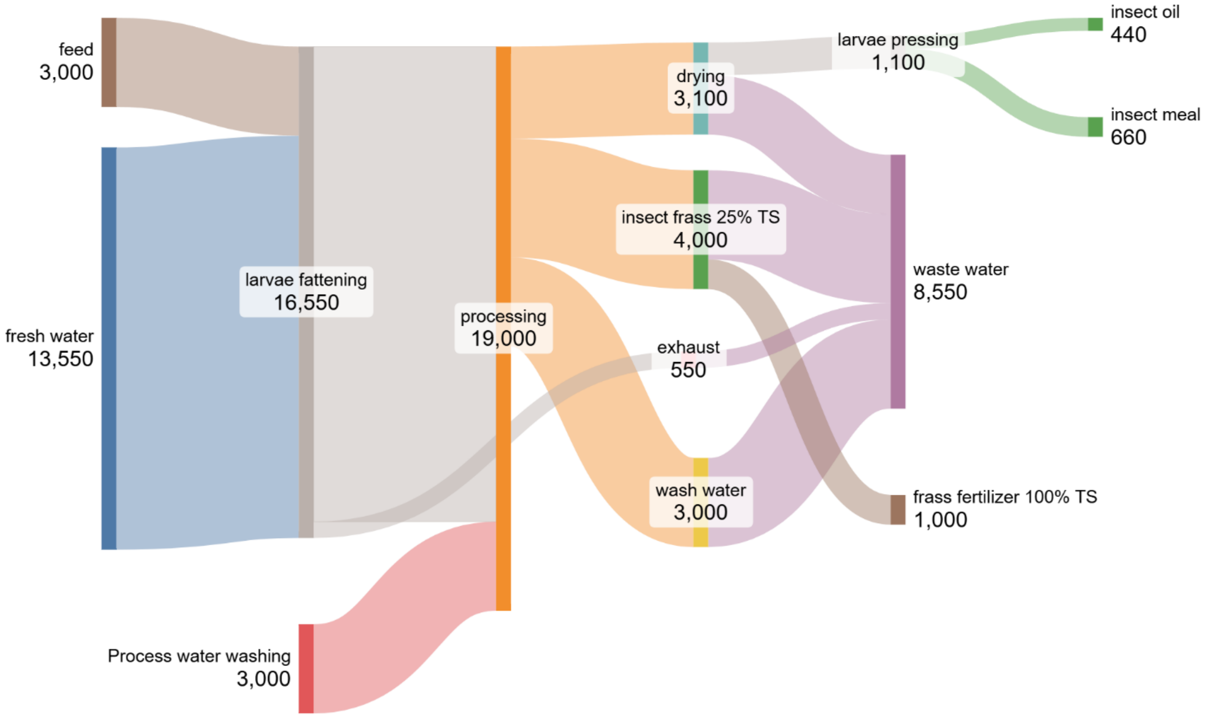

Figure 33: Sankey diagram of the mass balance of the production of black soldier fly larvae. Depicted numbers are estimates according to industry information in tons/year

Business Case

The use of residual streams and waste for the feeding of insects is strictly regulated by EU law (Regulation EC No. 1069/2009), so that insect fattening is only permitted with approved feedstuffs. This regulation stands in the way of the business case for the use of residual streams, which also limited a more detailed analysis of this pathway within the BIOTRANSFORM project. Further collaboration and development of the pathway was suspended, and further analysis was only carried out on the basis of the second transformation pathway presented below.

This path nevertheless has potential and further development in NRW is supported. However, future regulation will have a significant influence on the feedstocks used and therefore the cost structure of the products produced from insect fattening. In order to be able to compete with fossil fuels or existing solutions based on vegetable oils in technical areas.

[44] Fraunhofer IGB, *InBiRa – Die Insektenbioraffinerie*, 2024.
[45] Fraunhofer IGB, *InBiRa – Die Insektenbioraffinerie*.

Sugar beet pulp as a feedstock for lactic acid production

The second transformation pathway, the conversion of sugar beet pulp to lactic acid by a fermentative process, was evaluated as the most promising process. The local sugar industry converts 7.8 million tons of sugar beet annually[46] for the production of household and industrial sugar, resulting in large amounts of the side streams sugar beet pellets and molasses. As these side streams are mainly used as fodder in livestock farming or as feedstock for yeast and ethanol production respectively, processing them into lactic acid has a potential of increased added value.

Lactic acid is a versatile chemical, used in food applications, cosmetics pharmaceutical and the chemical industry. It is the monomer to the biopolymer poly lactic acid (PLA) that shows a huge impact on the European and international biopolymer market.

Due to the high water content of the sugar beet, the transport of fresh sugar beet is not economically feasible. Sugar beet pulp is pressed after the extraction process and usually dried or silaged and used as feed for livestock. With a water content of 30 % DM it is prone to spoilage which complicates further transport and storage steps. This case study was based on the assumption that the necessary fermentative processes, as well as the pre-treatment and downstream processing, can be integrated into the ongoing operation of sugar production, cutting transport routes short and making use of the existing infrastructure.

This results in the following advantages:

- Minimisation of transport requirements
- Utilisation of storage capacities
- Recycling potential of the process water from sugar production
- Utilisation of waste heat for downstream processes
- No need to dry the sugar beet pulp

Figure 34 shows the integration of this fermentation in existing sugar production refineries.

[46] Communication Pfeifer & Langen GmbH & Co. KG (02/25)

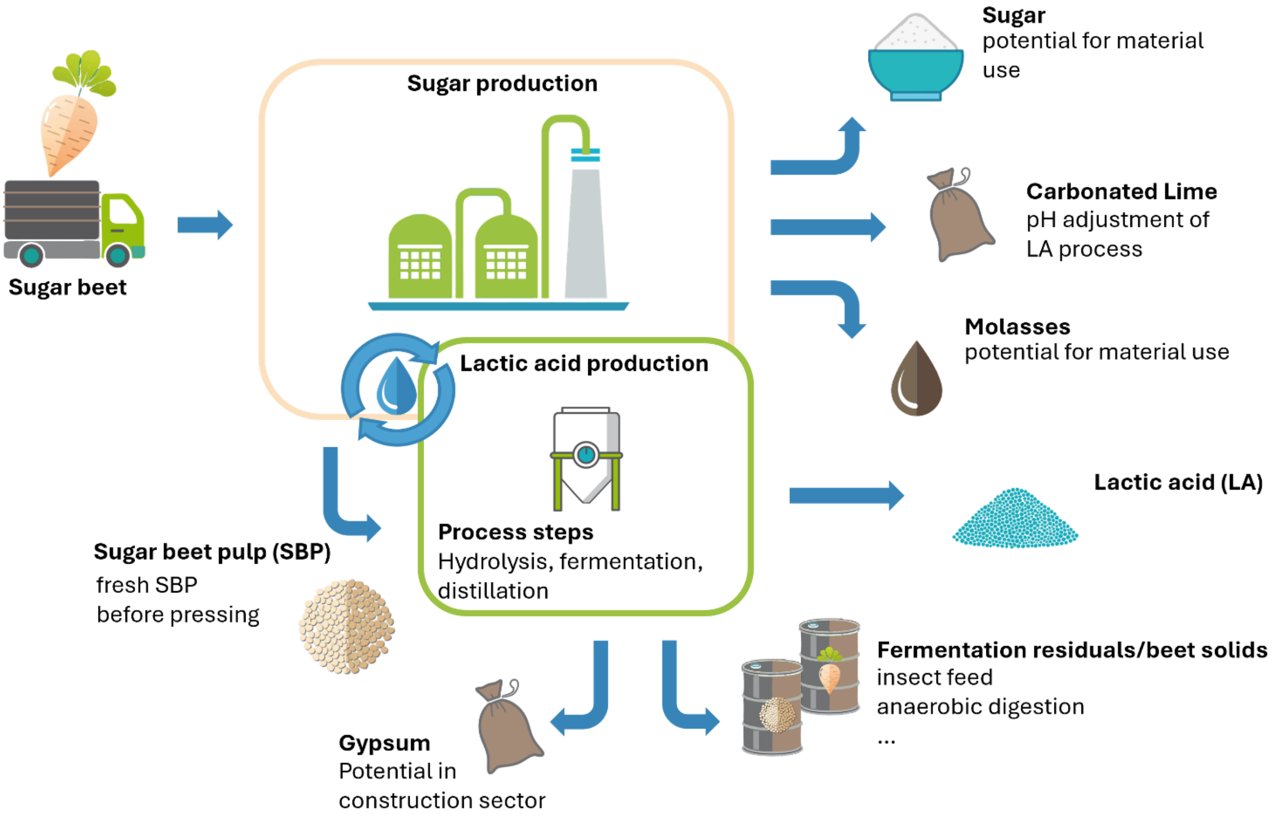

Figure 34: Integration of the fermentative process of lactic acid production into the local sugar production.

The initial discussions with experts from the Technical University of Munich (Zavrel Group TUM CS BVT) led to a collaboration on modelling the necessary process. Assumptions from the context of the sugar industry based in North Rhine-Westphalia, data from the regional statistical offices in NRW and the databases of the Super pro Designer modelling program were used as the basis for the modelling.

The proposed process includes preprocessing of the pressed sugar beet pulp. To break down the hemicellulose fraction, enzymatic hydrolysis is needed to acquire a fermentable hydrolysate. After fermentation the microbial culture is separated and can be recycled in the next batch. A solid-state fermentation of stored, untreated sugar beet pulp could be considered as alternate form of pretreatment. Downstream processing yields lactic acid as the main product. Apart from gypsum which can be used in the construction industry, the biogenic side streams of the process, sugar beet pulp residues and solid fermentation residues, can still be used as a feedstock for biogas plants or as feed for insect fattening.

The Sankey diagram in Figure 35 shows the water intensity of the process. Hydrolysis and fermentation take place in aqueous solutions. While treated water from sugar production could cover the required quantities, the process of lactic acid production produces corresponding quantities of wastewater.

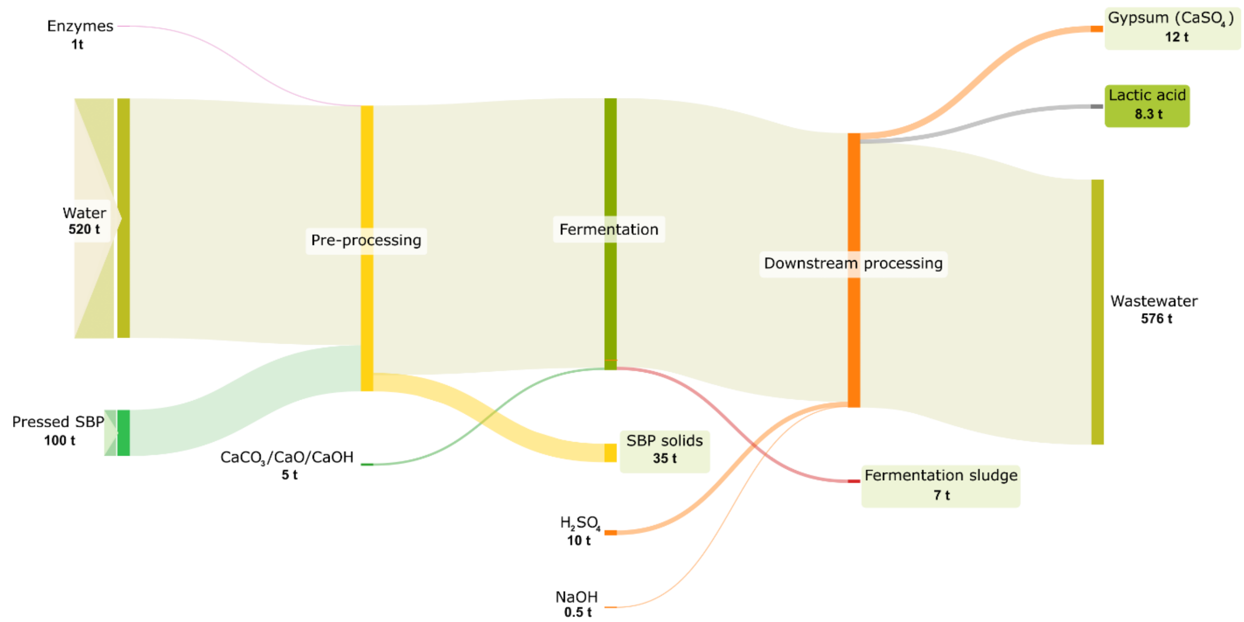

Figure 35: Sankey diagram of one batch of sugar beet pulp valorisation to lactic acid.

In this figure, dimensions are given in tons for the production capacities of one local sugar plant. The batch size was estimated according to standard demo scale facilities. A total of 1.500 t of lactic acid could be produced from 18.000 t of SBP per year. Depiction on the basis of the estimations of Estelle van der Walt, M.Sc.; TUM CS BVT.

Business case

The business case of the above proposed transformation pathway has the potential to generate additional value from sugar beet pulp and provide valuable base chemicals for chemical and polymer chemistry. Additional utilization in cosmetics and food chemistry will depend on the purity of the product, microorganisms used and regulatory requirements. The transformation pathway shown can offer an alternative added value to feed applications and additional side streams for cascade use. In addition, the processing of SBP represents a higher-value use compared to thermal utilization, which is part of the sugar associations' carbon neutrality strategy depending on energy prices[47].
Since this concept is still in conceptional phase, a cost estimation is difficult and may vary immensely towards the timepoint of detail engineering. The listed main cost drivers are according to literature references, the modeling program Super Pro Designer (license TUM, Zavrel Group) and general estimations of manufacturers in early-stage planning phases ((Estelle van der Walt, M.Sc.; TUM CS BVT, TansBIB).

- Capital Expenditure (CAPEX): Fermentation and distillation equipment
- Operating Expenses (OPEX): Enzymes, water (can be reduced through recycling), chemicals, energy, wastewater management
- Market Potential and Economic Impact:
    - Growth of world lactic acid market expected (CAGR 8.3%)[48]

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[47] Roadmap klimaneutrale Zuckerwirtschaft https://www.zuckerverbaende.de/wp-content/uploads/2024/02/Feb-2024_Roadmap_klimaneutrale_Zuckerwirtschaft.pdf
[48] Vantage Market Research, *Marktgröße für Milchsäure: 8.80 Milliarden US-Dollar bis 2035*, 2024 <https://www.vantagemarketresearch.com/de>.

    - PLA represents highest share among bio-based polymers[49]
- Business Model Application: diversification of production portfolio and operation time of sugar refinery
- Alternative optimization steps and process intensification[50]
    - Extraction of additional components, like pectin, proteins, phenolics[50]
    - Partially energetic use of SBP to lower energy requirements[51]
    - Recycling of water streams

4.5.3 Stakeholder roles

In the course of the case study, a range of direct and indirect stakeholders for the LA case were identified by the project partner and external experts (see Table 5). The value chain studied directly involves farmers, sugar biorefineries, and converters to lactic acid. Thereafter it branches to the different potential users of lactic acid (chemical industry, bioplastic producers, food industry, fertiliser industry), their customers and end consumers, as well as the end-of-life scenarios of each.
Indirectly, other stakeholders are touched as well: stakeholders in agricultural technologies (Ag-tech: fertiliser, pest control, etc.), potential users of the new side streams generated (e.g. biogas plants, insect breeders/rearers, farmers), providers of infrastructure for the new processing plant(s), and logistic providers. In addition, since the analysis of the process to date showed potential for improvement, e.g. by optimised downstream processes or a shift to continuous fermentation, academic institutions in the region should also be included in the list of stakeholders. They have the necessary expertise and are active in relevant research areas.

Table 5: NRW stakeholders for the SBP case study.

Actor	Stakeholders
Academia	Research and development centres
	Universities
	Universities of applied science
Industry	Farmers (sugar beet production/valorisation of side streams as fertilisers)
	Sugar biorefineries (4 existing in NRW)
	Enzyme developers/producers
	Lactic acid producers
	Chemical industry (polymers, cosmetics)
	Bioplastic producers
	Feed producers

[49] IfBB – Institute for Bioplastics and Biocomposites, *Biopolymers - Facts and Statistics 2024* (Hannover | Germany, 2025) <https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter_broschueren/f+s/IfBB-Biopolymers-FactsAndStatistics-2024.pdf>.
[50] Regiane Alves de Oliveira and others, 'A Simple Biorefinery Concept to Produce 2G-Lactic Acid from Sugar Beet Pulp (SBP): A High-Value Target Approach to Valorize a Waste Stream', *Molecules*, 25.9 (2020), p. 2113, doi:10.3390/molecules25092113.
[51] FutureCamp Climate GmbH, *Roadmap Treibhausgasneutrale Zuckerindustrie in Deutschland - Pfade Zur Treibhausgasneutralität – Perspektiven Im Jahr 2024*, 2024 <https://www.zuckerverbaende.de/wp-content/uploads/2024/02/Feb-2024_Roadmap_klimaneutrale_Zuckerwirtschaft.pdf>.

	Food producers
	Ag-Tech companies
	Plant breeders
	Infrastructure providers, chemical parks
	Insect rearing
	Waste-management companies
	Biogas plants
	Logistics, Transportation
Government, Administration	Regional ministries: MWIKE, MULNV
	Municipalities
	Funding Agencies
Finance providers	Investors
	promotional bank for NRW

It will be essential to solidly network these different stakeholders to connect the entire value chain and surrounding stakeholders, generate enthusiasm and confidence, and ensure acceptance of the new value network. The transformation process has a direct influence on previously established value chains (for example the utilisation of SBP as feed), and their disruption will need to be managed to avoid adverse effects, e.g. on regional animal husbandry. The material use of sugar beet pellets compared to its use as feed or thermal utilisation holds great potential in terms of sustainability and resource efficiency. Networking and mediating between stakeholders will require a grasp of the bigger picture and the to be expected mid to long term benefits, especially in a market driven ecosystem. The necessary investments will only be made if clear benefits can be expected, and de-risking will be essential.

In the subregion of NRW which is affected by structural change, there are several organisations active in the organisation and management of the transition, such as the Zukunftsagentur Rheinisches Revier (ZRR) or municipal transition managers. In the state of NRW, a range of cluster organisations have been established, some funded directly by the state, others with private funding. These have been networking stakeholders and inspiring transformation, and clusters such as BIO.NRW, Chemie.NRW or CLIB are thematically relevant to the case study presented here.

4.5.4 Regional governance & financing

NRW as a region has several relevant strategies for the transition to a circular bioeconomy, as well as monitoring systems (see also D1.2). These are supportive of the use of side-streams as feedstocks for the chemical industry, want to revitalise rural areas, and mitigate climate change.

Potential sources of financing for the SBP to LA case study exist on regional, national, and EU levels. These change regularly or have certain cut-off dates. The following gives an overview of regional, national, and European programmes in place in March 2025. Current information is available via e.g. the National Contact Point (NCP) Bioeconomy and Environment (for EU funding), the funding database at the German funding agency PtJ (regional and national), or the German project partner of the BIOTRANSFORM project CLIB.

Regional

Productive.NRW, Circular production, Regio.NRW – Transformation, ZRR: regional structural change programme

National

KMU Innovativ: Bioökonomie, KMU-innovativ: Ressourcen und Kreislaufwirtschaft, Förderprogramm „Industrielle Bioökonomie“

European

CBE JU, Innovation Fund, ECBF, LIFE Programme, INTERREG Deutschland-Nederland

4.5.5 Roadmap

In this case study, the proposed transformation pathway was discussed with a diverse group of regional stakeholders from associated initiatives, markets and other groups of interests (see Table 5). It was shown that numerous stakeholders in the region are directly or indirectly involved and could potentially benefit from implementation. Opportunities like regional valorisation and feedstock resilience were apparent and welcomed by stakeholders. It was however noted that the demand for lactic acid in its further processing into polylactic acid is restricted by a lack of infrastructure and regulation for recycling and confusion among end consumers about biodegradability. As a results of this workshop, a clear and structured adaptation of the regulatory framework was seen as the most important item on the developed roadmap Figure 36.

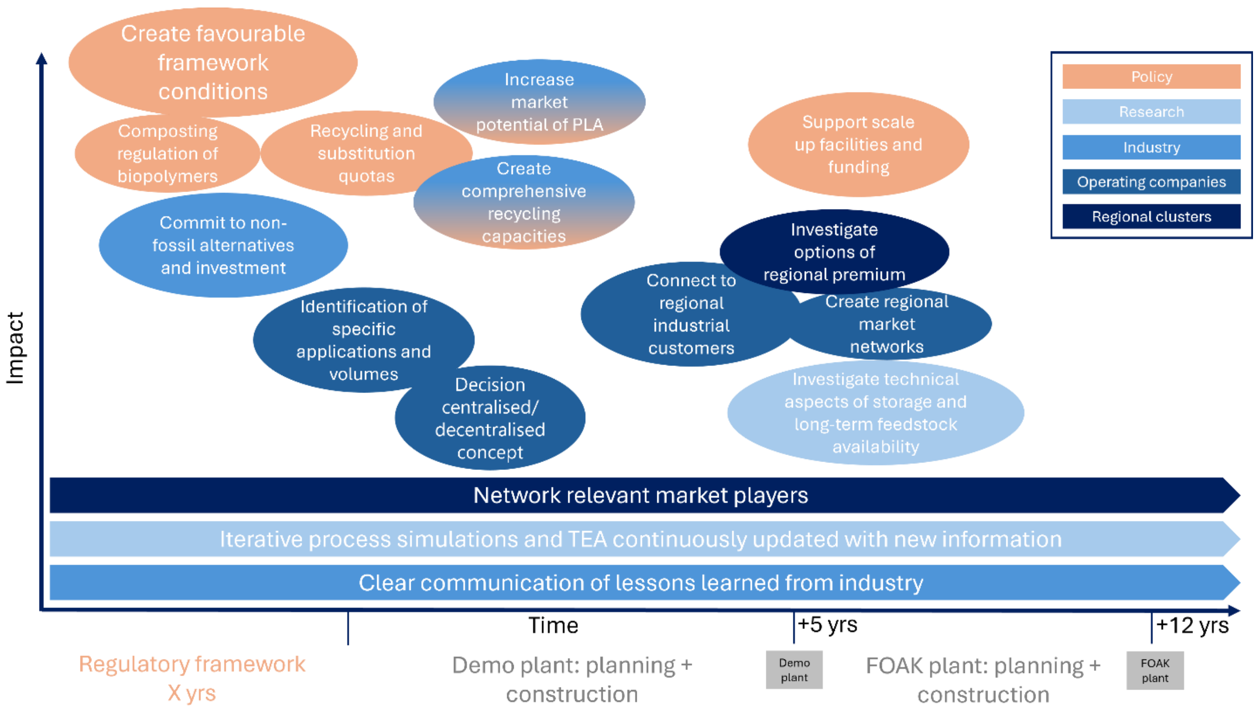

Figure 36: Roadmap of the proposed transformation pathway sugar beet pulp to lactic acid. The roadmap was developed through the input of stakeholders along different value chains connected to the pathway.

Main goals

The overarching goal is to establish a regional bioeconomy value chain that transforms sugar beet pulp - a currently underutilised resource - into high-value bio-based materials such as lactic acid and PLA, supporting climate goals, feedstock diversification, and the development of new bio-based industrial value networks in North Rhine-Westphalia.

These can be the main achievements for the NRW roadmap:

- Develop a local lactic acid production pathway integrated into existing sugar beet production processes, utilizing 2G feedstocks [52]. This will promote the regional valorisation of agricultural residues and support the transition to renewable bio-based industries.
- Scale up lactic acid production for further processing into polylactic acid (PLA), addressing the growing demand for bio-based plastics in the chemical industry. This will contribute to reducing reliance on fossil-based materials and foster sustainable practices in the plastics industry.
- Overcome regulatory challenges by collaborating with policymakers to adapt the regulatory framework, specifically for the composting of biopolymers and recycling quotas. This will help create a supportive environment for bio-based plastics and encourage investment in biorefineries.
- Create local job opportunities and promote rural development by providing training and employment in the circular bioeconomy sector, while simultaneously diversifying market opportunities for side streams from processing industries.
- Increase regional collaboration by engaging stakeholders from the sugar industry, academia, and local communities to foster synergies and improve the overall market development for bio-based products.

Proposed transition timeline

Short-term (2025–2028): Foundation and system alignment

Policy and regulatory groundwork

- Initiate dialogue with national and EU policymakers to revise regulations on composting, recycling, and substitution quotas for bio-based plastics.
- Clarify legal pathways for the composting of bioplastics and improve end-of-life treatment infrastructure for PLA.

Stakeholder engagement and concept definition

- Conduct targeted stakeholder workshops with the sugar industry, chemical sector, waste managers, and regional authorities to consolidate interest in 2G lactic acid production.
- Define a shared vision for local valorisation of sugar beet pulp, leveraging stakeholder input to co-design a viable transformation pathway.
- Promote NRW as a bio-based investment hub, targeting regional and EU funding mechanisms and attracting private investors MA.
-

Planning of demonstration phase

- Develop technical and economic feasibility assessments for decentralised vs. centralised lactic acid production models.
- Prepare the groundwork for a FOAK (First of a Kind) demonstration plant in consultation with potential industrial partners.

Mid-term (2028–2035): Demonstration and infrastructure build-up

Demonstration plant construction and operations

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[52] Ali Abdelshafy and others, 'Opportunities and Challenges of Establishing a Regional Bio-Based Polylactic Acid Supply Chain', *Global Challenges*, 7.7 (2023), p. 2200218, doi:10.1002/gch2.202200218.

- Construct and commission a demonstration-scale biorefinery to process sugar beet pulp into lactic acid.
- Ensure the plant is designed to serve as a replicable model for other bio-based transformation processes in NRW and beyond.

Market development and early adopters

- Identify and engage with downstream users of PLA and bio-based materials to secure offtake agreements.

Public awareness and training

- Implement targeted communication campaigns to address public misconceptions around bio-based and biodegradable plastics.
- Launch vocational training programmes and academic collaborations to upskill the regional workforce in circular bioeconomy processes.

Long-term (2035–2050): Scaling and system consolidation

Policy implementation and monitoring

- Support national and EU policy frameworks that incentivise substitution of fossil-based plastics with bio-based alternatives.
- Establish continuous feedback loops with policymakers to adapt regulations in line with technological and market evolution.

Technology scaling and replication

- Expand production capacities through scale-up of biorefinery operations, potentially adding new feedstocks.
- Facilitate replication of the lactic acid pathway in other sugar-producing regions of Germany and the EU.

Circular ecosystem establishment

- Position NRW as a frontrunner in bio-based materials production by integrating circular economy practices across chemical value chains.
- Establish a full value chain from regional biomass to high-value applications in packaging, consumer goods, and industrial materials.

Anticipated benefits

The following benefits, in all areas of sustainability, have been identified through interviews, and stakeholder workshops. The sustainability score was determined according to the methodology for the semi quantitative assessment in WP2 and depicted for the proposed transformation pathway in Figure 37.

<u>Social</u>

- Promotion of circular bioeconomy principles and practices
- Rural development and reduction of rural-urban migration
- Training and job opportunities for local workers in circular bioeconomy technologies
- Income diversification and stable, well-paid employment in rural areas
- Potential for collaboration between academia, industry, and local communities
- Contribution to energy, food, and water security

<u>Environmental</u>

- Reduction of CO_2 emissions associated with fossil-based manufacturing
- Reduction of GHG emissions caused by burning sugar beet pulp for energy recovery
- Renewable feedstock for chemical industries
- Contribution to climate change mitigation efforts in the agricultural sector

<u>Economic</u>

- Diversification of income streams for sugar beet processors
- Increased revenue for sugar beet processors, growers, from bio-based products
- Access to new markets, particularly in the growing sustainable products sector
- Attraction of investments in circular bioeconomy initiatives
- Retention/creation/improvement of jobs in the area, for qualified workers

<u>Summary of findings</u>

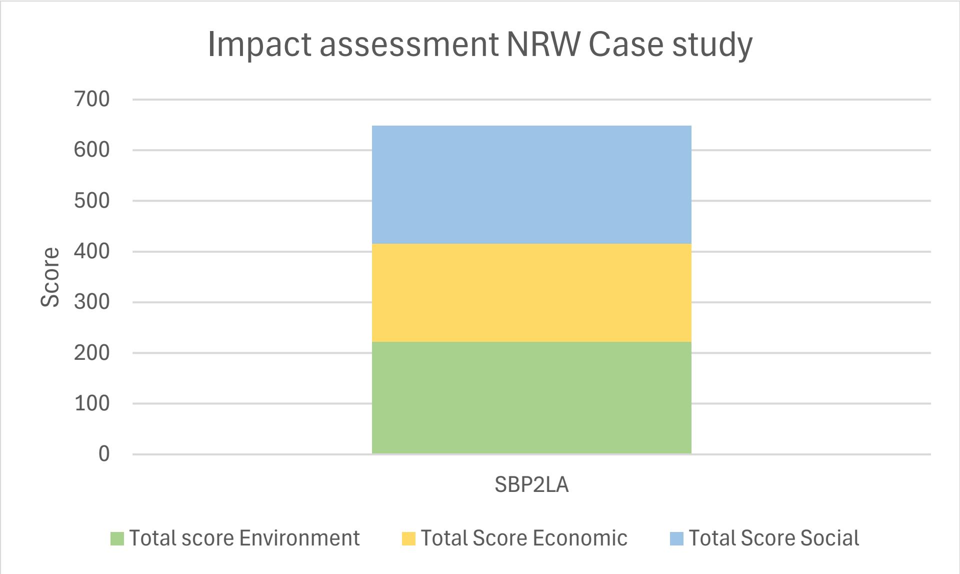

Figure 37. Semi quantitative assessment of the environmental, economic, and social impact on the NRW region according to stakeholder opinions. Score is depicted as the as the sum of the individual assessments from a possible maximum value of 1000 points.

4.6 Western Macedonia (Greece)

4.6.1 Challenges

Region

The current challenges in Western Macedonia involve optimizing the use of underutilized resources for energy production and enhancing the region's economic significance. The region also faces one of the highest unemployment rates in the country. However, the ongoing lignite phase-out has raised concerns among the local population, who fear it may further deteriorate the region's socioeconomic conditions [53].

A key challenge identified during the project implementation is the effective valorisation of natural resources and by-products in relevant markets, while simultaneously increasing employment opportunities and positioning the region as a national hub for innovation and sustainable economic development.

Non-integrated pathways

After an internal mapping for understanding in-depth the main gaps in the primary activities, some bioeconomy experts in the region were reached. It was observed that wood (mainly MDF and pellets industry) and green hydrogen (H_2) production by sewage sludge, are having the special attention by projects in the region and by policy makers.

A discussion with stakeholders, to understand the trends of policies in the region, and an overall analysis to understand the main possible pathways (see Figure 38), were conducted, which was observed a non-circularity and non-integration in the current pathways.

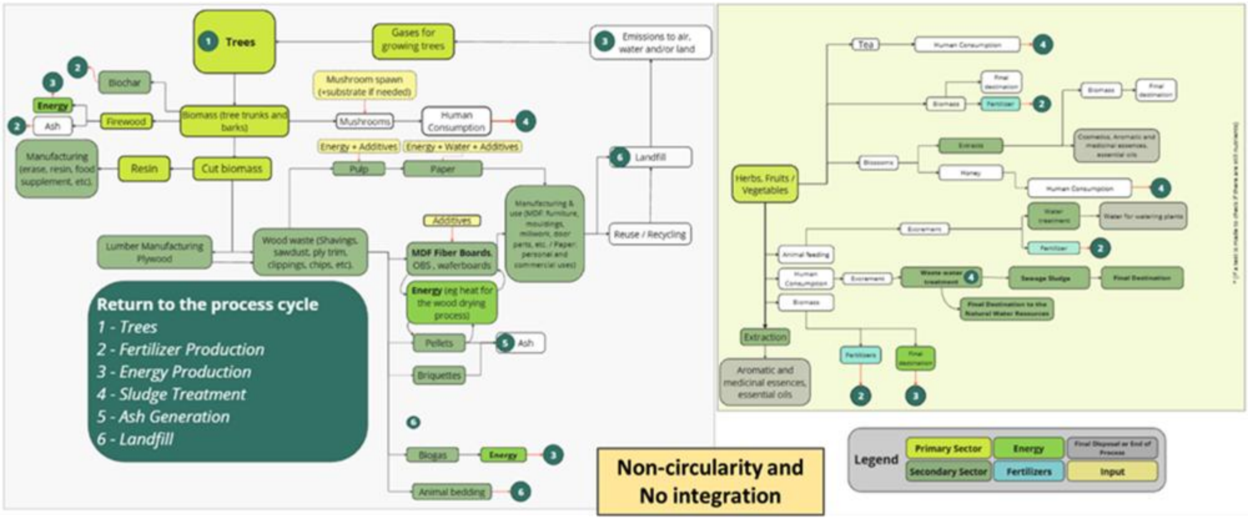

Figure 38: Pathways observed in the current scenario of Western Macedonia

4.6.2 Proposed pathways

For Western Macedonia region, BIOTRANSFORM project identified the possibilities of integrating them in a circularity model, as presented below.

[53] Eurostat, 'Unemployment Rate by NUTS 2 Region', 2024 <https://ec.europa.eu/eurostat/databrowser/view/tgs00010__custom_16102914/default/table?lang=en>; Francis Pavloudakis, Evangelos Karlopoulos, and Christos Roumpos, 'Just Transition Governance to Avoid Socio-Economic Impacts of Lignite Phase-out: The Case of Western Macedonia, Greece', *The Extractive Industries and Society*, 14 (2023), p. 101248, doi:10.1016/j.exis.2023.101248.

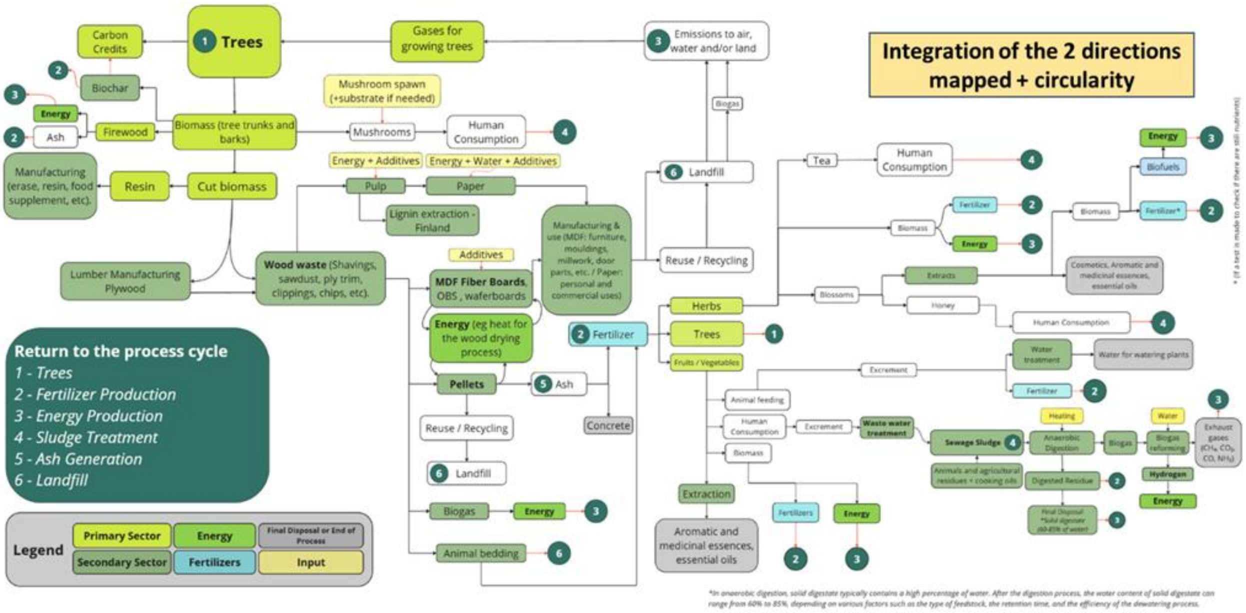

Figure 39: All the possible pathways identified for Western Macedonia, integrated but also with a special focus in circularity. Main pathways selected, in the approach of BIOTRANSFORM, are in bold.

A third step was to focus on the pathways that the region can incorporate in numerous benefits through national and regional plans for green transition. The figure below presents the possibilities of the pathways and the main pathways considered in the Western Macedonia case study.

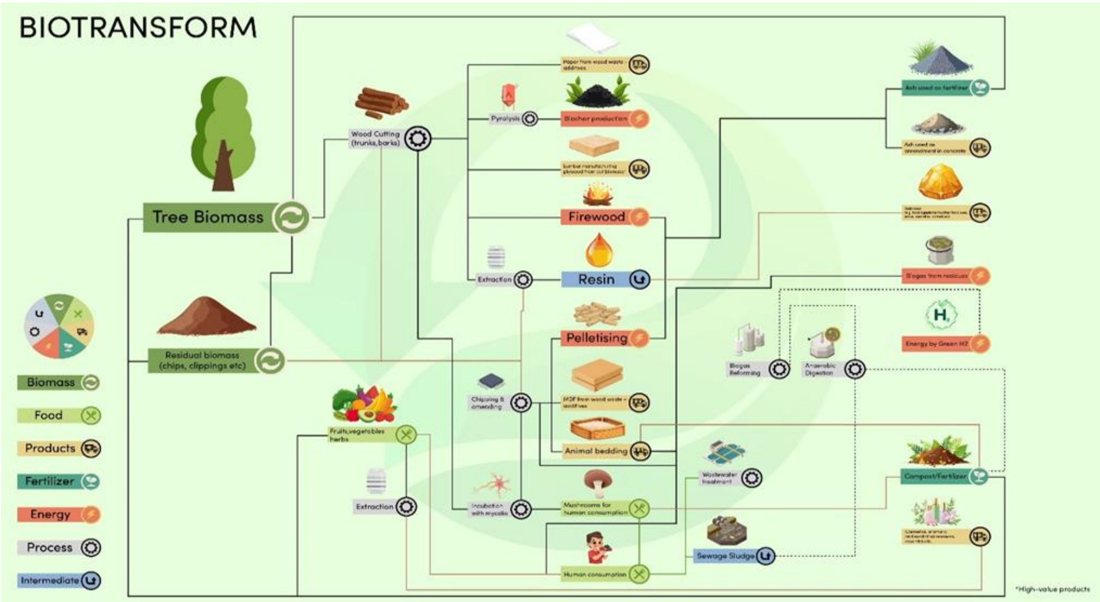

Figure 40: Illustrated diagram for the integrated pathways for Western Macedonia case study

MDF from wood residues

Wood residues from the wood processing industry is a strong alternative which can boost the socioeconomic aspects in the region. The scaling-up of MDF industry bears great potential in increasing significantly the number of jobs, relevance of the sector in a national and international approach after solving the challenges. The successful transition to biomass valorisation will largely depend on early-stage regulatory adaptation, targeted investment support, and the strengthening of stakeholder networks.

- Scaling-up potential of 500x
- Increase in the job's generation directly and indirectly, and in rural areas.

- Increase the relevance of Greece in the international trade market of MDF.
- Potential of generation by the industry: currently: 100.000 tons, after the scaling-up: 300.000 tons.
- High quality wood will be used.

To allow the conditions for the scaling-up, adjustments in the current policies and increase of the details in the regional approach about the forest management, will be needed

Pellets

The pellets industry has great potential in increasing the number of seasonal jobs, circularity guaranteed, reduction of the housewarming costs due to local production. The remaining challenge is related to using quality wood material to produce MDF instead of Pellets, because the economic return from the first one is more significant than Pellets, which currently is destined most low-quality wood material.

- Scaling-up potential of 300x.
- Increase in jobs generation in rural areas and villages.
- Possibility of decreasing costs in the pellets for low-income families and local industries.
- The ashes are foreseen to be collected in a common point and be destined to fertilizers or concrete industries.

The current and projected scenarios for biomass pathways - specifically the scaling-up of MDF and pellet production - indicate significant potential for expansion. Depending on investment capacity, the effectiveness of governance, the implementation of supportive environmental policies, and the revision of regional guidelines, production could increase by a factor of 300 to 500.

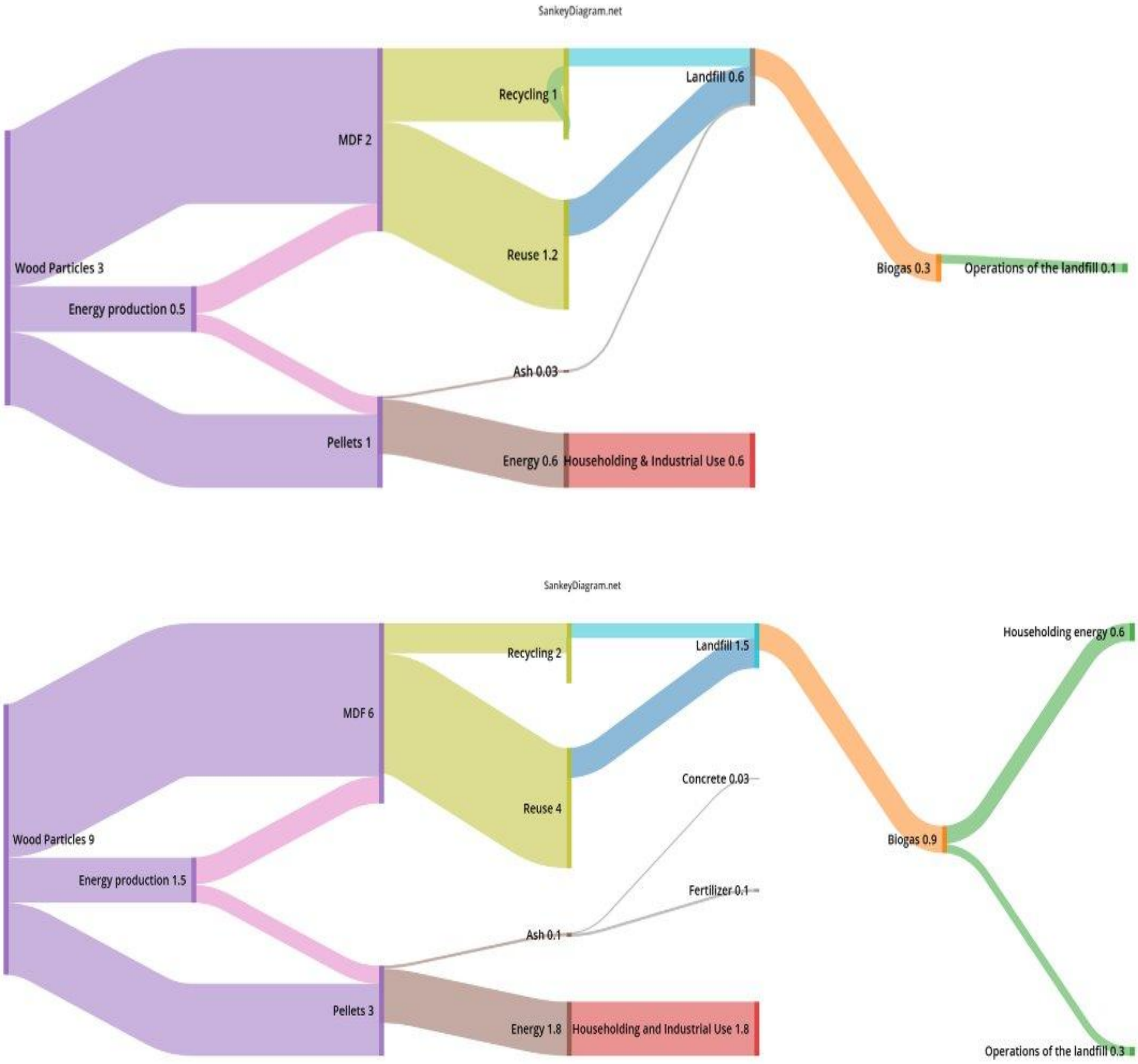

Figure 41: Current (top) and future (bottom) scenarios to biomass pathways (numbers refer to tons per year)

The current and future scenario for biomass pathways (MDF and pellets scaling-up) is foreseen. The future scenario will allow not only the scaling-up, but also the product generated by pellets, that is ash, for example, to be destined to concrete and fertilizer industries. There are already plans for the collection, which will strengthen the cooperation between communities.

Green hydrogen (H_2) from sewage sludge

The use of sewage sludge as an energy source, which is already under discussion in the region, need to be optimised and adopted to reduce the emissions along the transport of garbage trucks in the city, through the energy optimisation. At the same time, it can centralise the region as an innovative area, reducing the fossil fuel need for heavy vehicles through the incorporating H_2 fuelling on garbage trucks. It can support jobs generation and boost innovation, research and promote sustainable energy generation and the bioeconomy in the region. These are the main points that speak for this pathway

- Use of sewage sludge to generate green energy, instead of exclusively destinate it to agricultural soil without any other cascade use.
- After the generation of green energy, it will be possible to analyse the quality of the compost in the plant`s laboratory and destine it to the fields through donation or sale.
- The green H_2 will fuel 14 of the garbage collection trucks that operate in the city.
- Training has a high potential to generate more bioeconomy-related jobs, while increasing the skills of groups that can work in the plant (lignite workers, young people, unemployed people).
- It offers a possibility for the Western Macedonia region to become a reference point in this kind of technology, being able to attract investments and multiplier groups from other regions and countries.

In the next figure, it is possible to analyse in detail the processes needed in the H_2 production by sewage sludge, where the use of the raw material as sewage sludge can promote the energy production for fulfil garbage trucks.

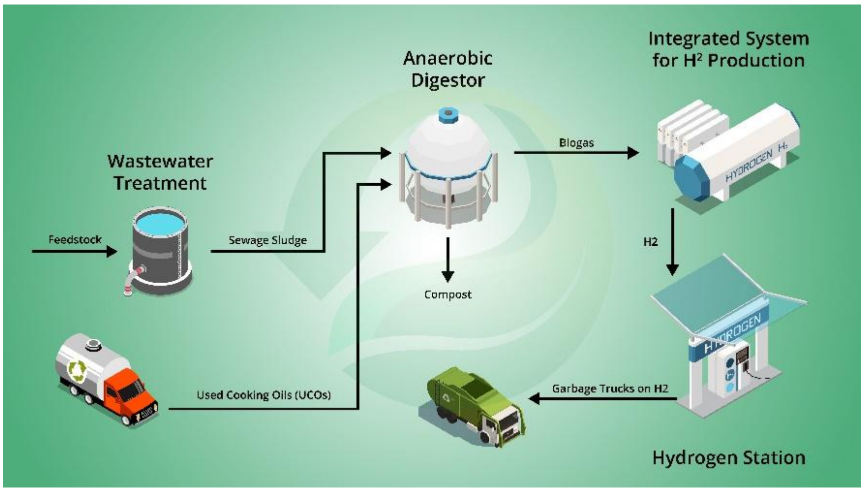

Figure 42: Schematic representation of H2 production using sewage sludge

Below in Figure 43, the representation of the future scenario of the use of sewage sludge to produce green H_2 is shown, considering that the current scenario is not clear and the destination of sewage sludge in Greece is not foreseen in recommendations and laws.

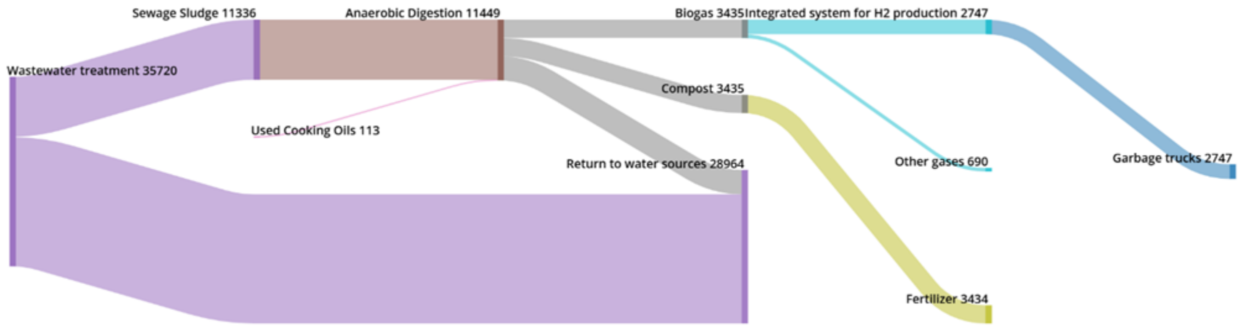

Figure 43: Western Macedonia case – Sankey diagram for the green hydrogen production (numbers refer to kilograms/day)

It can be confirmed that the process is inherently circular, sustained by the natural flow following wastewater treatment and operating independently of direct anthropogenic interventions.

4.6.3 Stakeholder roles

- Local industry & manufacturing: wood industry (MDF, pellets, briquettes), producers' machinery for wood industry and biogas+H2 generation, biomass development companies, wastewater management company.
- Policy makers: Local, regional and national policy makers, EU program officers.
- Research institutions: Universities, Technical Schools, Technical High-Schools, CERTH
- Primary producers: forestry owners, farmers and associations.

4.6.4 Regional governance & financing

Governance model

Western Macedonia currently lacks in a CBE strategy, but CluBE, through projects such as Biomodel4Regions, is developing a blueprint. As a next step, the public authority will formalize it, with publication expected by 2030.

Kozani, the capital of the region, is part of the European Mission 100 cities aiming for climate neutrality by 2030. The strategy process involved stakeholder discussions, resource flow mapping, and focus groups on wood biomass and hydrogen. A pathway selection is ongoing, with continuous feedback and stakeholder engagement. Financing options, including EU programs, are being explored for implementation.

Funding opportunities

For the hydrogen production pathway using sewage sludge, capital expenditure (CAPEX, excluding VAT) is estimated at €20,502,047, with annual operational expenditure (OPEX) of approximately €892,522. For the two biomass-based pathways, cost estimates are not yet available.

In the region, there are some options of funding, such as National and Local/Regional Grants and initiatives, Operational Programs, such as European Funds and funding and Private Funding and Investments. The European Investment Bank (EIB) also plays a critical role in financing circular economy projects through loans, guarantees, and advisory services.

Western Macedonia has actively pursued funding and support for its transition to a circular bioeconomy (CBE). A notable success is the 80-million-euro loan from the European Investment Bank (EIB), aimed at transforming the region's economy from lignite-based to sustainable development. This funding is part of a larger framework involving the Just Transition Mechanism and state or regional budgets.

Additionally, the "White Dragon" project, submitted under the Important Projects of Common European Interest (IPCEI), aims to produce green hydrogen using renewable electricity. This initiative underscores Western Macedonia's strategic move towards a hydrogen economy, highlighting its commitment to sustainable energy solutions and innovation.

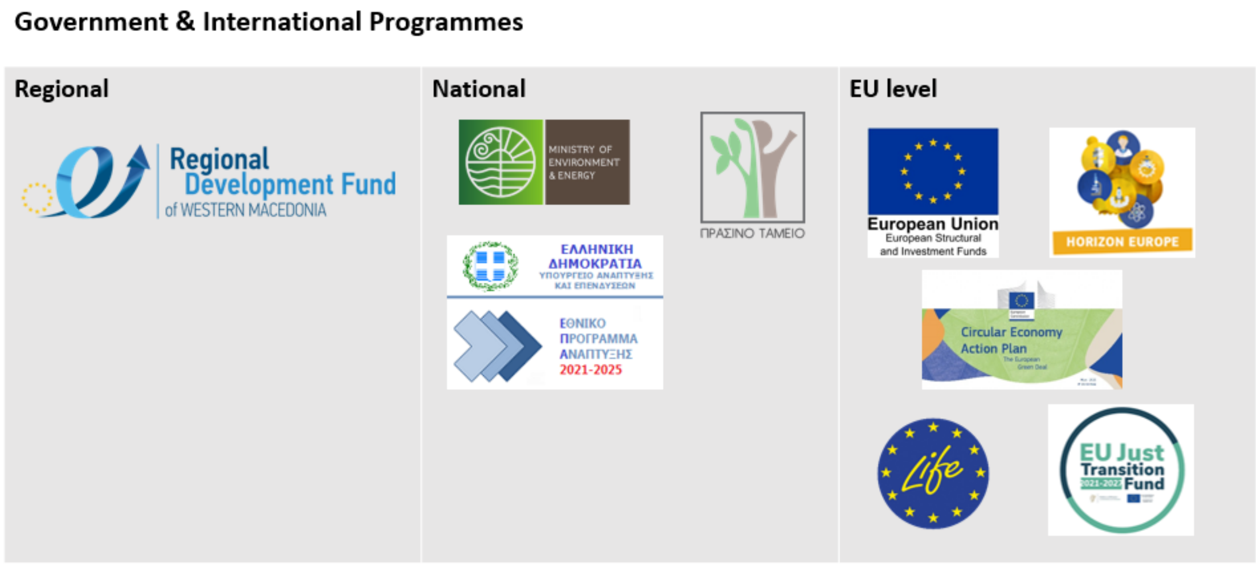

Figure 44: Funding programmes suitable for Western Macedonian cases

The funds selected for the pathways analysed for Western Macedonia region are the ones informed in Figure 44. The **Regional Development Fund** of Western Macedonia has developed a key-role in several activities, including supporting the development of the region, supporting beneficiaries in diverse steps since the preparation to the implementation and integration into the programmes. The **Green Fund** can finance programmes proposed by the Ministries and its supervised organizations, that focus on the waste valorisation and environmental recovering. Through the **Ministry of Environment and Energy and the European Structural and Investment Funds**, the companies and citizens obtain subventions for more sustainable infrastructure and equipment, what can be beneficial for wood industries, as well as investments that support clean energy production capacity, agricultural sector and rural SMES, and fishing and aquaculture sector. The **National Development Programme** focus on financial support of projects that aim at regional and national development and local resilience, sustainability and inclusivity. The **Horizon Europe** can finance basic research projects and other innovative programmes/thematic areas in case there is need for producing new or improved products or services. The Circular economy and quality of life, sub-program into the LIFE programme, aims at facilitating the green transition toward restoring and improving the quality of the environment, either through direct interventions or by supporting the integration of those objectives in other policies. So, LIFE continues to co-finance projects in the environmental sector, in particular in the area of the circular economy, including recovery of resources from waste, water, air, noise, soil and chemical management as well as environmental governance. It is possible to observe a directly relation to the pathways selected to the region, and at this point, increase awareness of wood companies, fertilizers, concrete, aligned with the wastewater management company in the region. This is the key to reach investments and increase a positive impact towards Green Transition.
All the funds and projects to be supported are aligned to the **Action Plan for Circular Economy,** that has a wide approach in diverse value chains.

4.6.5 Roadmap

Main goals

1. Hydrogen production from sewage sludge

Develop and scale up hydrogen production from sewage sludge, aiming for a fully operational hydrogen plant by 2040. The goal is to create a sustainable hydrogen economy that generates jobs and supports regional energy transition efforts.

2. Biomass valorisation

Achieve the sustainable valorisation of biomass (e.g., forestry and agricultural residues) by 2050. This includes the development of bio-based products such as MDF, pellets and biofuels, contributing to a circular economy while enhancing regional economic resilience and job creation.

3. Policy and infrastructure development

Align policies and develop necessary infrastructure for hydrogen production and biomass valorisation, ensuring regulatory support, efficient logistics, and public-private collaboration for successful scaling of circular bioeconomy initiatives.

4. Job creation and local economic development

Foster job creation in key sectors such as renewable energy, biotechnologies, and sustainable resource management, driving local economic growth and reducing unemployment.

5. Regional leadership in bioeconomy

Position Western Macedonia as a regional leader in the circular bioeconomy, establishing best practices that can be replicated across other regions and contributing to EU-wide sustainability and decarbonisation goals.

Proposed timeline

The successful transition to hydrogen production from sewage sludge and biomass valorisation will largely depend on early-stage regulatory adaptation, targeted investment support, and the strengthening of stakeholder networks.

Short-term (2025–2028): Concept validation and initial capacity building

Hydrogen from sewage sludge

- Begin concept validation and early-stage feasibility studies for hydrogen production from sewage sludge (TRL 2-4).
- Initiate capacity building activities, focusing on strengthening Circular Bioeconomy (CBE) networks and raising awareness among stakeholders.
- Engage with local stakeholders (municipalities, waste management companies, and technology providers) to align on regulatory frameworks and infrastructure needs, especially around compost logistics and city-level readiness.

Biomass valorisation

- Initiate research and stakeholder engagement on biomass valorisation, especially forestry and agricultural waste streams.
- Develop initial technology concepts for biomass valorisation and begin building stakeholder networks for sustainable forest management.
- Establish collaborative efforts with regional industries to explore potential for sustainable biomass use in bio-based product development.

Mid-term (2029–2035): Investment and pilot project implementation

Hydrogen from sewage sludge

- Develop and secure funding for pilot-scale trials for hydrogen production from sewage sludge, in collaboration with local and national partners.
- Begin pilot projects with local municipalities and companies, focusing on building lab-scale installations to validate the hydrogen production concept.
- Align with national and EU funding schemes to ensure investment support for scaling up infrastructure and research.
- Establish training and knowledge exchange partnerships with local educational institutions to support skills development in hydrogen technologies.

Biomass valorisation

- Conduct feasibility studies and scaling-up research for biomass valorisation processes (e.g., converting forest residues into high-value bio-based products).
- Update forest management policies to align with circular economy principles and promote sustainable biomass harvesting.
- Launch pilot projects for biomass conversion, with a focus on ensuring sustainable, certified biomass use and exploring industrial-scale valorisation.
- Support local workforce training on biomass certification and sustainable management practices, aligning with regional policy frameworks.

Long-term (2036–2050): Full-scale implementation and regional leadership

Hydrogen from sewage sludge

- Full-scale implementation of hydrogen production plants by 2040, achieving operational maturity (TRL 9).
- Expand the hydrogen production infrastructure, transitioning to a fully operational, sustainable hydrogen economy in the region.
- Foster job creation in the hydrogen sector, including roles in plant operation, research, and technical maintenance.
- Replicate successful pilot projects and share best practices across other regions, contributing to a European-wide hydrogen network.

Biomass valorisation

- Achieve full operational status for biomass valorisation plants, utilizing sustainable forest and agricultural residues for bio-based product manufacturing.
- Scale up biomass valorisation across the region, ensuring that biomass resources are efficiently utilized for a variety of products, including bioplastics, biofuels, and bio-based chemicals.
- Position Western Macedonia as a leader in the circular bioeconomy, with robust, scalable biomass valorisation systems in place by 2050.
- Ensure policy frameworks are aligned with EU bioeconomy strategies, continuously improving the sustainability and efficiency of biomass management practices.

Visual Roadmap

<u>Hydrogen from sewage sludge</u>

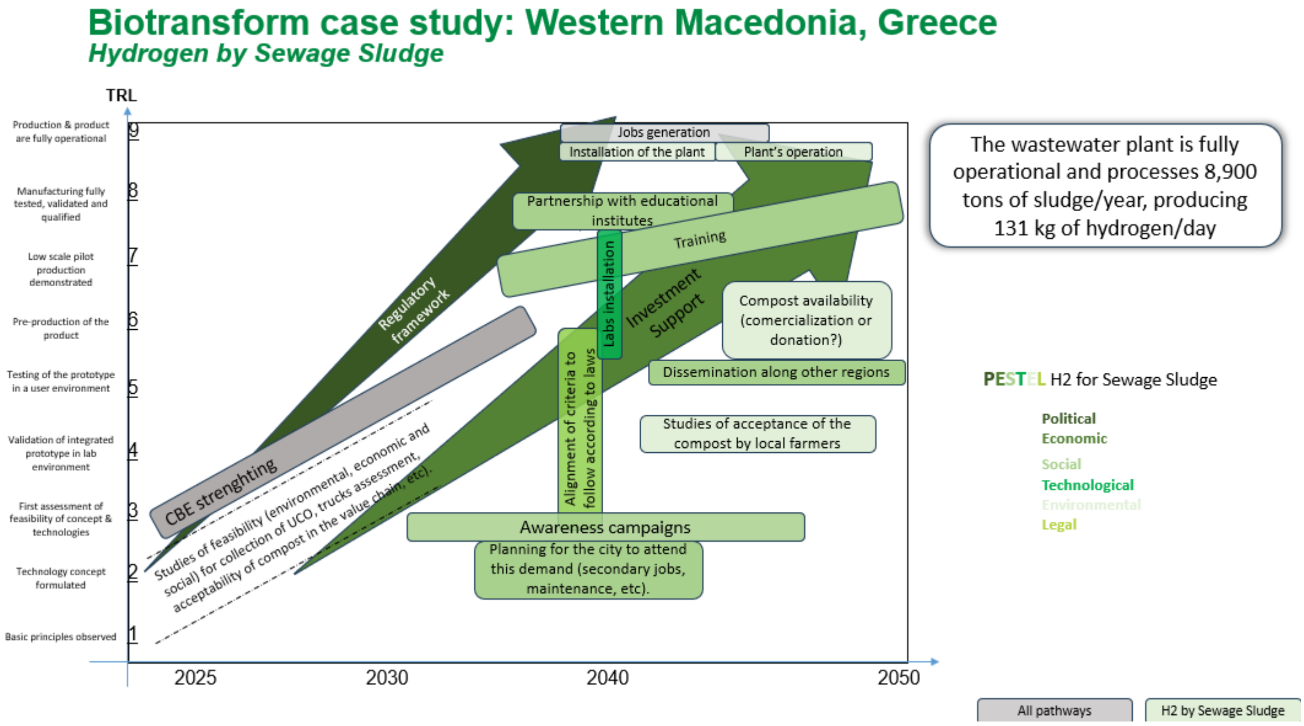

Figure 45: Hydrogen by sewage sludge roadmap in Western Macedonia, Greece

Biomass

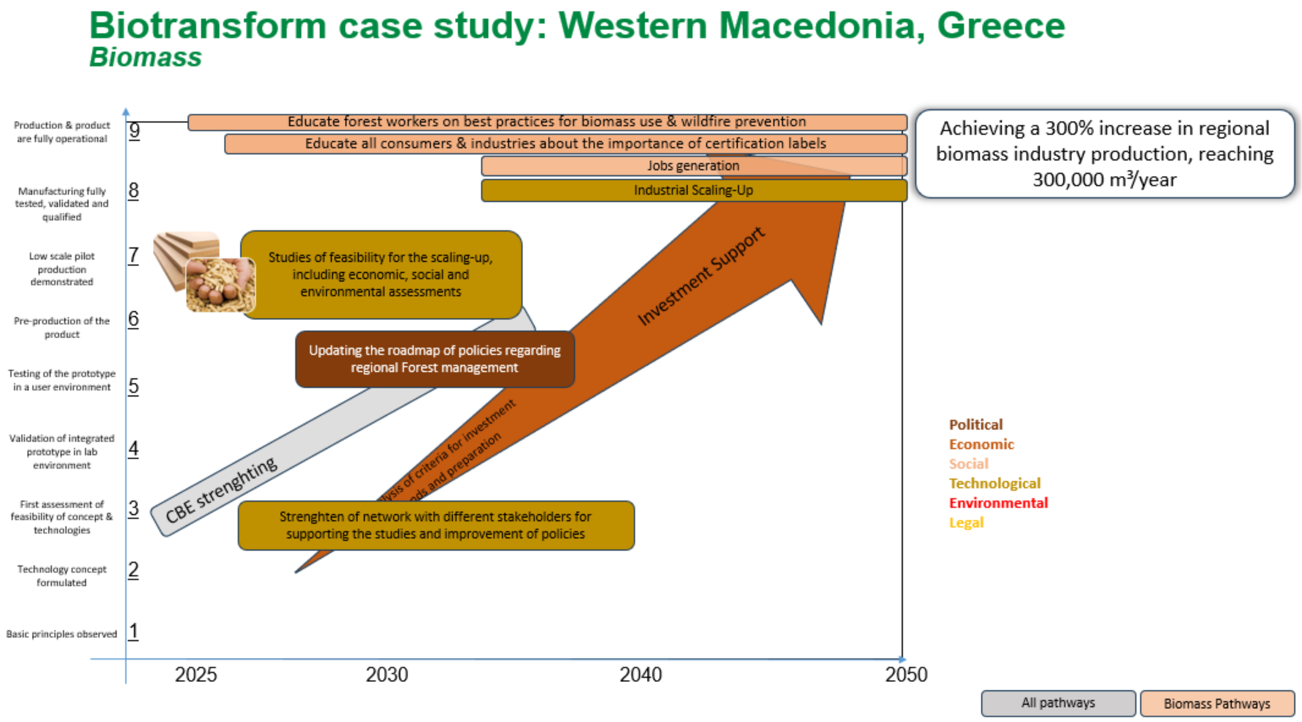

Figure 46: Wood biomass valorisation roadmap in Western Macedonia, Greece

Anticipated Benefits

Social

- Creation of new, stable job opportunities in hydrogen and biomass sectors (including plant operation, maintenance, logistics)

- Strengthened collaboration between municipalities, academia, industry, and local communities
- Increased awareness and training for workers and consumers on sustainable practices and waste-to-energy technologies
- Promotion of circular economy practices, especially in urban and rural transition areas
- Work-life balance will foster a healthier, more satisfied workforce, leading to improved well-being, stronger community ties, and a higher quality of life for individuals in the region
- Improved public health, cleaner, more sustainable environment, fostering a higher quality of life and enhancing community well-being for current and future generations
- Enhancement of overall life satisfaction

Environmental

- Substantial reduction of CO_2 and GHG emissions by replacing fossil fuels with renewable hydrogen and biomass energy
- Enhanced use of renewable, local feedstocks (e.g. sewage sludge, wood biomass residues)
- Improved compost and organic waste management, reducing the need for landfill and incineration
- Support for wildfire prevention through proper use and removal of excess biomass residue
- Contribution to the circular economy by converting waste into valuable energy and bio-based materials
- Lower fossil resource depletion promotes energy independence
- Minimal land use change in MDF and Pellets pathways makes them suitable for sensitive regions
- Flexible application of technologies allows regional adaptation and maximizes local environmental gains

Economic

- Diversification of income streams through by-product valorisation (e.g. compost, hydrogen, certified biomass)
- Access to new bioeconomy markets and investment attraction for novel technology facilities
- Cost savings for municipalities managing sewage sludge and forest biomass
- Boosted regional economy through local job creation and infrastructure development
- Training will lead to increased skill levels, higher productivity, and enhanced economic growth, driving overall prosperity in the region
- Stimulation of local industries, creation of jobs, and boost of the region's economic development by retaining and reinvesting capital within the country

Impact category summary

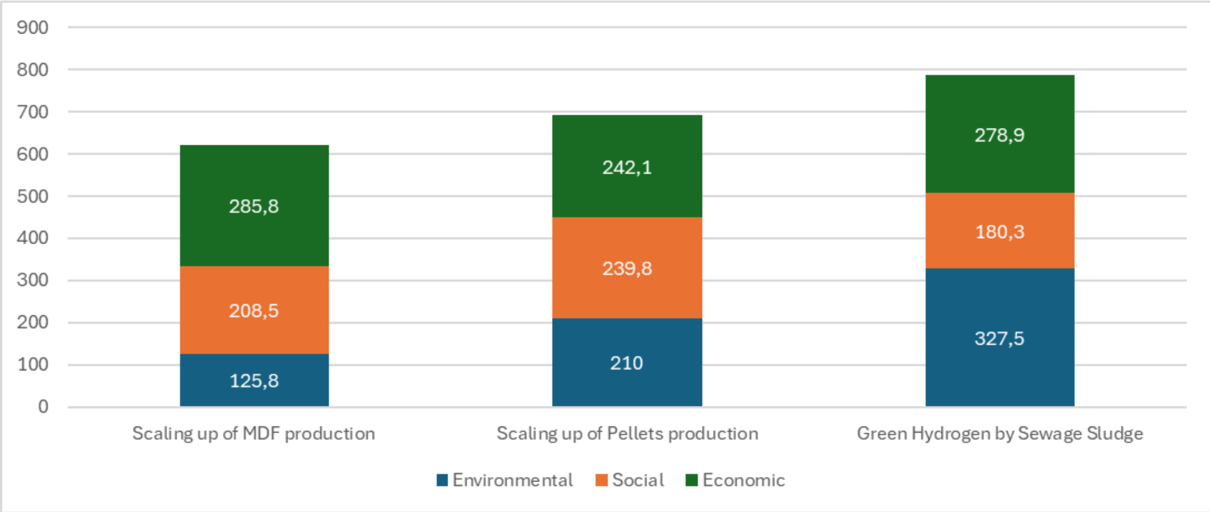

Figure 47: Summary of environmental, social and economic and impacts

It is evident that each category - environmental, social, and economic - exhibits varying levels of significance across the different pathways. This variation does not imply a reduction in the relevance of any single dimension but rather offers a strategic overview of stakeholder-prioritized regional concerns. Accordingly, whether the emphasis is on social, environmental, or economic aspects, the case study provides a robust framework to support informed and context-specific decision-making.

5. Cross-Regional Insights

5.1 Comparative analysis of case studies

Common challenges and solutions

The six BIOTRANSFORM case studies – Andalusia (Spain), Northern Burgenland (Austria), Charles Spa Region (Czech Republic), Finland, North Rhine-Westphalia (Germany), and Western Macedonia (Greece) – each faced distinct regional conditions but shared several common challenges in the transition to a circular bioeconomy:

- Fragmented value chains and underutilised biomass. Many regions reported a lack of integration across sectors (e.g. between agriculture and industry), leading to inefficient resource flows. For instance, wastewater sludge, lake sediments or olive pomace were often discarded or minimally valorised. Solutions involved detailed mapping of secondary resources (WP1) and the identification of high-value conversion routes supported by local actors.
- Weak coordination and institutional capacity. In several cases (e.g. Western Macedonia, Charles Spa Region), regional institutions had limited experience in managing cross-sectoral transformation processes. Multi-actor engagement and the creation of governance models (e.g. clusters or observatories) helped to overcome institutional silos and increase co-ownership of transitions.
- Access to finance and innovation support. Across all regions, funding gaps were noted - particularly for SMEs and pilot infrastructures. BIOTRANSFORM supported this with aligned financing models and roadmaps that incorporate suitable instruments such as the Just Transition Mechanism, Horizon Europe, LIFE, LEADER approach and national development programmes. Examples like the EIB-financed transition in Western Macedonia or Burgenland's alignment with LEADER and KEM showcase regionally tailored finance strategies.

- Data availability and tool applicability. Applying the assessment package revealed that data scarcity (especially on resource availability, composition, and impacts) remains a bottleneck. Solutions included capacity-building workshops and close collaboration with local industries. Through the adaptability of the tools in the BIOTRANSFORM assessment package (Sankey, MOOV, sustainability assessment), we could create a more detailed view of underanalysed contexts.
- Regulatory complexity. Several regions highlighted administrative burdens in implementing new bio-based projects (e.g. Andalusia, Western Macedonia). The co-development of roadmaps and support from regional policy actors helped ensure alignment with RIS3/S4 priorities and bioeconomy strategies. This also fostered smoother navigation of permitting and compliance processes.

Lessons learned for replicability and extrapolation

The BIOTRANSFORM case studies offer replicable insights for regions across Europe that seek to transition from linear to circular bioeconomy systems:

- Adopt a modular co-creation process. The iterative co-definition and validation approach used in BIOTRANSFORM, combining stakeholder engagement with assessment tools, proved effective in tailoring pathways to diverse regional realities. The five-phase roadmap methodology is adaptable to different maturity levels of CBE development (from scouting to scaling).
- Leverage regional strengths and identity. Successful cases built on pre-existing assets - e.g., Andalusia’s olive value chain, Finland’s forest industry residues, or North Rhine-Westphalia’s chemical industry infrastructure - and reoriented them through circular innovation. Embedding circularity into regional identity (e.g. “Sustainable Burgenland”) strengthens stakeholder alignment and citizen engagement.
- Facilitate rural–urban–industrial symbiosis (RUI-S). Integrating material and value flows across rural, urban, and industrial sectors created new opportunities for cascading use of biomass and infrastructure sharing. This was evident in cases like Neusiedl (reed and sediments), or the Finnish lignin cascade. Such symbiosis models are especially valuable in addressing depopulation and structural transition in peripheral regions.
- Integrate the 10R framework contextually. The application of the 10Rs (Refuse to Recover) was not uniform but contextualised per region and pathway. For example, "Repurpose" were strongly emphasised in Finnish forest-based pathways, while "Recover" featured in Andalusian olive pomace valorisation. This flexible integration ensures applicability across industrial, agricultural, and service-based economies [54].
- Prioritise stakeholder trust and transition brokers. Multi-level trust building was critical in fragile or transitioning economies (e.g. post-lignite regions). The creation of trusted intermediaries – such as bioeconomy hubs, local clusters, or “transition brokers” – supported knowledge transfer and long-term roadmap uptake. As highlighted by the OECD [55], transition brokers are key to bridging innovation and policy ecosystems.
- Promote cross-case learning and peer exchange. The diversity of BIOTRANSFORM regions enabled meaningful peer-learning. Webinars, pan-European workshops, and feedback loops facilitated

[54] El-Chichakli and others, ‘Policy’; Kirchherr, Reike, and Hekkert, ‘Conceptualizing the Circular Economy’.
[55] OECD, *The Circular Economy in Cities and Regions: Synthesis Report*, OECD Urban Studies (OECD, 2020), doi:10.1787/10ac6ae4-en.

knowledge transfer across contexts – a model that can be expanded in follow-up initiatives such as the Circular Cities and Regions Initiative (CCRI).

External alignment

These learnings align closely with the EU Bioeconomy Strategy[56], the Circular Economy Action Plan[57], and the Just Transition Mechanism. They also contribute to the implementation logic of initiatives such as the Circular Bio-based Europe Joint Undertaking (CBE JU) and the European Green Deal. Importantly, the findings are also relevant for the European Committee of the Regions' agenda on empowering local governments to lead bioeconomy transitions.

5.2 Policy and financing insights

Support of regional bioeconomy transitions

The successful implementation of circular bioeconomy transition pathways across the BIOTRANSFORM case study regions has highlighted the central importance of enabling policy frameworks and accessible, fit-for-purpose financing mechanisms. This chapter presents key insights derived from regional roadmaps with a focus on local governance support structures and financing strategies - in particular, the role of transition brokers, the potential of symbiosis funding schemes, and the alignment with EU bioeconomy financial instruments.

The role of transition brokers in regional transformation

In each region, a key barrier to implementation was the fragmentation between policy, funding, research, and business actors. To overcome this, the BIOTRANSFORM project promotes the establishment of regional transition brokers as key facilitators. These individuals or institutions serve as intermediaries who:

- Build trust across sectors and administrative levels
- Map regional resource flows and business models
- Identify suitable funding and policy instruments
- Assist stakeholders with regulatory, technological, and organisational challenges
- Coordinate local and EU-level engagement and support replication

For example, in Western Macedonia and Andalusia, the role of local bioeconomy clusters and development agencies was critical in co-implementing the transformation roadmaps. Such brokers should be trained and ideally embedded in existing regional development structures, e.g. Smart Specialisation Platforms or LEADER regions. Their financing can be derived from regional funding for example from CAP Strategic Plans, the Just Transition Mechanism, or regional development funds (ERDF).

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[56] European Commission, *A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment. Updated Bioeconomy Strategy*.
[57] European Commission, *A New Circular Economy Action Plan For a Cleaner and More Competitive Europe*.

Financing opportunities for circular bioeconomy

A wide range of financial instruments exist to support bioeconomy pathways, as mapped by the European Commission's Bioeconomy EU Financing Instruments portal [58]. The key insights relevant to BIOTRANSFORM's regional roadmaps include:

- EU-level programmes
  - Horizon Europe (especially Cluster 6 and Circular Bio-based Europe JU) supports research and demonstration for new bio-based value chains.
  - LIFE targets environmental and climate innovations, especially useful for waste valorisation and ecosystem restoration.
  - InvestEU and Innovation Fund offer blended finance and de-risking for industrial-scale investments in bioeconomy infrastructure.
- Structural and Investment Funds (ESIF)
  - Particularly relevant for less developed regions (e.g. Western Macedonia, Charles Spa), ERDF and ESF+ can finance skills development, R&D infrastructure, and SME support in circular bioeconomy sectors.
- CAP & Rural Development
  - For biomass valorisation, support for farmers, foresters and cooperatives through CAP eco-schemes, LEADER, and EIP-AGRI operational groups can be targeted more towards circular farming, bio-based construction, or nutrient recycling.
- National and regional funding
  - Several case-study regions (e.g. Andalusia, Finland) have dedicated bioeconomy or innovation strategies that offer public grants and co-financing for SMEs and clusters. However, uptake remains low due to administrative burdens and lack of awareness.

In general, regional infrastructure investments either at EU or even at regional level are typically funded at lower rates compared to cooperative research or innovation funding programmes. Regional investments often rely on a mix of EU Structural Funds (ERDF, ESF+) and local contributions, which usually result in lower funding rates, sometimes ranging from 30% to 70%. In contrast, cooperative programmes such as Horizon Europe or national innovation funds often provide higher funding rates, ranging from 60% to 100% in some cases, to stimulate large-scale collaborative projects that contribute to national and EU-wide strategic objectives. These higher funding rates are designed to incentivise research, innovation, and the scaling-up of new technologies and business models, supporting the transition to a circular bioeconomy.

Funding symbiosis schemes and systemic innovation

Circular economy transitions often require investment in shared infrastructure (e.g. pre-treatment units, logistics centres, shared biorefineries), long-term partnerships, and coordinated governance models. These systemic requirements are not always addressed by traditional funding tools. As such, BIOTRANSFORM proposes:

- Promoting symbiosis-oriented funding calls, similar to those in Interreg Europe or LIFE Integrated Projects, focusing on inter-municipal and rural-urban cooperation.
- Developing place-based financing models, tailored to each region's resource base, policy landscape, and actor constellations.
- Leveraging public-private partnerships, involving municipalities, cooperatives, and investors, to scale viable models (e.g. for reed harvesting, lignin processing, or mycelium-based products).

[58] European Commission, 'Bioeconomy & EU Financing Instruments | Knowledge for Policy', 5 March 2021 <https://knowledge4policy.ec.europa.eu/bioeconomy/bioeconomy-eu-financing-instruments_en>.

Summary and recommendations

To mainstream the outcomes of BIOTRANSFORM, a few policy and financing measures are essential:

- Institutionalise the transition broker function as part of regional development planning, training and certifying such actors across Europe.
- Ensure bioeconomy-relevant measures are integrated into Regional Innovation Strategies (S4) and future CCRI roadmaps.
- Simplify access to financing through one-stop-shop mechanisms and capacity-building, especially for SMEs and municipalities.
- Create EU and national indicators (e.g. a bio-based substitution index) to monitor progress and allocate funding more effectively.

The developments of BIOTRANSFORM suggest that when funding is combined with regional capacity and strategic governance support, systemic circular bioeconomy transformations are not only feasible, but replicable across Europe.

6. Conclusion

The six regional transition roadmaps developed within BIOTRANSFORM provide a practical framework for steering the shift from linear, fossil-based systems to circular, bio-based economies. Each roadmap reflects the specific context, challenges, and opportunities of the respective region - Andalusia, Northern Burgenland, Western Macedonia, North Rhine-Westphalia, the Charles Spa Region, and Finland - while sharing a common foundation of circularity, stakeholder co-creation, and cross-sectoral synergies.

The proposed pathways cover a wide spectrum of resource types and valorisation strategies, including agricultural residues, biogenic waste streams, lake sediments, and emerging applications such as mycelium-based products or biopolymers. They offer replicable examples of how underutilised regional resources can be transformed into high-value bio-based products, contributing to climate mitigation, rural revitalisation, and industrial innovation. The integration of rural-urban-industrial symbiosis across most case studies further enhances circularity and regional resilience.

The methodology applied - based on stakeholder-driven multi-criteria analysis, quantitative and qualitative assessments, and visual tools such as resource flow diagrams - ensures that each roadmap is grounded in regional realities while remaining adaptable and scalable.

6.1 Next Steps for Scaling and Replication

The next phase of BIOTRANSFORM will focus on scaling these roadmaps beyond their pilot regions. To support this process, the following actions are foreseen.

- Policy uptake and integration**.** Further engagement with regional and national authorities to embed the roadmaps into Smart Specialisation Strategies (S3/S4), regional development plans, and climate transition frameworks.
- Capacity building**.** Continued development of local competencies through training of transition brokers and regional hubs to facilitate stakeholder coordination and implementation support.
- Financing**.** Application of targeted funding instruments (e.g. Just Transition Fund, Horizon Europe, CAP, cohesion funds) to finance innovation, infrastructure, and collaborative initiatives linked to the roadmaps.
- Replication**.** Utilising the replication guidance and Q&A framework provided in D3.3, new regions can adapt the BIOTRANSFORM approach to their own bioeconomy potential and policy context.

Ultimately, these roadmaps are not static plans but living frameworks that enable regions to act with confidence, engage their communities, and advance Europe's green and circular transformation.

All regional case study lead partners have access to much more information, results of workshops, and evaluations, etc. In case of interest, please look at the BIOTRANSFORM website (https://www.biotransform-project.eu/) or contact the lead author of this deliverable who can connect further.