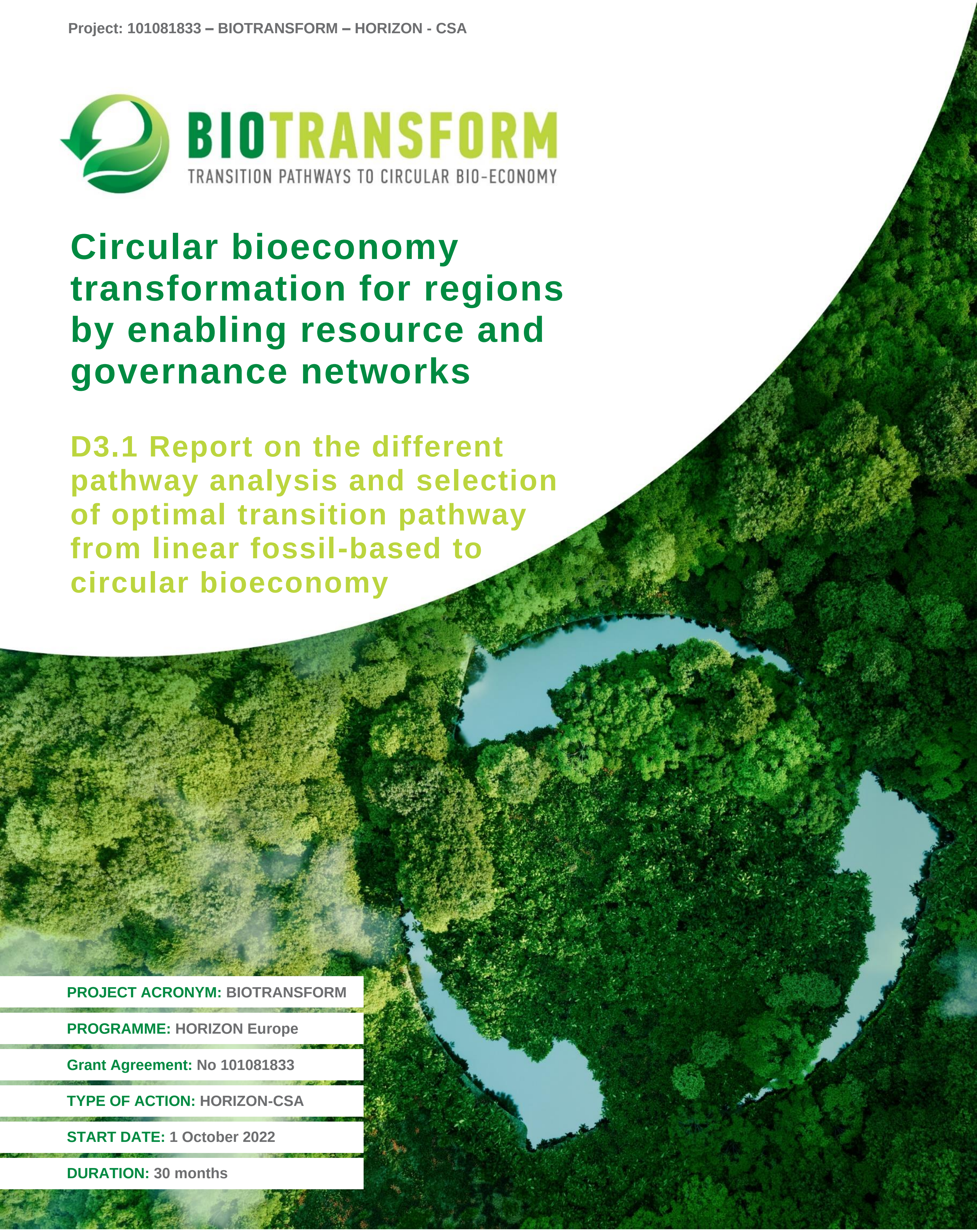
BIOTRANSFORM
TRANSITION PATHWAYS TO CIRCULAR BIO-ECONOMY

Circular bioeconomy transformation for regions by enabling resource and governance networks

D3.1 Report on the different pathway analysis and selection of optimal transition pathway from linear fossil-based to circular bioeconomy



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List of Terms and Definitions

Abbreviation	Definition
BSF	Black soldier fly
CBE	Circular bioeconomy
CO_2	Carbon dioxide
FDCA	2,5-Furandicarboxylic acid
GHG	Greenhouse gas
IAT	Impact assessment tool, provided by LIST
JRC	Joint Research Centre - European Commission
LA/ PLA	Lactic acid/poly-lactic acid
MAA	multi-actor approach
MDF	medium-density fiber board
MooV	logistics optimization tool, provided by VITO
NRW	North Rhine-Westphalia
OFMSW	Organic fraction of municipal solid waste
PHA	Polyhydroxyalkanoate
RFA	Resource flow analysis
SDGs	Sustainable Development Goals by the United Nations
SME	Small and medium enterprise

Table 1: Terms and Definitions

Executive Summary

BIOTRANSFORM provides European policymakers with an adequate assessment and policy development framework, knowledge base and expert support ecosystem to accelerate the transition from linear fossil-based systems to circular biobased systems. Through an assessment package of three tools (resource flow analysis, environmental, social, and economic assessment, and a logistics management tool) European policy makers will be provided by the means to evaluate and further develop regional transformation actions. To achieve this, BIOTRANSFORM develops and tests its framework to establish and roll out circular bio-based systems transitions by applying a multi-actor approach to six regional cases: Andalusia (Spain), Northern Burgenland (Austria), Western Macedonia (Greece), Finland, Charles Spa Region (Czech Republic) and North Rhine-Westphalia (Germany). These regional case studies represent a range of important industries and scenarios for Europe.

This deliverable describes the process of co-defining the pathways of the individual case study regions within the BIOTRANSFORM project. Each of the six participating regions pursues the goal of driving the transformation towards a circular and bioeconomy in BIOTRANSFORM. To this end, transformation paths were co-defined together with stakeholders from the respective regions and selected in terms of their relevance for the respective region. This multi-actor approach was preceded by the selection of regional indicators in order to collect relevant and measurable key figures for the respective transformation pathways and to communicate the developing transformation pathways in a simple and transparent manner. These Indicators are aligned with EU-wide sustainability objectives, including the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). While all case-study regions started from this common set of indicators, the final selected indicators were developed according to the regional needs and specifications of the transformation pathways. A consolidation of the most recent indicators of each case-study region is presented.

The BIOTRANSFORM approach relies on region-specific circular valorization processes of biomass developed through collaborative discussions with stakeholders, ensuring alignment with local needs and EU standards. In each case-study region, transformation pathways were identified to replace fossil-based or bio-based linear industries with circular, bio-based alternatives. The BIOTRANSFORM partners are well connected within their respective regions. They used their knowledge, available literature, and local networks to research available bio-based raw materials, suitable processes, and sustainable products. The results of this data collection could be used to draft and evaluate transformation pathways with a regional focus and in line with local needs. Through a stepwise multi-actor approach, these pathways were filtered for their potential and further refined following the BIOTRANSFORM methodology. As part of this process, additional feedback loops with local experts and the owners of the BIOTRANSFORM assessment package toolkit (ALCN, VITO and LIST) were conducted to analyze the pathways according to material flows, logistic challenges, and their economic, environmental, and social impact.

While challenges in data availability and stakeholder engagement necessitated slight adjustments of the methodology, each case study drafted several promising transformation pathways for its region based on the use of lignin, straw, and other biogenic waste and side streams. In this deliverable, each region presents three transformation pathways harboring potential for regional development that were co-developed by regional stakeholders.

1. Introduction

1.1 The role of indicators in transformation processes

Indicators are a summary measure related to key issues or phenomena and derived from a series of observed facts. They can be used to reveal relative positions or show positive or negative change. While they do not reflect all possible aspects of a development or change, but rather take one or several examples, they are an important tool to assess them. Indicators allow comparisons over time between, for instance, countries and regions, and in this way assist in gathering information for decision making[1]. In the European context, they are typically aligned with the strategic objectives of the EU, such as those related to economic performance, social inclusion, environmental sustainability, and public health.

The importance of globally applied indicators was revealed by the approval of the 2030 Agenda on Sustainable Development by the General Assembly of the United Nations in 2015. A total of 17 Sustainable Development Goals (SDGs) were agreed as the groundwork for urgently needed transformational steps towards sustainability[2]. As a global approach, the achievements towards reaching the 17 SDGs and the 169 actions detailed in the goals are monitored by a global set of indicators[3] developed by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs).

This global and EU wide pursuit of the SDGs also has had a direct influence at national and sub-national level as well as on regional administrations. Encouraged by the 2030 Agenda[4], regions may develop their own strategies aligned with the SDGs, while taking the local context, available resources, and potentials into account. They can then report their progress in Voluntary Local Reviews (VLRs). These VLRs often include a mixture of indicators that were adapted from either the IAEG-SDGs or other sources including national and local indicators with a complex and at times unknown origin. The need of an adaptation of monitoring indicators on a sub-national or regional level is reflected by the development of the European Handbook for SDG Voluntary Local Reviews that aims to make the monitoring process more uniform and the results comparable[5] [6].

An important part to achieving the SDGs is the implementation of circular economy and bioeconomy practices, which have become an integral aim of the European Union's (EU) strategy [7]. Much like the efforts of pursuing the 2030 Agenda and its goals, the progress of transitioning towards a bioeconomy and circular economy is tracked by indicators making the process uniform, comparable, and easy to communicate. Again, indicators on regional level are determined by various factors and reflect the

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[1] Glossary: Statistical indicator - Statistics Explained (europa.eu)
[2] Agenda 2030
[3] SDG Indicators — SDG Indicators (un.org)
[4] https://sdgs.un.org/2030agenda
[5] Siragusa, A., Stamos, I., Bertozzi, C. and Proietti, P., European Handbook for SDG Voluntary Local Reviews - 2022 Edition, EUR 31111 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-53389-4, doi:10.2760/355330, JRC129381.
[6] Ciambra, A., European SDG Voluntary Local Reviews: A comparative analysis of local indicators and data, Siragusa, A. and Proietti, P. editor(s), Publications Office of the European Union, Luxembourg, 2021, ISBN 978 -92-76-32321-1, doi:10.2760/9692, JRC124580.
[7] Green Deal

political accents and economic orientation of a region as well as which transitional pathways are anchored in the region's overall strategy. Acknowledging the fact that there is no agreed upon standardized approach to measure the bioeconomy on a regional and national level, with different countries and regions using a range of methods and strategies, the EU Bioeconomy Monitoring System is an approach to create a means of comparability across EU states [8].

This JRC-led coherent approach was first reported in 2019. The development and the implementation of the monitoring framework are based on a set of indicators that were selected in a participatory process to provide information on the condition, performance, and trajectory of the bioeconomy as a whole – including ecosystems and their services, primary production sectors (forestry, agriculture, aquaculture and fisheries) and bio-based industries – at different levels[9]. Realized as an interactive web-based dashboard, the system was further updated to address existing gaps in the indicator list of the Monitoring System covering and adaptation of sectors to climate change[10], an update on trade-related indicators[11], and the further addition of social indicators[12].

The above-mentioned monitoring tools and guidelines are an invaluable tool to keep track of national and regional efforts. Especially in a regional context, these tools offer a framework for informed decisions and policy making that aligned with global sustainability efforts[13],[14]. In BIOTRANSFORM, the case-studies indicators go hand-in-hand with the regional challenges and local strategies. This allows an easy transfer of relevant information between different actors and a transparent display of the key factors of the desired transformation pathways. While some indicators will be pathway-specific, others strongly align with those in EU Monitoring datasets, making a comparison between similar regions possible and changes permanently traceable.

[8] Development of the Circular Bioeconomy: Drivers and Indicators (mdpi.com)
[9] Kilsedar, C., Girardi, I., Gerlach, H. and Mubareka, S., *Implementation of the EU Bioeconomy Monitoring System dashboards*, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-46204-0 (online), doi: 10.2760/691217 (online), JRC127762.
[10] Sanchez-Jerez, P.J., Raftoyannis, Y. and Rihimaki, M., EU Bioeconomy Monitoring System indicator update, Mubareka, S. editor(s), Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/19269 (online), JRC132405
[11] Kilsedar, C., Patani, S., Olsson, M., Girardi, J. and Mubareka, S., EU Bioeconomy Monitoring System dashboards: extended with trade-related indicators, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/217911 (online), JRC132356.
[12] Patani, S., Mubareka, S.B., Olsson, M., Girardi, J., Kilsedar, C., Zepharovich, E. and Camia, A., *EU Bioeconomy Monitoring System dashboards: extended with social indicators*, Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/827057,JRC136613.
[13] Why bioeconomy monitoring? - monitoring-biooekonomie.de
[14] EU Bioeconomy Monitoring System | Knowledge for policy (europa.eu)

1.2 Multi-actor approach

With growing complexity of research, development, and innovation in the modern and interconnected world, the demand is rising for a multi-directional knowledge transfer to develop solutions which answer real-life challenges and have the best chance to be taken up by society. This demand is met by new formats of co-creation such as the multi-actor approach (MAA) that focuses on the involvement of various stakeholders in research and innovation activities, thus developing solutions close to the practitioners or "end-consumers". In contrast to linear innovation models, the co-creation process in multi-actor groups is based on practical expertise, optimally reflecting all stakeholders of a value network or which serve the objective of a specific topic [15] [16]. The multi-actor approach has been overall reinforced under Horizon Europe and the EPI-Agri, by making it an eligibility criterion for project proposals and implementing this tool in thousands of projects under the Horizon2020 and the Horizon Europe framework [17] [18] [19]. Amongst many others, the topics targeted also included the implementation of bioeconomy practices [20].

Within the ecosystem of a European R&D project, the objective of the multi-actor or multi-stakeholder methodology is to propose suitable techniques for transferring research results and knowledge to the end-users (farmers, policy makers, etc.) while addressing their needs for a demand-driven innovation approach. This generates an iterative process for the identification, co-creation and effective transfer of the existing scientific knowledge into real practice at EU level. On the level of innovation ecosystems this can lead to the creation or strengthening of Regional Innovation Networks (RIN) that may take over important responsibilities and key actions in the process [21].

Within the BIOTRANSFORM project, the six case-study regions aim to foster the implementation of sustainable and circular transformational pathways to strengthen the regional bioeconomy. The regional networks of actors and consumers represent a perfect starting point for co-creation processes. BIOTRANSFORM partners utilize existing regional networks and the complementary knowledge from research and practice within them to develop and implement new tailor-made solutions. In this process, existing infrastructure can be rethought, and resources redefined.

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[15] https://horizoneuropencpportal.eu/sites/default/files/2023-12/2.multi-actor-approach_dg-agri-presentation.pdf
[16] Horizon Europe - Work Programme 2023-2025
[17] Multi-actor projects – research and practice co-creating solutions | EU CAP Network (europa.eu)
[18] eip-agri_brochure_multi-actor_projects_2017_en_web.pdf (europa.eu)
[19] Projects | EU CAP Network (europa.eu)
[20] h2020-wp1820-food_en.pdf (europa.eu)
[21] Franco Ferreira, Lucía & Justo, Almudena & Cotelo, Carmen & Arias, Ines & Garrido, Lucía & Lloret, Lucia & Rodríguez-Aubó, Nuria. (2019). Multi-actor engagement: an open innovation process of knowledge exchange and co-creation. 10.21125/iceri.2019.0969.

1.3 Potential of local biorefineries in Europe

The concept of a biorefineries is characterized as the use of biomass as a diverse source of raw materials for the production of a variety of intermediates and value-added products, allowing the fullest possible use of all biomass components. This process chain consists of different unit operations for the pretreatment and the preparation of biomass, the separation of biomass components and the conversion of these components into a range of products. Byproducts or side streams of these processes may be further refined for feed and food or other applications or used to supply process energy [22]. This cascading approach is essential for optimal valorization of biomass. A biorefinery concept can be implemented centrally or as a decentralized solution in which certain processing steps are carried out close to the source of the biomass [23]. In all cases technical issues arise from the type of the processed biomass and its variability in terms of quality and composition [24]. Finally, biorefineries can be implemented either as a new plant (greenfield) or as an upgrade of existing industrial plants (brownfield installation or retrofitting).

Every type of biorefinery requires the stable and long-term supply of feedstock and the required biomass is a decisive factor for the feasibility of the concepts. Both the availability and accessibility of primary biomass or secondary resources feeds into the logistic models on which decentralized or centralized biorefineries, biorefinery networks and bio-based value cycles are strategized. Different EU regions display a wide range of economic and geological conditions and therefore different settings for the effective implementation of sustainable value chains. This results in different requirements in terms of logistics, raw material supply, further processing, cascade utilization and end-of-life scenarios. Decentralized stages (possibly also mobile units) close to the source of residues could enable pre-processing on-site to reduce further transport volumes or energy required but can even support simple extractions or small-scale high-value fermentations (e.g., for local food, feed, or materials production), depending on the techno-economic feasibility. The centralized units can create platform chemicals for the bioeconomy, as well as commodities like bioplastics and other biochemicals, reaching the necessary economy of scale to deliver for these high-volume markets. Decentralized biorefineries can offer advantages in terms of lower costs and emissions for biomass transport, higher integration opportunities with other processing facilities, enhanced resilience, and increased flexibility in terms of feedstocks and products [25]. Additionally, regional biorefineries can contribute to rural development showing a positive impact socio-economic factors like employment [26].

In its current state, the database on chemical- and material-driven biorefineries in the EU and in selected non-EU countries, based on the JRC bio-based industry and refineries database[27], represents the most up to date overview of biomass processing plants. Considering this seemingly high potential present in the EU, foresights like the EU biorefinery outlook to 2030 show additional

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[22] Biorefineries Roadmap – BMBF 2012
[23] Biorefineries Roadmap – BMBF 2012
[24] Asghar et al., 2022 Current challenges of biomass refinery and prospects of emerging technologies for sustainable bioproducts and bioeconomy (wiley.com)
[25] Processes | Free Full-Text | An Integrated Approach to the Design of Centralized and Decentralized Biorefineries with Environmental, Safety, and Economic Objectives (mdpi.com)
[26] Regional Employment Impacts of Biorefineries in the EU - Zhu - 2023 - EuroChoices - Wiley Online Library
[27] Parisi et al., 2020

demand depending on various possible scenarios. Identified challenges consider (not exclusively) product demand, price of fossil counterparts, technical readiness, cost competitiveness of bio-based products, availability of second-generation feedstocks and a missing awareness of consumers [28].

While some of these aspects may be solved by intensified research and standards set by the industries involved, a decisive role falls to the policy makers, who can set the course for a strong transformation to bio-based products and effective utilization of the biorefinery concept at European, national, and regional level.

Connected to this, BIOTRANSFORM seeks to help regional stakeholders and policymakers to assess the local potential for the valorization of biomass. This considers the existing infrastructure and includes concepts of centralized and (integrated) decentralized biorefineries to achieve a holistic transformation of biomass into a wide range of bio-based products. The specific challenges of different EU regions are represented by the regional case studies, which include the analysis of local biomass flows and local logistics concepts, depending on the individual circumstances.

[28] EU Biorefinery Outlook to 2030

2. Transition pathways towards a circular bioeconomy

2.1 Methodology

2.1.1 *Indicators – keeping track of the transition*

The BIOTRANSFORM project aims to find suitable transition pathway to a circular bioeconomy in different EU regions and to convey these findings in an understandable and replicable way. In the case study regions included in the BIOTRANSFORM project, distinct transition pathways are tailored to the individual requirements of the respective regions, with the help of various stakeholders and policy makers. The individuality of the demo-case regions was already demonstrated in the initial compilation of the following four regional criteria, as outlined in deliverables D1.1 – D1.3.

a) Policy measures assisting circular bioeconomy transitions
b) Existing technologies
c) Biomass residues
d) Existing gaps

These results were the starting point for further discussions with local stakeholders (presented in Task 1.5), to elaborate the basis for the transition pathways for each case-study. This basis grew in complexity as the transition pathways were developed further. A simplified presentation of complex issues became therefore necessary not only in the final dissemination of the results, but also during the development phase. This will help assess the outcomes of the indicated transition pathways and make them comparable with each other.

In BIOTRANSFORM, the six case-study regions aim to provide a means of replicable actions and strategies for other EU regions to follow up on. The chosen indicators describing the characteristics of each case-study region were therefore derived from a common set of starting points.

Indicators provided by EU Bioeconomy Monitoring System[29]

As a commonly agreed on form of monitoring the bioeconomy across EU states, the indicators of the above-mentioned EU Bioeconomy Monitoring System were chosen as a starting point for the definition of relevant indicators to reflect the transition pathways. In this approach, identified indicators were summarized in headline indicators spanning the areas of “primary production systems”, “secondary production systems”, “waste and circularity”, “ecosystem conditions”, and “trade”, as shown in Figure 1.

[29] https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring_en

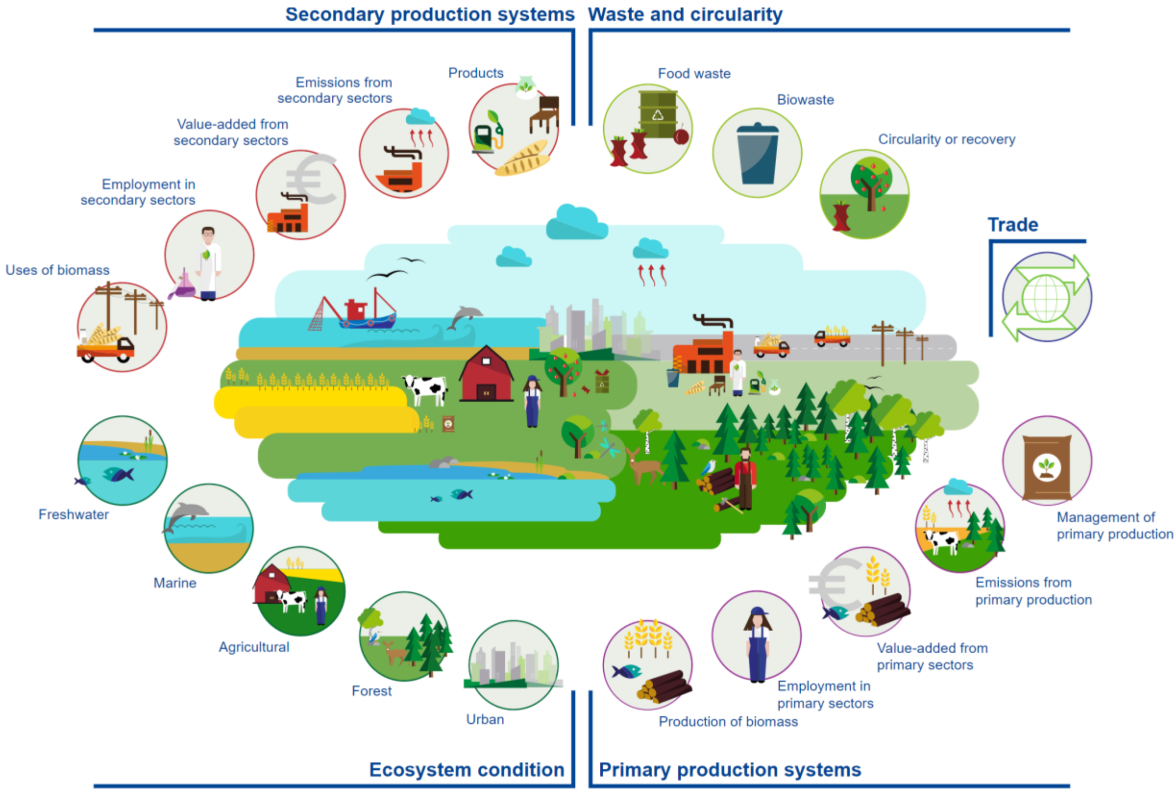


Figure 1: Headline indicators of the EU Bioeconomy Monitoring System

These headline and subsequently sub-level indicators represent one of the most recent approaches, which is easily applicable by stakeholders and political decision-makers.

For the definition of the case-study region related indicators, the headline indicator level was used as a starting point to develop more detailed and case-study specific indicators. Updates in terms of sub-level indicators were included in the refinement and indicator updates were added where applicable and relevant for the cases.

Indicators defined by the requirements of the analysis tool framework

The case-study regions represent diverse industries and activities that differ in terms of their economic background and sectors of the bioeconomy. A critical aspect of the project involves benchmarking the three tools combined in the project to determine their suitability for specific applications within these regions and beyond. Together, the three tools a) resource flow analysis (RFA, provided by ALCN), b) logistics optimization (MooV, provided by VITO), and c) impact assessment tools (IAT, provided by LIST) allow a holistic assessment of a transition pathway. Each of these tools requires a different dataset to operate. These datasets (e.g., greenhouse gas emissions, amount of biomass and its specific management and use, energy demands of connected processes and transport) will be crucial to measure the impact of the analyzed transition pathways and represent a comprehensive and holistic view of economic, environmental, and social progress of a region. Based on the previously defined headline indicators, the individual pathways analysis revealed necessary refinements as well as additional indicators to be introduced. The indicators necessary for the assessment tool framework have been described in more detail in Deliverable 2.1.

The baseline of indicators was elaborated by the project partners in a joint workshop during the consortium meeting in 2023. This workshop, led by task 3.1 leader CLIB, included a decision matrix based on the headline indicators of the EU Bioeconomy Monitoring system with the option to mark relevant indicators for the case-study region. The decision process was guided by questions targeting feedstock choices, processes, products, fossil products to be replaced, as well as questions regarding the support of stakeholder, the regional added value and the replicability in other EU regions. A documentation of the regions initial choices (indicated by the colored dots; each region used a different color to indicate its priorities) in the workshop is shown in Figure 2, while Figure 22 shows a broader overview of the workshop (Annex). Subsequently, each region refined the identified indicators further, to match the needs of their local transformation pathways or by aligning them with indicator sets already defined by existing regional sustainability and bioeconomy strategies.

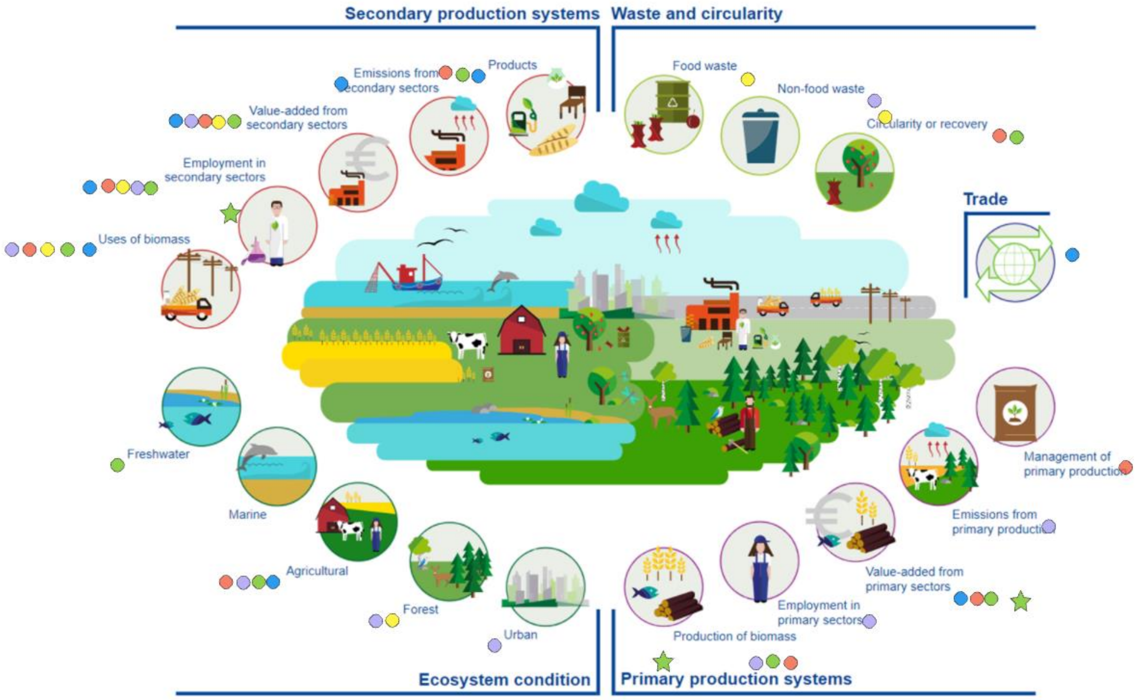


Figure 2: Result from internal workshop, first identification of headline indicators by each region

Initial choices of the case-study representing regions were made by colored dots representing the six different case-study regions.

During the implementation of pathways in each region, further exchange with local stakeholders will take place. These will provide additional knowledge which will be implemented into the pathways and the set of indicators. The constant development of this initial collection of indicators is therefore likely and desired during the project. This deliverable represents the current status of the indicators which have emerged from the development of the case studies, including the multi-actor approach.

2.1.2 *Definition of optimal transition pathways for each region*

BIOTRANSFORM aims to confirm the chosen indicators, define the most promising transformation pathways and refine its assessment package through a co-creational approach of workshops and feedback loops with regional stakeholders. The multi-actor approach (MAA) is a powerful and frequently used tool to incorporate realistic and demand-driven information into the decision-making processes and was utilized in this project. At the same time, it generates and engages with a stakeholder base which is an important value network for the later implementation of the pathways. Different actors and their specific professional and personal motivations to implement the bioeconomy led to a consumer-focused, non-linear innovation process that resonates with societal needs and may benefit from the feeling of co-ownership of knowledge for a fast implementation[30]. BIOTRANSFORMs MAA draws on a range of experts, regional stakeholders, and decision-makers to assess, evaluate, and refine the regional transformation pathways with the greatest potential to strengthen the development of the case-study region.

The co-definition of transformation pathways and MAA methodology used in BIOTRANSFORM was created for six different case-study regions and presents a multi-step process that each project partner applied tailored to the specific challenges and prerequisites of the represented region. The five steps listed below represent a broad co-definition approach for the selection and refinement of regional transformation pathways within the Tasks 3.1 and 3.2 in work package 3. These tasks required a close coordination of activities in work package 2 (Task 2.5). The interfaces between the co-definition of the transformation pathways and the analyses by the assessment tool kit were addressed in the regular meetings. In weekly spotlights on the progress of the individual case studies, the results were commented on by the head of Task 2.5 and starting points for more in-depth analyses were discussed within the consortium. Concrete applications of the BIOTRANSFORM assessment tools were discussed in bilateral meetings between the regions and the tool providers (ALCN, VITO and LIST) and the necessary data for the analyses was defined. The evaluation of the potential transformation pathways was carried out depending on a) the availability of relevant data and b) the relevance of the tools for the respective regional case studies. Where necessary, practitioners from the conversion routes were included in the discussions to obtain a better understanding of data availability, potential gaps needing to be filled, and, in the case of the life cycle impact assessment, to identify meaningful comparative data sets for the analysis.

The implementation strategies reported on later in Deliverable 3.2 will include collaboration with work package 4 (WP4) in terms of a deeper analysis of financing strategies and policy development. The following methodology was developed to serve as a guideline for the MAA of all case-study regions. It presents a multitude of steps, which enable regions at different stages of their transition to a circular bioeconomy to either scout for potential transition pathways or validate a set of them. Each case-study partner adapted the methodology to best suit the needs and realities of its region and stakeholder base. This approach was accompanied by weekly meetings of the consortium, in which feedback on the progress and challenges within each region was given. This allowed the consortium

[30] The Power of Multi-Actor Projects in Horizon Europe – Consulta Europa (consulta-europa.com)

to agree on further steps and adaptations of the regional approach to overcome problems encountered and ensuring a steady progress during the co-definition of pathways.

1. Regional data basis: The basis for the subsequent MAA was created in WP1 by mapping regional secondary resources, relevant stakeholders, and knowledge carriers, as well as existing and possibly underutilized infrastructure. By gathering this data from existing publications and through intensive desk research, the specific challenges and opportunities of each region were identified and verified by a first stakeholder interaction in the course of the BIOTRANSFORM Info Days. The results from this groundwork were summarized in the deliverables D1.1, D1.2 and D1.3 and served as the basis for the following steps in defining possible transformation pathways. Additionally, a first set of region-specific indicators which aligned with regional sustainability strategies was identified and scheduled to be further refined in the course of the project.
2. Defining resource conversion routes: Based on the data collected, possible and potentially favorable conversion paths were defined based on the available literature and compared with the regionally available resources and conversion technologies. The conversion routes were collected regardless of economic feasibility. The economic infrastructure and research landscape were noted so they could be taken into account at a later point for the pre-definition of the pathways as a part of Task 3.2. The definition of relevant conversion routes took place in feedback group sessions/workshops and involved stakeholders from different sectors including industry, academia, regional network representatives, consumers, suppliers, tech providers, policy makers, and public service providers. Although the exact composition of these groups varied from region to region, the aim was to narrow down the collection of conversion pathways to a smaller set of pathways which fit the demand of the specific case-study region.
3. Multi-criteria analysis: The further refinement of the transformation pathways again took place in form of discussion rounds with a range of experts. A multi-criteria matrix was developed through a more detailed quick assessment of the pathways (aligned with activities in Task 2.5) with regard to factors such as CO_2 emissions, recyclability, technical complexity and technical readiness as well as economic impact. The multi actor approach additionally included topics like research and development capabilities, potential partnerships, and estimated costs. The goal was to narrow down the pathway options to three top-ranked pathways as most relevant for the region in the scope of the BIOTRANSFORM project.
4. Assessment via quantitative data and the BIOTRANSFORM Assessment Tool Kit: Together with relevant stakeholders, the three desired pathways were each broken down into discrete process steps. Available quantitative data could be used to generate first mass flows in form of Sankey diagrams (Partner ALCN/ open-source tools), to establish logistic models where applicable using the MooV tool (VITO) and to perform the Life Cycle Impact Assessment (LIST).
5. Co-definition of the preferred pathway: Defining an optimal pathway for each region was performed via a co-definition process alongside local and regional actors and representatives through feedback group sessions and bilateral meetings. Through feedback loops between WP2 (Task 2.5) and WP3, the pathways were optimized and updated and therefore aligned with the feedback received by policymakers and other stakeholders.

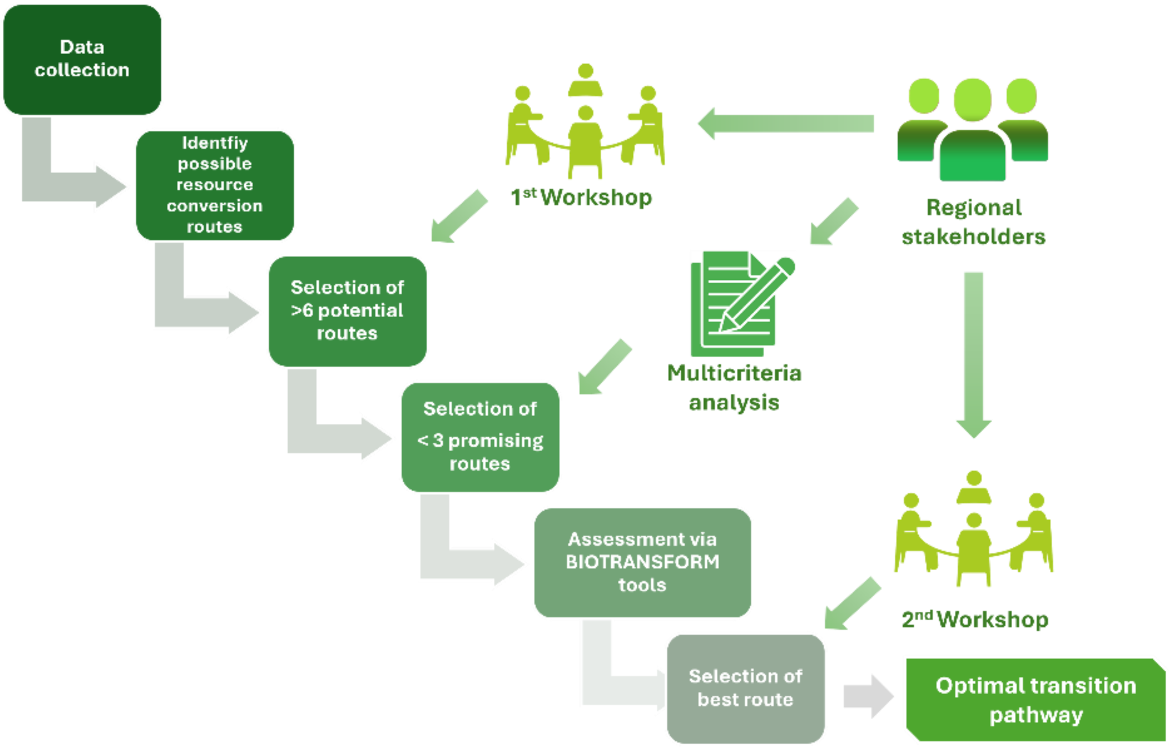


Figure 3: Overview of the methodology to determine the optimal transition pathway for each region within the BIOTRANSFORM project.

The different steps of the co-definition process are shown in Figure 3.

As presented above (see chapter 1.3), the existing infrastructure of local biorefineries within EU countries[31] represents a promising resource that BIOTRANSFORM is incorporating into the development of regional solutions. The partners in BIOTRANSFORM ascertained which assets, such as simple biorefineries or disused plants were already available in each region (D1.3). The objective was to determine whether these could be (re-)activated in circular bioeconomy transition pathways. The idea is to build upon a region’s strength instead of building entirely new installations, also given the complexity and long-term investment needed to build a refinery infrastructure. During the multi-actor approach, opportunities for decentralized and centralized biorefineries were discussed with regional stakeholders. These discussions also took logistical issues relating to the (dis-)continuous availability of biogenic side streams into account. The MooV tool is valuable in evaluating the best possible course to integrate feedstock, transformation, production, use, and recycling in a holistic view of an entire value chain. Whether these local refinery concepts are feasible, needs to be evaluated depending on each region’s transition pathway.

[31] Baldoni, E.; Reumerman, P.; Parisi, C.; Platt, R.; González Hermoso, H.; Vikla, K.; Vos, J.; M'barek, R., Chemical and material driven biorefineries in the EU and beyond, Publications Office of the European Union, 2021, ISBN 978-92-76-34252-6, doi:10.2760/8932, JRC124809

3. Analysis of the regional case studies

This Deliverable 3.1 reports on the process of the "Identification of current key parameters per demo-case scenario" and the "Co-definition of optimal transition pathways with regional actors", summarizing the results generated in task 3.1 and task 3.2. The data collection for this report was therefore aligned with the action points and milestones within the two tasks 3.1 and 3.2 and reflects how the process led to the outcome for each case-study region. While the five-step methodology (see Figure 3) had to be adjusted slightly depending on the availability of experts and the composition of the stakeholder groups, all regions followed the questionnaire listed below to evaluate and report their co-creation process.

In a first step, project partners reported how they identified key indicators for their case study region, as assessed in Task 3.1. Internally, this had been compiled in Milestone 3.1, which had been reached by M14 and handed over to Task 3.2 at the conclusion of Task 3.1. For this Deliverable, partners reported the current status, as iterated in Task 3.2. They were given the following questions to consider when reporting on the identification of key indicators:

- What was the process of selecting the key indicators?
- Which stakeholders were involved in the selection process?
- Which specific links between the key indicators and the case-study region were found?
- Have there been any changes or refinements to the indicators during the further analysis of the transition pathways considered?

In a second step, each partner responsible for a case-study region reported on their actions to co-define potential and further on optimal transition pathways with their regional actors. To collect this information in similar and comparable formats, again a set of questions was answered by all partners involved to describe their co-definition of optimal transition pathways with regional actors. They were requested to report on the co-definition process of transformation pathways considered for their case-study region by describing the key aspects of the multi-actor approach and feedback loops with regional stakeholders.

- What kind of information did the stakeholders provide and how was it beneficial for the co-definition process?
- Which stakeholders joined your feedback sessions? Why were these considered important for this process and your region?
- Was the aspect of centralized or decentralized refineries relevant for the chosen pathways?
- How easy was it to engage stakeholders for the exercise and the concept? How does this impact your case study?
- Did the process yield an optimal or preferred pathway?
- How is the final pathway uniquely adapted to your case-study region?

Finally, the case-study regions were asked to report on the current state of their pathway selection as of month 23 of the project. The progress of each individual region depended heavily on local factors such as its bioeconomy readiness, the availability and motivation of the stakeholders involved, as well as the accessibility of relevant data. Consequently, the definition of three most promising pathways and finally the most optimal pathway was not easily achieved for every region.

3.1 Andalusia (Spain)

3.1.1 *Identification of key indicators*

The transition pathway selected for the Andalusian region is linked to the olive value chain. Andalusia is the world leader in the olive grove sector, with more than 1.6 million hectares (60% of the national olive grove) and an average olive oil production of more than one million tons and table olives of around 450,000 kg (approximately 80% of national production in both cases). The olive grove sector generates around 20 million daily wages per season (depending on the production obtained), which represents approximately 40% of the agricultural employment generated in Andalusia. Furthermore, with a production value of more than 3,400 million euros (27% of the value of Andalusian agricultural production), it is the main crop in Andalusia. The region has become the leading producing region in the world, with a processing industry that has 850 oil mills, 772 packing plants, 17 refineries, 41 olive oil mills and 225 olive packing plants. Also, olive oil is the most exported foodstuff, with a volume that during the 2021/22 campaign amounted to 800,682 tons, with a value of 2,894 million euros. In terms of internationalization, this is a sector that still has a lot of room for growth and potential with the opening of new markets. This way, it can be concluded that the olive grove sector in Andalusia is a driving force for the generation of wealth, job creation, and retention of the rural population. It is important to note as well that the olive oil sector is also one of the leading proponents of organic agriculture in the region.

Currently, some side-streams of the olive value chain are valorized through low-value applications. Thus, considering the abovementioned information, it can be concluded that the sector has a strong potential to become a clear example of a circular economy and bioeconomy system through the efficient, high-value application of all the by-products of its production process.

In the context of BIOTRANSFORM, the indicators' identification process was carried out following a methodology where information coming from literature, both peer-reviewed as well as from relevant regional policy documents and regulation, was screened. A brief list of main policy documents and regulation which were screened is provided next:

- Regional Circular Bioeconomy Strategy 2018
- Andalusian Overall Plan for Waste - Towards a Circular Economy in 2030 Horizon" (PIRec 2030)
- Andalusian Innovation Strategy (RIS3Andalucía 2020)
- Regional Law for the Circular Economy
- Other horizontal strategic plans of the Regional Government of Andalusia: Agenda for Employment, Economic Plan of Andalusia 2014-2020, and Andalusian Plan for Research, Development and, Innovation-Spanish (PAIDI) 2020
- Other more specific plans such as the Andalusian Industrial Strategy 2014-2020, the Andalusian Energetic Strategy 2020, the Andalusian Strategy against Climate Change, the Andalusian Plan for Environment Horizon 2017 and the Law for Agriculture and Livestock production of Andalusia
- At the national level, Spanish Strategy for Bioeconomy Horizon 2030

As a result of the screening step, a preliminary list of indicators was drafted. Next step was to analyze the selected value chain (olive) to point out the main challenges faced when transitioning to circular bioeconomy approaches. That information was assessed against the preliminary list of indicators in order to select those that were more relevant in order to properly address the identified challenges. This provided an interim list of indicators. Last step was the identification, where the interim list of indicators was cross-checked with the available information. As the selected value chain is related to some waste flows valorizations, sometimes it is difficult to find quantified information for some source flows. Accordingly, a final list of indicators was produced as a trade-off solution of relevant indicators and information available that could lead to the calculation of those indicators.

The process of the identification of relevant indicators is shown in Figure 4.

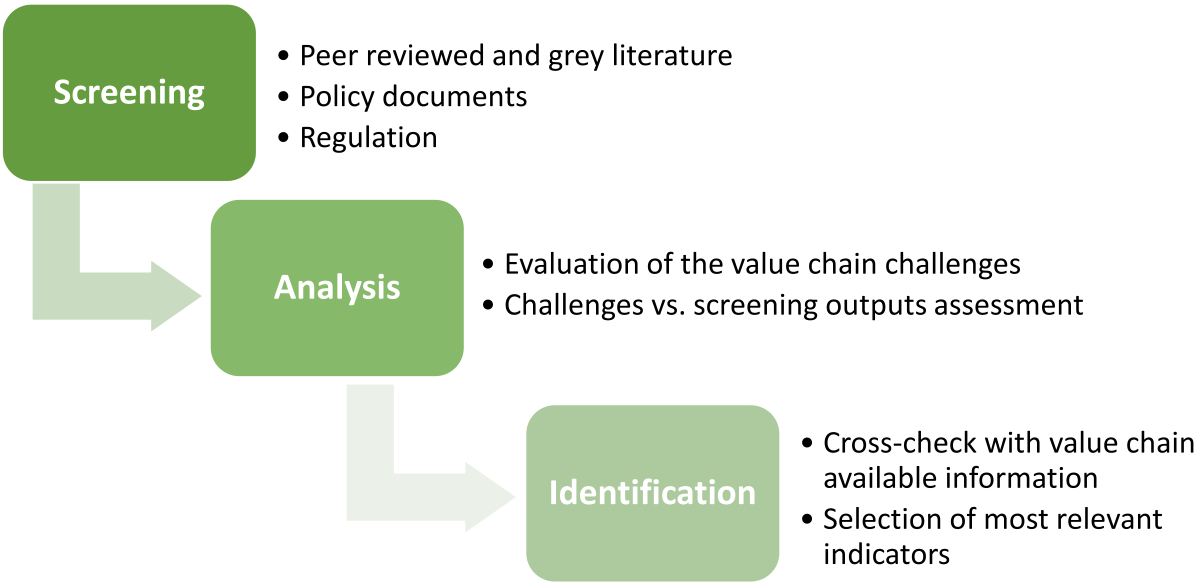


Figure 4: Andalusian region: methodology for indicators selection

As a result of this methodology, the indicators listed in Table 2 where selected. These were selected in line with the current challenges faced by the olive sector as discussed in the frame of a regional event organized as part of task 1.5 in March 2024. In terms of production, the demand for extra virgin olive oil is expected to continue to grow in the coming decades, driven by its recognized nutritional value and health benefits. However, climate change and climate variability could negatively affect olive production, especially in the main olive producing regions of the Mediterranean, with a worsening in rainfed areas. Biomass-related indicators are vital for analyzing the sector's evolution.

Table 2: Andalusian region selected indicators

Headline indicator / category	Case-study-specific refinement	Unit
Production of biomass	Related to olive value chain	[ktons]
Employment in primary sector	People employed in bioeconomy sectors	
Value-added from primary sectors		[million €]
Use of Biomass		[ktons]
Employment in secondary sectors	Connected to olive biomass valorisation	
Value-added from secondary sectors		[Million €]
Agriculture	Share of organic farming in utilized agriculture area	
Circularity and recovery	Biowaste recovered by source	[ktons]
Trade	International market prices	[billion $]

Accordingly, these indicators are relevant to the region, as the Andalusia case study aims to analyze the environmental, social, and economic impact that the revalorization of olive by-products has on the region. To this end, indicators such as biomass production, added value, or the number of employees in the primary and secondary sector have been chosen. During the co-definition exercise it was concluded that further update of these indicators was not needed. The analysis of these indicators will contribute to assess the implementation of circular bioeconomy processes in one of the main sectors of activity in Andalusia, promoting at the same time regional industrial development using natural resources coming from olive cultivation.

3.1.2 *Co-definition of optimal transition pathways with regional actors*

The co-definition of the transition pathways for the Andalusian region was carried out following main guidelines provided by T2.5, WP3 and WP4 leaders. The implemented methodology, together with the interactions and feedback loops involving stakeholders is depicted in Figure 5.

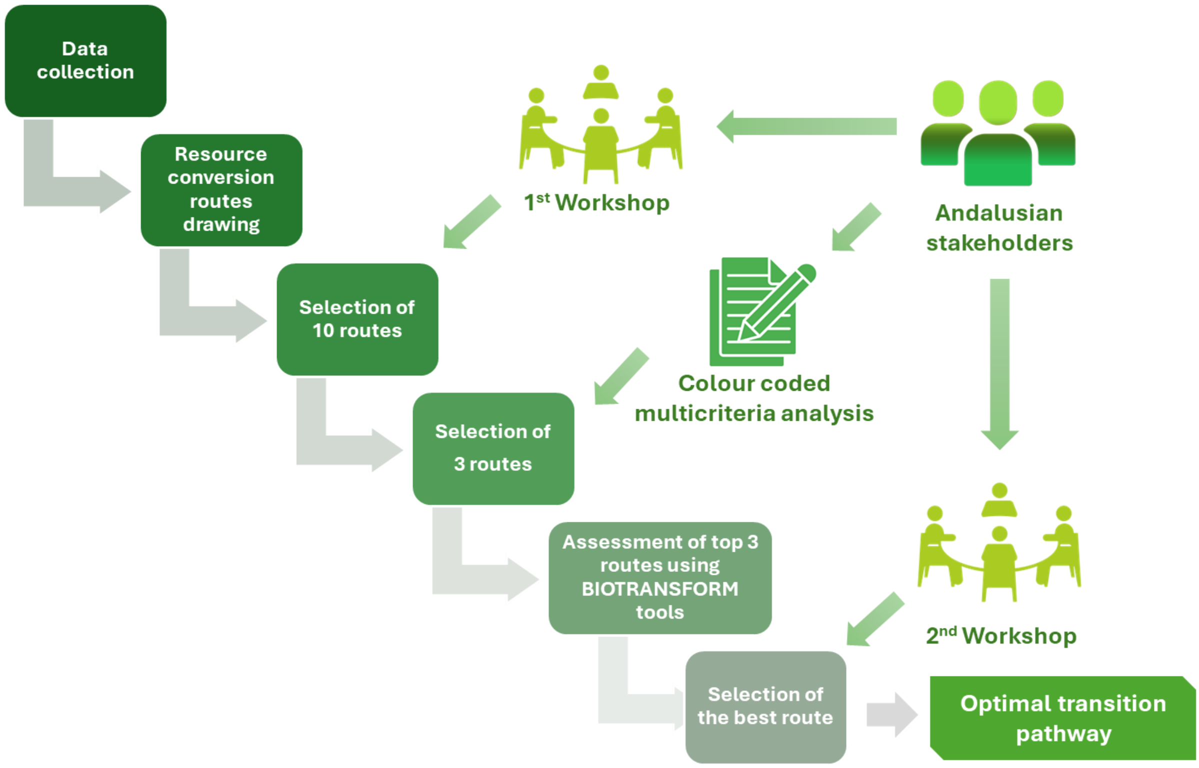


Figure 5: Co-definition of the transition pathways methodology for the Andalusian region

The process started by carrying out a data collection of the region in terms of available resources and the identification of regional stakeholders (Step 1). Regarding the identification of regional stakeholders, these were preliminary selected according to the following criteria: (1) quadruple helix representation; (2) link to the olive value chain; (3) previously shown interest in circular bioeconomy dimension. This initial pool of stakeholders was selected among the attendees to the regional event organized in the framework of T1.5 in March 2024 and from CTA network. The identified stakeholders are summarized in the following Table 3:

Table 3: Andalusian regional stakeholders identified

Business	Academia	Policy	Financial sector	Civil society
• DCOOP • Natac • Cooperativa San Isidro de Loja • AgroSevilla	• University of Jaén • Instituto de Desarrollo Regional • ANDALTEC • Citoliva	• IFAPA • Tragsatec • Andalusian Energy Agency	Austral Venture Gestion	Union of Consumers of Andalusia

Then, a thorough study of the selected value chain was carried out to delve into all the potential valorization approaches under the circular bioeconomy dimension. The main products obtained from the olive sector are olive oil and table olives. Their processing produces biomass that can be used for other secondary products, i.e., a set of secondary resources are available from the olive oil and olive table production processes. These are: olive pomaces, olive pruning debris and olive stones. Once these main secondary resources were identified, a bibliographic study was carried out to analyze all the possible conversion routes for each of them (Step 2 of the methodology), as well as the final products that can be obtained. The following diagrams, produced with the Xmind application, show all possible conversion routes identified as these could be key pathways to support the regional transition to circular bio-based approaches for the olive value chain.

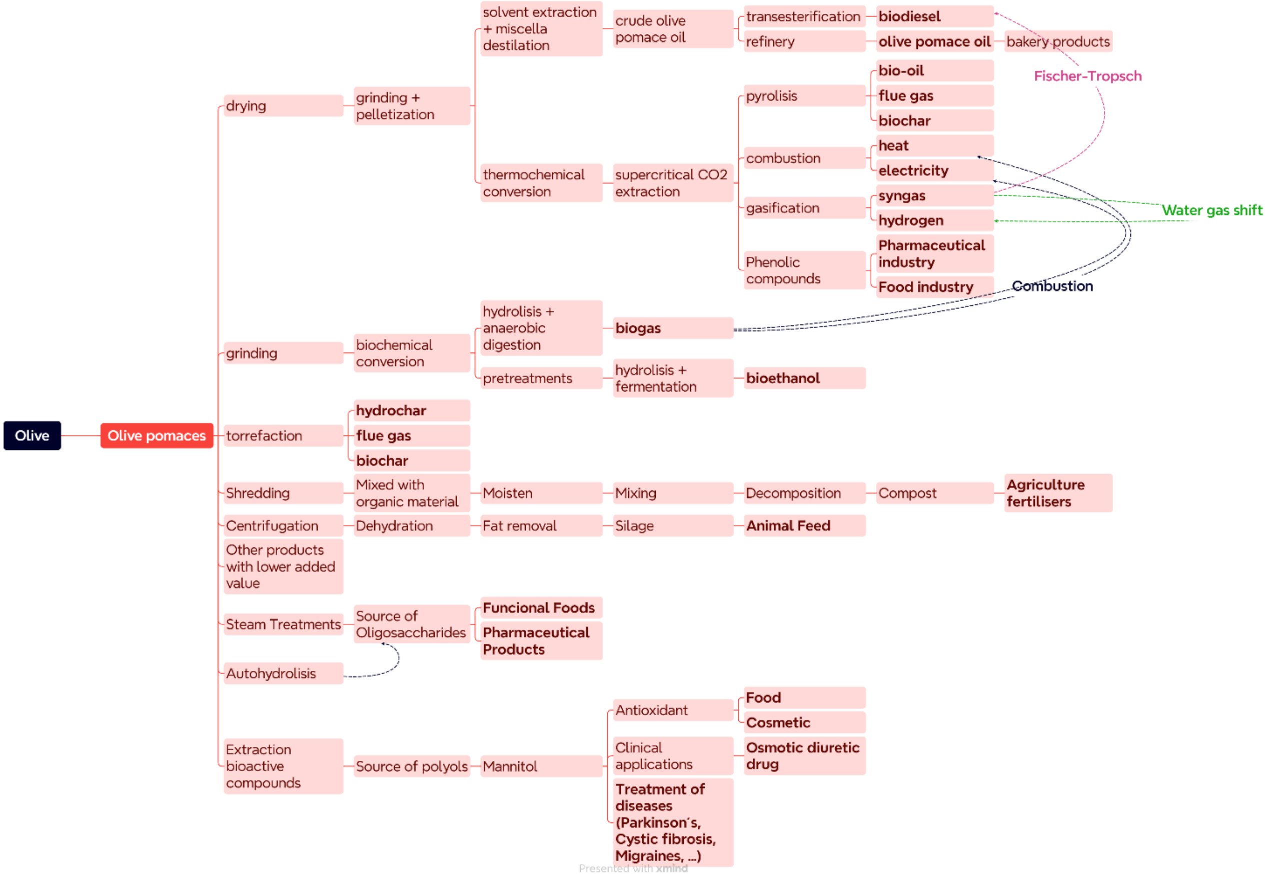


Figure 6: Olive pomace pathways (Source: CTA own)

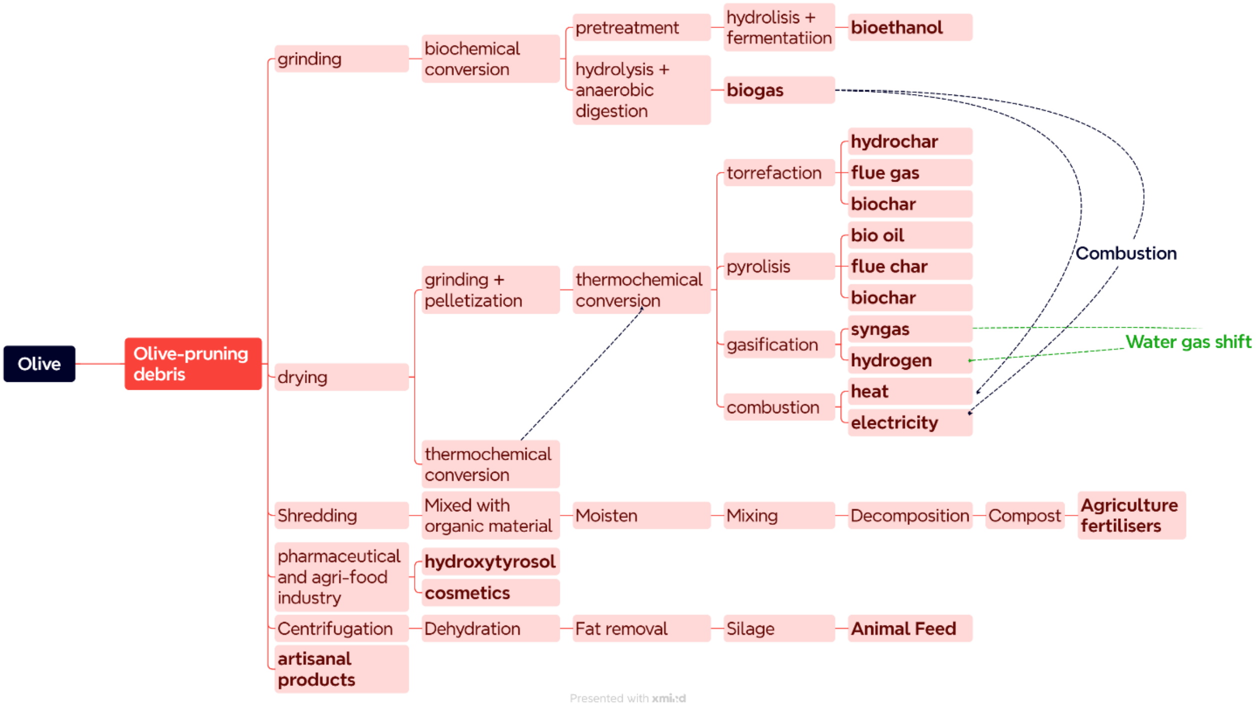


Figure 7: Olive pruning debris pathways (Source: CTA own)

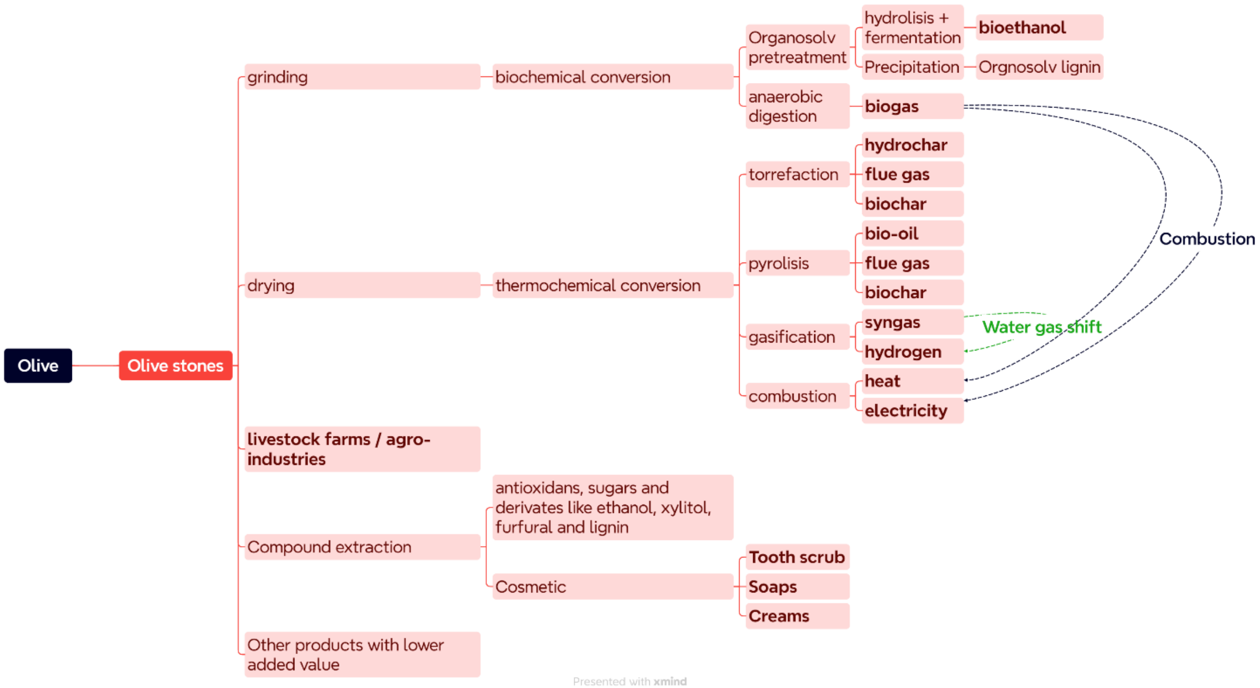


Figure 8: Olive stones pathways (Source: CTA own)

Step 3 of the methodology consists of the pre-definition of possible pathways through a co-creation exercise involving a group of regional stakeholders/experts. Thus, an online meeting with 5 experts from the sector was organized in March 2024. From the initial pool of stakeholders identified in Table 3 a selection was carried out according to the following criteria: (1) knowledge about secondary resource production and use; (2) ownership of information that might be relevant for indicators assessment; (3) availability and willingness to participate in the whole pathway selection process. Accordingly, the experts who participated in the session were from the following organizations: Andalucía Trade, Andaltec, University of Jaen, Citoliva and Agrosevilla,

The meeting was carried out with the main objective of selecting the 10 most interesting routes with high impact potential. Table 4 presents the 10 routes selected as well as the secondary source that could be used as feedstock.

Table 4: 10 selected routes with high impact potential for the Andalusian case study region.

Secondary source	Route
Olive pruning debris	▪ Reinforcement of polymeric materials ▪ Polymer production ▪ Bioethanol production ▪ Production of lignin
Olive stones	▪ Xylitol production ▪ Bioethanol production
Olive pomaces	▪ Hydroxytyrosol production ▪ Triterpene production ▪ Oleuropein production ▪ Tocopherol production

Step 4 was linked to the multi-criteria analysis of the selected routes, this to be carried out by the involved stakeholders. During the step 3 meeting, all experts agreed to do this online by themselves, with CTA compiling and streamlining all the communications (following a DELPHI methodology approach). CTA prepared an Excel file including the 10 selected routes and the main criteria as provided by ALCN, together with the main guidelines on how to conduct the assessment. Figure 9 shows the results of the multicriteria analysis for each of the selected routes, evaluating parameters such as resource availability, environmental impact, circularity and potential, water consumption, and economic aspects. As a result of this first analysis, it can be seen that for the routes 7 – 10, the results are not so positive, scoring “red” or the color-coded approach.

Residue	N°	Application	Resource availability	CO2 impact	Circularity potential	Water consumption	Freshwater quality impact	CAPEX	OPEX	Techn. Complexity	Economic relevance/feasibility	TRL	R&D needed
Olive pruning debris	1	Reinforcement of polymeric materials	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	High	Medium R&D requirements to improve chemical conditioning of the pruning wood fibre
Olive pruning debris	2	Polymer production	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	Low	Medium R&D requirement to improve chemical processes
Olive pruning debris	3	Bioethanol production	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Medium	Medium R&D requirements on enzyme development and pentose fermentation
Olive pruning debris	4	Production of lignin	Medium	Medium	Medium	Medium	Low	Medium	Medium	High	Medium	Medio	Medium R&D requirements
Olive stones	5	Xylitol production	Medium	Medium	Medium	High	High	Medium	Medium	Medium	Medium	Low	Medium R&D requirements on microorganism development and purification systems
Olive stones	6	Bioethanol production	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Low	Medium R&D requirements on enzyme development and pentose fermentation
Olive pomaces	7	Hydroxytyrosol production	High	Low	Low	High	High	Medium	Medium	High	Medium	Medium	Medium R&D requirements on green extraction and purification systems
Olive pomaces	8	Triterpene production	High	Low	Low	High	High	Medium	Medium	High	Medium	Low	Medium R&D requirements on green extraction and purification systems
Olive pomaces	9	Oleuropein production	High	Low	Low	High	High	Medium	Medium	High	Medium	Medium	Medium R&D requirements on green extraction and purification systems
Olive pomaces	10	Tecoferol production	High	Low	Low	High	High	Medium	Medium	High	Medium	Low	Medium R&D requirements on green extraction and purification systems

Figure 9: Multi-criteria analysis of proposed conversion routes in the Andalusia case – version 1

At this point, CTA discussed with task leader ALCN how to best proceed in order to progress with the optimal transition pathway selection. ALCN suggested to merge some of the routes in order to show one route with a wider application range. Figure 10 depicts the final picture of the routes, these counting now to 7, together with the results from the multicriteria assessment for this new route. An extended version of Figure 23 and Figure 24 can be found in the corresponding Annex.

It was possible then to select the top 3 routes to be further analyzed. These 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)

The next step is the use of the BIOTRANSFORM tools in order to carry out a deeper assessment of the top three routes. As of September 2024, CTA is currently gathering information for the environmental, economic, and social assessment to be conducted by LIST. After assessing the amenability of the three main routes, it was decided to use the MooV to study the main logistic issues from route 1, in cooperation with the Andalusia stakeholder Andaltec (currently in progress). This information will support addressing in the stakeholder workshops the topic of the role of centralized or decentralized refineries and how this pertains to the Andalusian region. As for the upcoming period, the aim is to finalize the assessment by LIST and VITO and to produce a resource flow analysis (e.g. in form of Sankey diagrams) with support from VTT. All the resulting information will be presented in an online workshop where stakeholders are expected to select the most optimal transition pathway for the Andalusian case.

Residue	N°	Application	Resource availability	CO2 impact	Circularity potential	Water consumption	Freshwater quality impact	CAPEX	OPEX	Techn. Complexity	Economic relevance/feasibility	TRL	R&D needed
Olive pruning debris	1	Reinforcement of polymeric materials	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	High	Medium R&D requirements to improve chemical conditioning of the pruning wood fibre
Olive pruning debris	2	Polymer production	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	Low	Medium R&D requirement to improve chemical processes
Olive pruning debris	3	Bioethanol production	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Medium	Medium R&D requirements on enzyme development and pentose fermentation
Olive pruning debris	4	Production of lignin	Medium	Medium	Medium	Medium	Low	Medium	Medium	High	Medium	Medio	Medium R&D requirements
Olive stones	5	Xylitol production	Medium	Medium	Medium	High	High	Medium	Medium	Medium	Medium	Low	Medium R&D requirements on microorganism development and purification systems
Olive stones	6	Bioethanol production	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Low	Medium R&D requirements on enzyme development and pentose fermentation
Olive pomaces	7	Antioxidants production	High	High	Medium	Low	Medium	Medium	Medium	Low	Medium	Medium	Medium R&D requirements on green extraction and purification systems

Figure 10: Multi-criteria analysis of proposed conversion routes in the Andalusia case – condensed version (2)

3.1.3 *Experiences with the co-definition approach*

Regarding the carried-out work with the stakeholders, following a quadruple helix approach when selecting them has ensured that all points of view have been considered in the co-definition exercise.

The multi-criteria color coded analysis has proven to be a powerful tool to conduct the assessment, especially when non-technical stakeholders are involved. It has been especially important, in order to succeed with this exercise and reach an objective evaluation, to provide careful guidelines on how to allocate the different color codes.

As for the analysis, some difficulties on assessing economic aspects have been encountered, even using the color coded approach.

3.2 Northern Burgenland (Austria)

This report on Task 3.1 and Task 3.2 as well as their connections to WP2 includes the activities and efforts performed by ALCN until month 22 of the project. The report is based on meeting minutes and content that was handed over to the consortium after they withdrew from the consortium on 20 July 2024. Any gaps are due to the cessation contributions by ALCN as of their insolvency being declared in June 2024. The further analysis of the North Burgenland region will be continued by another partner in the course of the project. At the time of reporting of this deliverable D3.1, the decision-making process has not yet been finalized.

3.2.1 *Identification of key indicators*

The case-study of Northern Burgenland focusses on the utilization of local biogenic feedstocks like straw and vineyard residues, as by-products from the agricultural sector, and reed and sludge from the lakes that cover 21 % of the region. While the use of lake sludge follows a relatively direct conversion into soil additives and classic building materials, agricultural side streams can be converted through different low- and high-tech processes (e.g. cutting, milling, mechanical pressing, extraction, and fermentation) to create added value and to circularize material and nutrient flows in this rural area of Austria.

Indicators were chosen based on the regional demands in sustainability as well as the natural resources available in the regional agricultural sector. The selection was made based on available indicators at national and EU level and was adapted to the specific circumstances of the region in line with the regional strategies, through discussions with experts, and on the basis of literature research.

Table 5: Headline indicators for the Norther Burgenland case (Austria)

Headline indicator / category	Case-study-specific refinement	Unit
Use of Biomass	Of connected sectors	[ktons]
Employment in secondary sectors	Employees total	
Value-added from secondary sectors	Sales Revenue and gross value added	[1000 €]
Products	From analysed value chains	
Circularity or recovery	Biowaste recovered by source	[ktons]
Freshwater		
Agricultural		
Production of biomass	By class of biomass/ crop	[%/ha]
	Quantities of Biogenic waste	[ktons]
	Production of lake sludge	[m^3]
Value-added from primary sectors		[million €]
Emissions from primary productions		[million €]
Emissions from primary productions		[Mtons CO_2eq]

The chosen indicators (see Table 5) are crucial for assessing the success of the transition pathway in Northern Burgenland. Monitoring the use of biomass evaluates the region's commitment to sustainable resource utilization. Production of biomass and the subsequent classification mirrors the different sort of residual biogenic side streams derived from this sector. Due to the location of Northern Burgenland in the dry Pannonian climate region, combining the economic indicators with the freshwater indicators helps to assess the sustainable production, especially of the primary sector. Employment in secondary sectors measures the pathway's socio-economic impact by tracking job growth, especially in the bioeconomy sector. Assessing value-added from secondary sectors, related to the bioeconomy, and value-added from primary sectors quantifies the economic benefits and potential for regional economic development, utilizing biogenic feedstocks. Identifying and categorizing products derived from the transition provides insight into the initiative's diversity and market potential. Quantities of biogenic waste maps out the income of biogenic feedstocks which obviously serves no purpose a reduction in the amount should reflect a better distribution of side streams. The production of lake sludge reflects the condition of the shoreline around Lake Neusiedl: due to the decline in use, the stock is becoming increasingly aged, and the lake area is silting up and needs to be drained.

Overall, these indicators offer a comprehensive framework to gauge the environmental, economic, and social dimensions of the transition pathway.

3.2.2 *Co-definition of optimal transition pathways with regional actors*

The co-definition process was mainly achieved by a focus group meeting in July 2024 where regional experts from local sustainability networks, the food production and food chemistry, economic agencies, and the soy producing and processing sector were present. The session was introduced by highlighting the concept of a circular economy and contrasting it with traditional, petroleum-based economies. The key goal of reintroducing waste into the production process as valuable resources rather than discarding it was underlined.

The bioeconomy value chains are complex and involve multiple actors, such as producers, farmers, sellers, experts, and policymakers, working together to find sustainable solutions. Infrastructure, especially in agriculture and food production, was highlighted as crucial. Leveraging underutilized infrastructure, such as vacant facilities and underutilized waste streams can unlock valuable resources and improve regional biomass usage. North Burgenland's bioeconomy strategy focuses on utilizing local biomass to diversify the economy beyond tourism and create jobs.

Three key biomass resource streams – straw, soy by-products, and wine by-products – were identified for the North Burgenland region. A Multi-Criteria Analysis (MCA) was used to evaluate these streams and identify suitable processing pathways. Participants at the co-definition session discussed how creating material flow diagrams will help visualize complex information.

Additionally, funding opportunities were mentioned to help create jobs and raise awareness about the circular economy. Due to the high interest, the group decided to discuss all three resource streams together rather than splitting into smaller groups.

The participants shared concerns and ideas, particularly regarding the use of soy and straw. Straw was emphasized for its importance in soil health, and stakeholders stressed that removing straw from fields could deplete soil nutrients, as well as require significant energy for further processing.

There was broad support for focusing on using entire plants and finding alternatives to petroleum-based products. The session also introduced the concept of cascade economics, where biomass streams like straw, soy, and wine by-products could serve as raw materials for high-value products. The importance of using these materials in value-added processes, beyond a simple use as animal feed, was stressed.

Participants explored the potential uses of the three key resource streams (straw, soy, wine by-products) using mind maps on the Miro online whiteboard. The discussion covered various topics, such as the potential issues of soy by-products due to estrogen-like compounds and the differences in bioplastic production, emphasizing biodegradable options like PLA. Participants also discussed capturing CO_2 from fermentation to increase biomass production, which could be applied in DIY greenhouses. Individual ideas and concerns were added to the whiteboard, and good practices from Austria and the EU were showcased as potential models.

At the end of the session, participants gave positive feedback and expressed strong interest in continuing to collaborate with Alchemia-nova. The session concluded with a discussion of potential follow-up projects.

Results from the Focus Group

Key resource streams were explored further, and several upgrading processes were identified:

- **Straw**:
    - Pelletizing straw for use as a substrate in mushroom cultivation, possibly using empty wine cellars for this purpose.
    - Extracting sugar alcohols from straw for producing sugar alternatives, with potential partners in Burgenland.
    - Utilizing hollow straw for sustainable building materials (e.g., straw-clay construction, roofing).
- **Soy**:
    - Various upgrading processes were identified, including producing high-value fermented soy products. Interviews with local soy producers and processors, such as MANUFABA and Farmento, will further explore these possibilities. Consideration was given to incorporating residual soy materials into animal feed.
- **Wine**:
    - Extracting sap from vine shoots for cosmetic applications.
    - Using grape pomace in biorefineries to produce high-value platform chemicals.
    - Producing grape seed oil from grape seeds as a high-quality product.

In summary, the co-creation session successfully identified key pathways for upgrading three different regional biomass streams and fostered collaboration among diverse regional stakeholders.

The information for the further refinement of the identified pathways was, to date, gathered through bilateral expert meetings for the three agricultural sectors. Regular exchange with the regional Economic agency revealed connections to future projects in North and South Burgenland favoring the pyrolytic use of residual material with a focus on biochar as the desired product. At the time of writing of this deliverable, no optimal pathway has been identified yet, as this needs further stakeholder engagement.

3.3 Charles Spa Region (Czech Republic)

3.3.1 *Identification of key indicators*

The key strategic regional indicators for the Charles Spa Region were selected based on economic, environmental, and socio-demographic criteria to reflect the region's unique strengths and align with broader policy goals.

- Economic Relevance: Indicators were chosen based on the economic significance of sectors like spa tourism and traditional manufacturing, including glass and porcelain.
- Environmental Factors: Consideration of natural resources, particularly mineral springs, and medicinal waters, as these are vital to the region's spa and tourism industries.
- Socio-Demographic Trends: Population trends such as aging and outmigration were included to address the region's socio-economic challenges.
- Infrastructure and Investment: Indicators related to infrastructure, such as transport connections and investment levels, were selected to assess economic growth potential.
- Policy Alignment: Indicators were aligned with regional development plans and the EU's bioeconomy strategies to ensure consistency with broader policy objectives.

- The Charles Spa Region is one of the least favored of the Czech Republic, recovering from brown coal mining activities and a traditional manufacturing sector in decline. Although unemployment is not a big challenge for the region, the demographics showcase an aging population, with a tendency of young people migrating to other regions with more opportunities. Furthermore, innovation, research infrastructure, entrepreneurial spirit and education opportunities are limited and make the sustainable transition challenging despite the local sustainability goals voiced in regional strategies, (note: no dedicated Bioeconomy strategy in place neither on the national nor on the regional level). The most developed sector in the region is tourism, centering around natural springs and spa. Therefore, the selection of the key indicators was based on regional strategy goals regarding the energy transition using renewable resources, combined with the most profitable economic activity, tourism and its contributing factors and stakeholders.

Specific indicators regarding tourism concern food and gastro waste, which is a not fully utilized biomass resource in the region. Due to its touristic character, the Charles Spa Region has many accommodation and catering facilities and restaurants. These units produce food waste daily, from leftovers and/or non-consumed food, adding to the volumes produced just from domestic use.

Table 6: Relevant indicators for the Charles Spa region (Czech Republic)

Headline indicator / category	Case-study-specific refinement	Unit
Use of biomass	Food production and imports	[ktons]
Employment in secondary sectors	People employed in the tourism sector	
Value-added from secondary sectors	Tourism industry value, food sector value	[million €]
Emissions from secondary sectors	Emissions generated by food production	[Mtons CO_2eq]
Food waste/ circularity or recovery	Waste per category, generation and recovery	[ktons]
	Food waste along the supply chain	[ktons, dry]
	Household waste	[ktons]
	Industrial and agricultural waste	[ktons]
	Waste in landfills	[ktons]
Forest		

Headline indicator / category	Case-study-specific refinement	Unit
Social	Bioeconomy focused legislation	[Number of policies]
	Working hours	
Circular	Replacing non-renewable feedstock by biomass	
	Substitution share indicator	
	Recycling for specific waste streams (RSWSI)	[%]
	Recycling rates (RRI)	[%]
	Specific energy consumption in operations	[kWh/m2.a]
	Energy intensity	Joules/ US Dollar ($)
	Material utilization score	%
	Eco-efficient value ratio	Ratio
Environment	Ozone depletion potential (ODP)	kg CFC-11 eq
	Global warming potential	kg CO2 eq
	Fossil fuel dependence	MJ
	Share of renewable mix	% of electricity coming from renewables

The Charles Spa Region is defined by its unique geographical position, natural resources, economic reliance on traditional industries, and demographic challenges.

- Geography and natural resources: The region is characterized by its geographical location bordering Germany, with rich natural resources such as mineral springs.
- Economic structure: Historically, the region relied on industries like mining, manufacturing, and spa tourism, with the latter playing a crucial role due to its natural resources.
- Demographic challenges: The region faces population decline, aging, and a low birth rate, affecting its labor market and economic vitality.
- Environmental context: The spa industry is heavily dependent on positive environmental conditions, such as high water and air quality, influencing regional health and wellness tourism.

Closely related to the tourism industry, the waste from the food sector originating from catering businesses and restaurants is crucial to this case-study, as it contributes significantly to the amounts of available biomass. Identifying the number of people working in the sector and the value generated can give us the idea of the compact and importance of the case for the region. Adding to the tourism sector, which in Charles Spa is not susceptible to seasonality, household food waste is a promising additional source of biomass, also given the fact that recycling has already become a habit of the local population.

Other indicators regarding the environmental impact and energy mix are relevant since the region is under transition from coal mining activities. Some bioenergy infrastructure exists but looking into the capacities can give us a hint of the biomass conversion possibilities.

Key challenges for the region include economic stagnation, demographic decline, environmental degradation, infrastructure limitations, and industrial transition.

- Economic stagnation: The region has faced long-term economic stagnation, with slow growth compared to other Czech regions.
- Demographic decline: Aging population and youth outmigration pose significant socio-economic challenges.
- Environmental degradation: Historical mining activities have left environmental burdens, affecting land and water quality.
- Infrastructure limitations: Insufficient transport and digital infrastructure hinder economic development and connectivity.
- Industrial transition: Transitioning from traditional fossil-based industries to more sustainable bioeconomy models remain a critical challenge.

On the regional level the strategic regional indicators have been changed for the following reasons:

- Increased focus on bioeconomy: Recent strategies have emphasized bioeconomy development, influencing changes in economic and environmental indicators.
- Policy-driven adjustments: Alignment with national and EU policies has led to updates in regional strategies, affecting indicator selection and prioritization.
- Infrastructure development: Efforts to improve transport and digital infrastructure have resulted in changes to relevant indicators.
- Socio-demographic shifts: Updated demographic data reflecting population trends have led to adjustments in socio-economic indicators.
- Environmental considerations: New environmental policies and reclamation projects have influenced changes in ecological indicators.

During the meetings with stakeholders, no further indicators were identified. The local stakeholders, mainly the regional representatives who participated, were interested in advice for their bioeconomy implementation due to their as yet limited expertise on the topic. They preferred to consider readily applicable solutions, which could relatively easily be implemented. Considering this specificity of the region, we presented the opportunity presented by the BIOTRANSFORM project along with the pre-selected indicators from the perspective of how the local goals can be supported from such an analysis. The floor was open for further proposals, but in fact our initial suggestion was confirmed.

3.3.2 *Co-definition of optimal transition pathways with regional actors*

Overall, the co-definition process with the local stakeholders can be described in the following steps:

- Initial design
- Meeting with local stakeholders 2023
- Further research on local reality and feasibility, identification of more players
- Meeting with local stakeholders in the context of local Innovation Conference May 2024
- Presenting how the project can refine their existing practice and contribute to the local goals.

Given the region’s characteristics, the focus of this case-study was food-waste. The suggestion was to emphasize the reduction of food waste and the development of an effective methodology for the transformation and valorization of the remaining waste. Processes like anaerobic digestion, composting, insect-based conversion, and the use as a feedstock in biorefineries can lead to a range of value-added products which was considered at the first phases of the pathway design. Initially, the following options were considered:

- Biogas from food waste
- Composting from food waste
- Biofuel from used cooking oil

It was important to keep local connections, established infrastructure, works, contracts, customs regarding waste collection in mind. Food waste originating from households and gastro waste from restaurants and catering facilities appeared to be a promising source of secondary biomass, given the intense tourism industry as well as the household food collection being part of citizens customs anyway. The existing collection facilities and needed sanitation processes were considered in cooperation with local specialists to identify the best logistics options. Existing infrastructure for those pathways eases the transition since there is no need to invest into newly built facilities from scratch. Joining forces on food waste with neighboring Bavaria to increase the biomass input was considered, but after talking with Bavarian local experts, this idea had to be dropped due to the high legislative barriers. Another potential source for biofuel production was used cooking oil. Although initially promising, this case was also dropped due to the small available quantities and potential competition with private companies already collecting this oil.

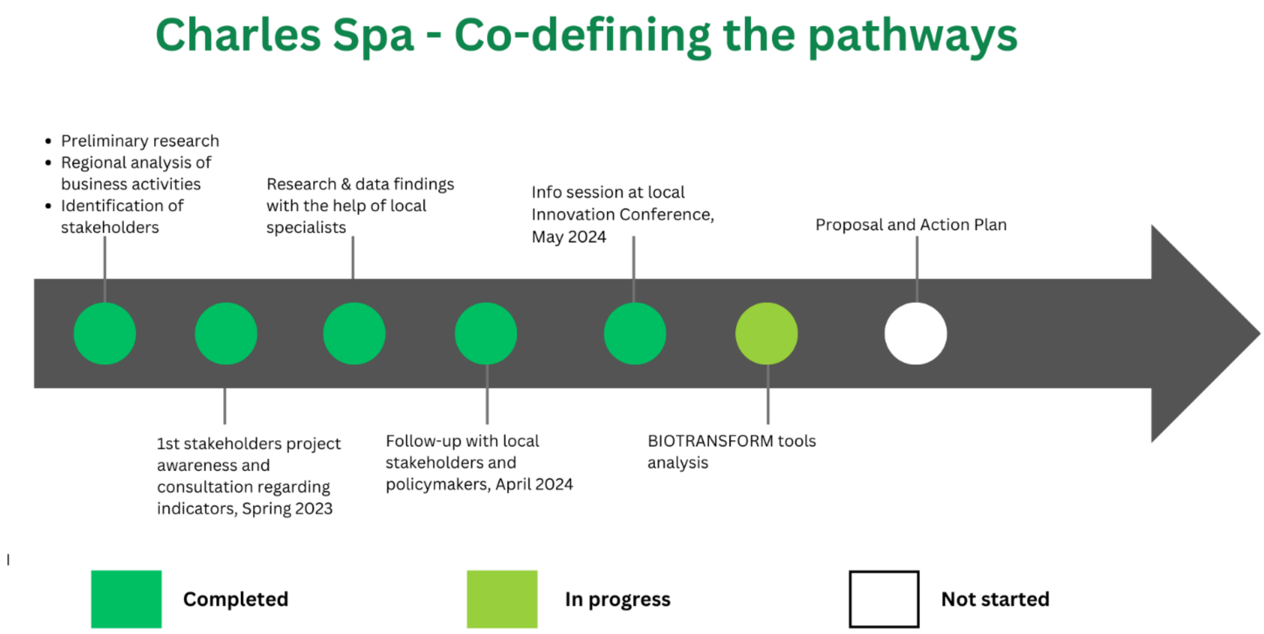


Figure 11: Pathway co-definition for the Charles Spa case study

The identification of stakeholders in Charles Spa was conducted by applying a scanning of the key players both for the value chain but also in influential terms. Given that the region suffers from lack of innovation, entrepreneurial spirit, and educational opportunities, we invited a wide range of stakeholders from local representatives, the existing innovation centers, support, and subsidy organizations, and also representatives of the tourism and hospitality sector. The ones that were more engaged, although there still a huge effort to be made in raising bioeconomy awareness, were the local representatives, the innovation centers, and a few entrepreneurs.

In the first meeting with stakeholders in spring 2023, the BIOEAST HUB CZ (BHCZ) introduced the idea of the transition as tackled by the BIOTRANSFORM project, focusing on the concept and the opportunities for the region based on its needs and strengths. Several structural issues were identified then, and it was rather clear that there was no common understanding of the bioeconomy concept. Following that meeting, individual discussions followed whenever there was an opportunity. We discussed the idea of food waste valorization with policymakers and governance actors. Due to the region's resistance to change and suspicion towards sustainability changes, it was important to us to engage the most influential stakeholders by proposing already familiar topics and concepts which the BHCZ then transcribed into project specific targets and indicators.

From the interaction with stakeholders, no technical information was acquired but rather experience and ways on how to approach a rather closed society and a bit rigid existing practices. In the Charles Spa case, actionable steps and concrete examples were deemed more important than co-designing at the request of the stakeholders themselves. An opposite way of descriptive case/results from the project and instructions to implement were requested turning it into a carefully applied trial scheme.

Given the nature of the proposed pathways, already in line with local practices for food collection, this turned quickly into a more research-oriented activity with the assistance of local experts. Local experts gave a more thorough insight into the way the gastro waste collection system currently works in the region, the quantities, collection points, local legislation and what sanitation processes are needed. This helped to make the case study more concrete. It was also important to make necessary optimizations considering already existing networks and interests. For example, entering the used cooking oil valorization field would confront already existing business valorization, not mentioning the non-worthy quantities.

Regarding the question of whether to use centralized or decentralized refineries, this was important for the collection of food waste to optimize the logistics and storage capacities. The answer to this was directly given by the existing infrastructure (even though one scenario involves building additional facilities) and the nature of the proposal. Centralized facilities are more efficient because a necessary critical mass needs to be reached for the conversion of food waste into energy and compost/fertilizer. The comparison of centralized versus decentralized refineries will be done using the MooV-tool. Beside investigating the (financial and environmental) impact of the transition from decentralized to a centralized processing facility, it will also be investigated what the impact is when introducing other processing types (such as anaerobic digestion) than composting, what the impact is of combining anaerobic digestion and composting, and finally what the impact is of bypassing the transfer collection point. For these analyses, the focus will be on the cities Karlovy Vary and Mariánské Lázně, both tourist hotspots, which generates peaks in biowaste production in the tourist season.

Stakeholder consultation

In a following session with stakeholders with the opportunity of an Innovation Conference in May 2024, the case was described in more detail highlighting the potential economic and sustainability benefits for the region using existing resources. Again, the reaction was positive.

Chosen pathway

The transformation process in the Charles Spa region should focus on reducing food waste and developing an effective methodology for waste transformation and valorization into compost and biogas for several reasons:

- Economic Opportunities: Reducing food waste and transforming it into valuable products can open new economic opportunities, such as creating biogas or bio-based materials, which can boost regional economic development.
- Sustainability Goals: Addressing food waste aligns with broader sustainability goals and helps reduce the environmental impact of waste disposal, such as greenhouse gas emissions from landfills.
- Resource Efficiency: Efficient waste valorization processes enhance resource efficiency by utilizing by-products and waste streams, contributing to a circular economy that maximizes resource use.
- Policy Alignment: Aligning with national and EU policies on waste reduction and resource management can attract funding and support for regional projects aimed at bioeconomy transformation.
- Community and Economic Resilience: Developing local solutions for waste management can strengthen community resilience by providing local jobs and reducing dependency on external resources.
- Focusing on these areas will not only address environmental concerns but also drive economic and social benefits for the Charles Spa region.

The proposed pathways are closely connected to the region valorizing upon food waste which results both from households and is greatly enhanced by the tourism sector providing a relatively stable source of biomass. Furthermore, considering the lack of technical background expertise and awareness of local stakeholders about bioeconomy, the solutions proposed are something familiar, tangible, with some infrastructure already existing. This makes the pathway easily acceptable since it respects local balances. Additionally, despite the limited bioeconomy related awareness, locals are familiar with recycling all kinds of materials and comply to requirements on disposing waste in specific containers.

3.3.3 *Experiences with the co-definition approach*

Implementing a co-definition approach in the Charles Spa region faces several challenges. First, the region's socio-economic and demographic diversity complicates consensus-building among stakeholders with varying interests and priorities. Additionally, the historical reliance on traditional industries such as mining and manufacturing is creating a resistance to change and to the adoption of new bioeconomy models that is taking time to overcome. The lack of cohesive infrastructure and connectivity further hampers coordinated efforts and collaboration across the region. Limited financial resources and investment in innovation can impede the development and implementation of participatory approaches that require significant upfront costs. These factors combined make it challenging to successfully implement a co-definition approach that requires broad stakeholder engagement and cooperation.

In the Charles Spa case, choosing the optimal pathway was challenging in terms of accessing the optimal solution given that the feedback received from local stakeholders was not necessarily the one an expert would offer. In similar cases, we have seen researchers suggesting and designing tailored solutions fitting the local needs and priorities, with local stakeholders being invited to consider their implementation. This can ensure local acceptance and participation. While a bottom-up approach would be ideal, sometimes it is more efficient to apply a top-down decision which does not radically change the customs of local actors and can better balance their interests.

3.4 Finland

3.4.1 *Identification of key indicators*

The process of identifying key indicators began by conducting a literature search (current research, and future actions of policymakers and industry towards circularity) of possible side streams and wastes of forestry, that are currently unutilized. The suggestions, including also input from Finland's CBE strategy to promote the circular economy, were introduced to associated stakeholders including industry representatives and policymakers at the organized info days. Based on the comments received from the stakeholder meetings, we continued the discussion with researchers studying the utilization of side streams, and lignin was chosen as the most promising side stream at the moment in forest industry among the six side-streams identified as potential. The other five were green liquor dregs, bark & sawdust, hemicellulose, ash (from forest industry) and post-consumer wood. The current utilization of lignin was evaluated, and three pathways were identified by searching scientific topics and industrial investments around lignin. Three pathways were validated by experts, industry representatives and local decision makers.

Black liquor, which is the main source of lignin in forest industry, is currently incinerated for energy production. In 2023, wood-based energy had a share of 66 % of the total renewable energy in Finland. Thus, a key indicator for circular lignin use is to monitor the source of renewable energy in the future alongside of the amount of extracted lignin. Another important indicator is to control the CHG emissions and water usage during the lignin extraction process, which are monitored from the environmental permits. For this, LCA analysis has been conducted for three lignin application using fossil-based alternatives as references, which validates the potential of the applications in the light of environmental and social aspects.

The challenges of the transition are related to energy production and investments for new technology. The share of the wood-fuels, that are used for lignin extraction, has to be replaced with other sustainable source of energy. This might lead to the need for more power plants or the increase of imported energy. In the technological view, the easiest route of utilizing lignin has been incinerating it as black liquor. In the case of circular transition, more investments are required to update the technologies of the facilities. Moreover, the demand of bio-based alternatives has to be sufficiently high to make the applications economically feasible.

An overview of the indicators chosen is given in Table 7.

Table 7: Key indicators for the Finnish case-study.

Headline indicator / category	Case-study-specific refinement	Unit
Use of Biomass	Lignin extracted from black liquor	[ktons]
Forest	CHG emission	[kg CO2 eq]
Forest	Water consumption in lignin production	[m3/t lignin]
Energy use	Shift through lignin utilisation vs. burning	% of electricity coming from alternatives
Energy use	Production of bioenergy, decline of forest-based bioenergy	[TWh]
Climate change	Global warming potential	[kg CO2 eq]
Circular	Replacement of fossil-based products by lignin-based products	

3.4.2 *Co-definition of optimal transition pathways with regional actors*

The co-definition of the transition pathways for the Finnish case study region was carried out following the main guidelines provided by the leader of task 2.5, and work packages WP3 and WP4. The implemented methodology, together with the interactions and feedback loops involving stakeholders is described next and depicted in Figure 12. Two workshops were organized to gather stakeholders together to discuss on the circular thoughts, potential side streams in forest industry and the ideas of utilizing them. No major deviations have occurred.

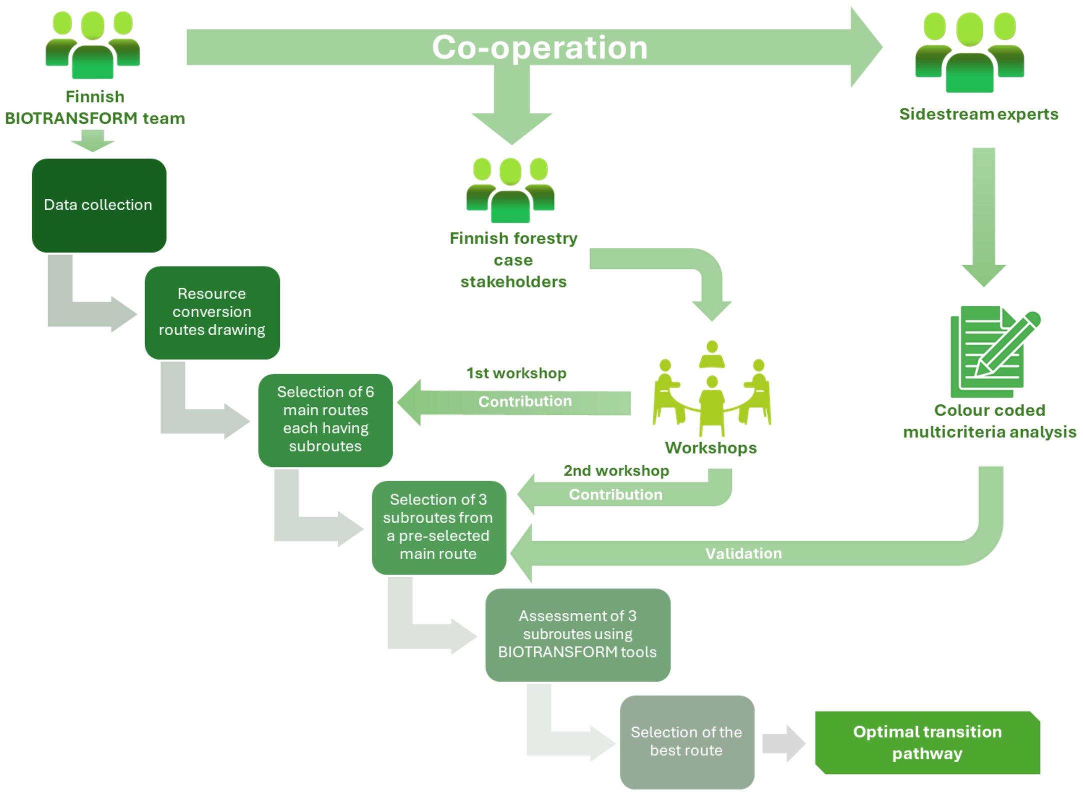


Figure 12: Co-definition of optimal transition pathways, Finnish case study.

The process started by carrying out a data collection of the region in terms of available resources and the identification of regional stakeholders (Step 1). Regarding the identification of regional stakeholders, these were preliminary selected according to the following criteria: (1) quadruple helix representation; (2) link to the forest value chain; (3) previously shown interest in circular bioeconomy dimension. This initial pool of stakeholders was selected among the attendees to the regional events organized in the framework of T1.5 in (20.3.2023 and 30.3.2023) and from VTT network. The identified industrial stakeholders are summarized in Table 8 for lignin (same identification was done for all 6 main routes).

Table 8: Identified industrial stakeholders for lignin as a secondary resource in the Finnish case-study region.

Facility name	
Billerud Finland Oy	Riga Wood Finland Oy
Corenso United Oy Ltd	Sappi Finland Operations Oy
Jujo Thermal Oy	ScanPole Oy
KOSKISEN OY	Sonoco-Alcore Oy
Kotkamills Oy	Stora Enso Oyj
Metsä Group Oyj (Board, Fibre, Tissue, Wood)	SUOMEN KUITULEVY OY
Mondi Lohja Oy	TERVAKOSKI OY
Oy SCA Hygiene Products Ab	UPM-Kymmene Oyj (fibers, raflatac, specialty papers, communication papers, plywood)
Pankakoski Mill Oy	VERSOWOOD OY, Vierumäki
Powerflute Oy	

In addition to the identified producers, invites to national workshops were extended to city (Äänekoski) and ministry representatives (the Ministry of Economic Affairs and Employment, MEAE), funding representative (Business Finland, BF), industry federation (the Finnish Forest Industries Federation FFIF), equipment manufacturers (several) and industry representatives (several) not producing lignin but having utilization potential from it.

Then, a thorough study of the selected value chain was carried out to delve into all the potential valorization approaches under the circular bioeconomy dimension. The researcher-driven process identified main new higher value products studied from the lignin, which are shown in Figure 13.

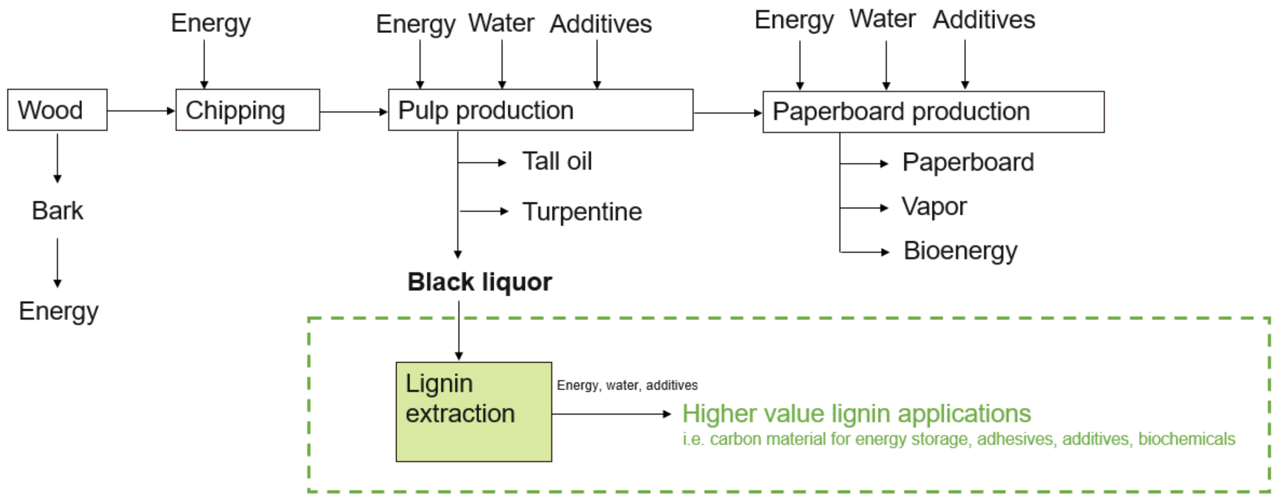


Figure 13. Product routes from black liquor valorization.

From the initial pool of stakeholders identified in Table 8, a selection was carried out according to the following criteria: (1) knowledge about secondary resource production and use; (2) ownership of information that might be relevant for indicators assessment; (3) availability and willingness to participate in the whole pathway selection process, supported by researchers. The workshop was held in April 2024.

Experts participated in this workshop were: One regional authority, one funding authority, one representative from industry federation, one senior researcher (specialized in lignin side stream utilization) and eight industry members. After a short introduction to the project, to resource use and potential conversion pathways, and the variables assessed, all participants joined a discussion supported by an online whiteboard tool. Stakeholders listed their ideas on the most potential conversion pathways, notes to policymakers and common comments regarding markets, customer awareness and material use. At the end of the workshop, conclusions were made based on the discussions. The suggested pathways were discussed at the workshops together with the stakeholder and the three pathways were confirmed by analyzing the workshop results. The chosen pathways are to use lignin in battery materials, adhesives and plasticizers.

The routes are validated using LCA tool and a simple Sankey diagram will be drawn. A use of the MooV-tool is not planned, as the logistics change is considered small, because forest industry companies have already optimized their logistic chains and logistics to mill remains unchanged.

3.4.3 *Experiences with the co-definition approach*

Regarding the work carried out with the stakeholders, following a quadruple helix approach when selecting them has ensured that all points of view have been considered in the co-definition exercise. The co-definition work was supported by a national level strategic program to promote a circular economy that helped to guide decision-making. Economic aspects are usually business-sensitive information and had to be carefully considered relying on only public information.

3.5 North Rhine-Westphalia (Germany)

3.5.1 Identification of key indicators

The chemical industry in North Rhine-Westphalia (NRW) is heavily dependent on imported fossil-based feedstock and replacements are needed for the future de-fossilization. This case-study aims to evaluate the use of regional biobased feedstocks to produce intermediates for the chemical industry. The focus lies on converting bio-based, C6-sugar rich feedstocks by fermentation or other means to create added value in the form of products that may be used as a building block in the chemical industry or possibly directly replace fossil-based products on the market. Due to the large demand of the chemical industry for feedstock (fossil- and bio-based), a local concept can only be part of a bigger solution. Analyzing optional feedstocks and processes might however strengthen incentives for small scale biorefineries and other concepts to be part of the transition of the NRW region after the phase-out of lignite mining. While the transition away from lignite mining sparked several initiatives that foster the regional development towards a bioeconomy e.g., the "Model region Bioeconomy in the Rhenish mining region (Modellregion Bioökonomie im Rheinischen Revier), North Rhine-Westphalia is currently in the process of developing a bioeconomy strategy. The responsible body, the NRW Bioeconomy Council, was convened by the state government in March 2024 and the first key points of a bioeconomy strategy already outline important topics for further analysis, which is to be aligned with European and national standards and adapted to the needs of NRW.

The indicators for the presented case-study of NRW were chosen based on the headline indicators of the EU Bioeconomy monitoring system and aligned with the regional sustainability strategies and literature of regional and national research institutes [32] [33] [34]. Further indicators relevant for the case-study region align with the sustainability indicators tracked for NRW [35], including employment (in biobased-sectors). Market- and trade-specific indicators were included to reflect the high competitiveness bio-based products face on the market, which is one of the major challenges businesses face in this sector. The set of relevant indicators for the case-study of North Rhine-Westphalia is listed in Table 9.

With a focus on the enormous demands of feedstock of the local industry, the indicators based on production volumes and biomass availability proved to be of high priority. Regional biomass flows have been a field of interest in the region over the past ten years, including the availability and cross-border utilization of biomass in small-scale German and Dutch cooperation projects, some of which with CLIB participation. The importance of a constant availability of high-quality biogenic feedstock is additionally reflected by a large-scale monitoring within the project "Biomass potentials in the Rhenish mining region"[36] (Biomassepotenziale im Rheinischen Revier). The project develops a regional set of

[32] Ermittlung wirtschaftlicher Kennzahlen und Indikatoren für ein Monitoring des Voranschreitens der Bioökonomie | Publikationen | ifo Institut
[33] Zirkuläre Bioökonomie für Deutschland – Fraunhofer Gesellschaft
[34] Nationale Bioökonomiestrategie (publikationen-bundesregierung.de)
[35] Übersicht Indikatoren | Nachhaltigkeitsindikatoren (nrw.de)
[36] LANUV (nrw.de)

biomass specific indicators. These will be compared with those developed in BIOTRANSFORM as soon as they are available.

Table 9: Relevant indicators for the NRW case-study

Headline indicator / category	Case-study-specific refinement	Unit
Use of biomass	Biomass supply for materials/ energy/ food/ feed purposes	[ktons]
Production of biomass	Side streams from agricultural sector	[ktons]
Employment in secondary sectors	In bioeconomy sectors	
Value-added from primary sectors	Higher valorization of biogenic feedstocks	[million €]
Value-added from secondary sectors		[million €]
Emissions from secondary sectors		[Mtons CO2eq]
Products	Share of bio-based products	
Food waste	Waste per category	[ktons]
	Mass flows along the supply chain	[tkons]
Trade	International market prices (biogenic feedstocks)	[EUR/t]
	Energy prices	[EUR/kWh]
Economical	Investment in scale-up facilities	[EUR]
	Investment in reskilling of workforce	[EUR]

The NRW case-study aims to use bio-based feedstocks to reduce the chemical industries' dependency on fossil fuels. This can add resilience to the local industry. A key factor in these alternative pathways is the easy and constant availability of biogenic feedstocks. Long distance transport, seasonality, high market prices, a well-organized collection of (optimally homogeneous) feedstocks and other factors can impact the feasibility of its use. As further conversion into value added products includes the pretreatment and further processing, the availability of cheap, green energy is a major contributing factor. If implemented, mass flows and bio-based product shares (in products and intermediates of the chemical industry) can be used to measure the impact of the alternative pathways. One of the biggest challenges in the utilization of biogenic raw materials is that entrepreneurs find it difficult to finance their innovations in order to bring them to market. While several national and regional instruments are available to offer funding to start-ups and SMEs, large investments are necessary to reach the scale needed to create impact and to meet the demands of the industry. Monitoring the amount of investment to implement bio-based processes and practices will therefore be an important factor, both within the established industry as well as for new players on the market. Financing strategies for the pathways developed in the case-studies will further improve the communication to policy makers in WP4 and the replication of bioeconomy practices in the similar regions.

3.5.2 *Co-definition of optimal transition pathways with regional actors*

The identification of relevant transformation pathways started based on literature data and foresight studies focusing on the circular economy and bioeconomy in Germany. Biomass is seen as an elementary raw material for both energy use and material utilization, and numerous processes show possibilities for replacing fossil-based processes and products.

The material utilization of biogenic raw materials in the chemical industry can be achieved in various ways, but these are always associated with economic challenges. Drop-in products are usually bio-based equivalents that can be used seamlessly in existing processes. This change can be associated with high CO_2 savings, but the drop-in will require the same performance and economic efficiency. The scale required to replace fossil products to a relevant extent is also crucial. The marketing of an alternative product also places high demands on the product. Existing processes may have to be changed in favor of the alternative, so that added value must be considered even more critically here. Additionally, the development of alternative pathways takes time to reach the relevant technological readiness. However, studies, particularly on alternative, bio-based polymers, are revealing interesting possibilities and their design is being adapted to industrial challenges with the involvement of industrial partners[37] [38]. These inspiring examples show that a transformation is happening slowly but gradually and proof that the adaptation of bio-based processes is, given economic feasibility, welcomed by the regional industry to meet the demand of regulations and sustainability targets. For this case-study several value-added products from biomass were considered as interesting targets. In scope of the BIOTRANSFORM project, products that can be produced by fermentative processes and via (bio-)chemical conversion were deemed most promising. A collection of value-added products from biomass is depicted in Table 10.

Table 10: Preliminary collection of bio-based products and intermediates for the chemical industry, NRW case study.

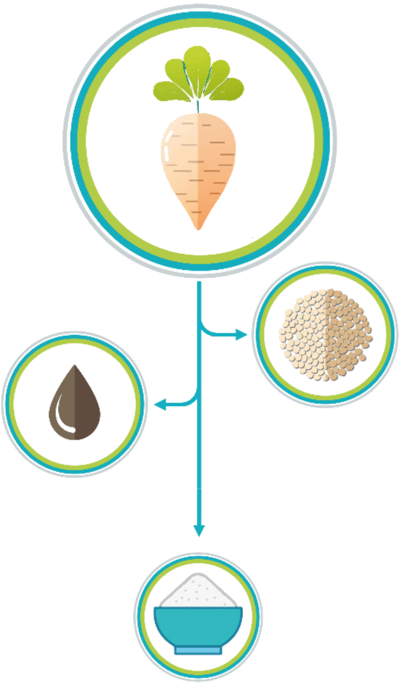
Compound	Category
Ethanol	Alcohol
1,4-butanediol	Alcohol
Lysine (and others)	Amino acid
Hydroxymethylfurfural (HMF)	Furan
Succinic acid, malic acid, fumaric acid	Organic acid
Aspartic acid	Organic acid
Glutamic acid	Organic acid
2,5-Furan dicarboxylic acid (FDCA)	Organic acid
3-Hydroxypropionic acid (3-HPA)	Organic acid
Glucaric acid	Organic acid

[37] Towards aromatics from biomass: Prospective Life Cycle Assessment of bio-based aniline - ScienceDirect
[38] Projektverzeichnis - Details (fnr.de)

Itaconic acid	Organic acid
Levulinic acid	Organic acid
Lactic acid	Organic acid
Glycerol	Sugar alcohol
Sorbitol	Sugar alcohol
Xylitol/arabinitol	Sugar alcohol

Based on this preliminary collection, four experts from the chemical industry provided verification and up to date market relevance in bilateral discussions. These meetings revealed a set of promising products to follow up on, as well as several challenges to overcome when using secondary feedstock in the process.

Most commercial and industrially applied manufacturing processes for bio-based chemical products use C6 sugars, vegetable oils, starch, proteins, or cellulose as feedstock. These biobased feedstocks account for 15 % of the raw materials used in Germany's total chemical production (2022)[39]. While many processes for utilizing, these primary resources are established, the real challenge lies in the use of secondary feedstocks, such as biogenic side, residual and waste streams. Here, too, progress has been made towards industrial applications in recent years[40], but widespread industrial implementation is still facing technical and economic hurdles. The overall technical feasibility was hence considered for the predefinition, further narrowing down the selection of possible targets.



Sugar beet pulp

Relevance for NRW

Third largest producer in Germany

Locally based sugar refineries

Utilisation
- Animal feed
- Biogas plants

Key figures NRW (2022)	
Cultivated area	54 200 ha
Yield	799,1 dt/ha
Production Germany (2022)	
Sugar	4669 Tt
Sugar beet pulp	1712 Tt
Molasses	880 Tt

Price	
Sugar beet	25,8 €/t
Sugar	800 €/t
Sugar beet pulp	Bis 0,25 €/kg
Molasses	Bis 5 €/ kg

Figure 14: Information on sugar beet production and relevant side streams in NRW

[39] FNR, ANBAU UND VERWENDUNG nachwachsender Rohstoffe in Deutschland, S. 15

[40] Towards aromatics from biomass: Prospective Life Cycle Assessment of bio-based aniline - ScienceDirect

Germany is the biggest sugar producer in the European context [41] with NRW as one of the major contributing federal states. The self-sufficiency rate for sugar has remained relatively constant at between 140% and 150% in recent years[42], which makes sugar an export commodity. At the same time, the production of sugar, in Germany based on sugar beet, gives rise to numerous side streams that have been in the focus of further valorization in the past. Given the large production area for sugar beet and the high production values (ca. 800 dt/ ha in 2021[43], shown in Figure 14) in NRW, side streams like sugar beet pulp, sugar beet syrup, and molasses were considered excellent feedstocks for this case-study. Bilateral meetings with experts from the local sugar industry (Pfeifer & Langen) provided useful insights and underlined the importance and the potential of side-streams from this sector. As a water rich resource, however, sugar beet pulp valorization is limited through difficulties such as transport costs or energy demand for drying or other forms of processing. This feedstock therefore has a high potential of being pre-processed locally.

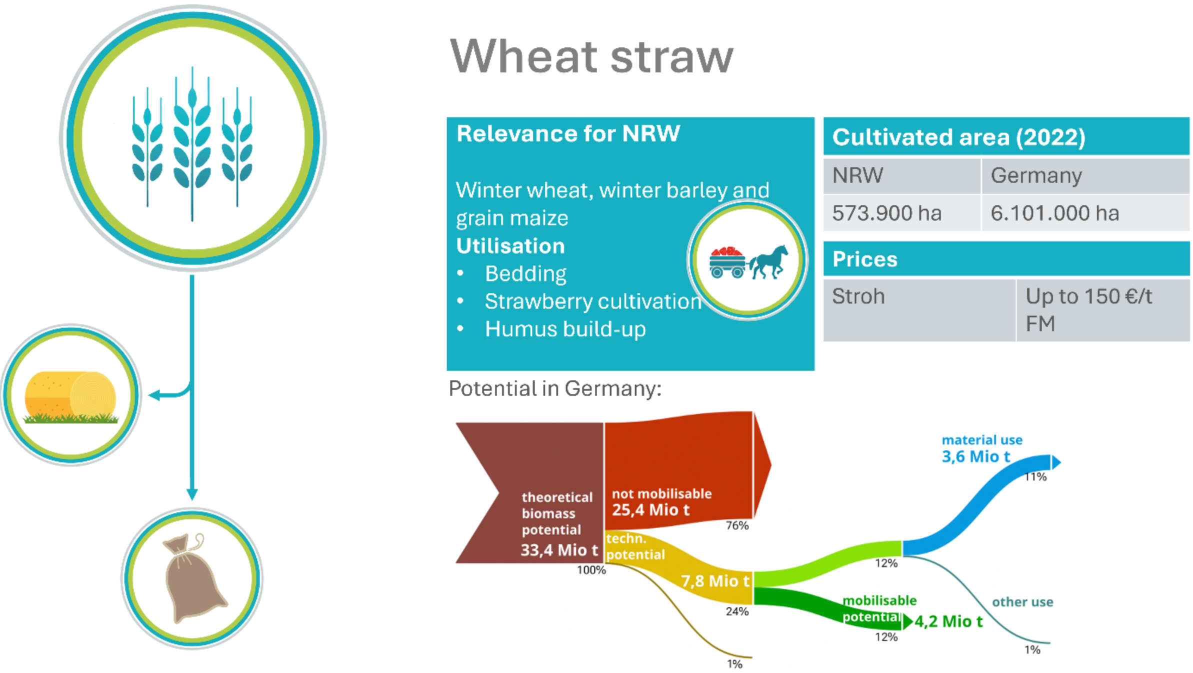


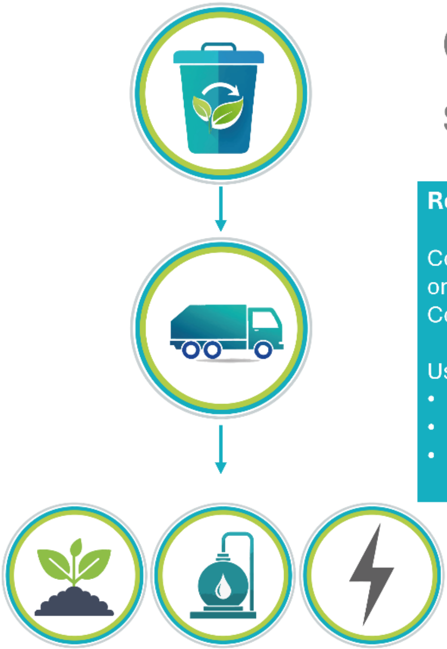
Figure 15: Information wheat production and availability of straw as a feedstock (NRW)

Other second-generation feedstocks to be considered were straw and solid fraction of municipal waste (OFMSW). Although not the biggest producer of wheat, NRW production area accounts for 573.900 ha (2022)[44] with wheat straw as the main side stream. Being sold as a bedding or in context of field strawberry production, a remaining potential for the use as a second-generation feedstock is promising. For Germany, a total of 4.2 million tons can be mobilized for these purposes (Figure 15). Detailed data for NRW is not available in the regional statistics and might be collected in the future in the course of the mentioned activities in the Rhenish mining area[45]. Interestingly, the valorization of

[41] https://cefs.org/wp-content/uploads/2022/04/CEFS-Statistics-2020-2021.pdf
[42] Bericht zur Markt- und Versorgungslage Zucker, BLE 2023
[43] Bericht zur Markt- und Versorgungslage Zucker, BLE 2023, s.10
[44] DESTASIS – Fachserien3 Reihe 3.2.1 (Artikelnummer: 2030321227165)
[45] Biomassepotenziale LANUV

hemicellulose feedstocks from straw is a well understood process and first implementations have occurred from start-ups to industrial scale and cover a product range from bulk biofuels to biopolymers. Those lignocellulosic biorefineries additionally hold a great potential in terms of regional employment and can yield interesting products to be utilized in the chemical industry[46] [47]. OFSMW contains interesting fractions for further valorization as well with some of them being collected separately by public disposal services. The waste collection system in Germany and NRW is well organized and NRW accounts for a volume of 1,92 million tons of collected OFMSW per year (2022) (Figure 16). In the EU, OFMSW is considered a mixture of biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants according to the EU Directive 2018/851. This diverse feedstock is mainly used to produce biogas, using anaerobic fermentation, the production of substrates and fertilizers via industrial waste processing units, and for its energetic value. However, several studies showed potential to produce platform chemical like succinic acid, lactic acid, or the production of production of polyhydroxyalkanoates (PHAs)[48] that are considered interesting for NRW chemical industry. As an additional pathway, the valorization of side streams of the primary production sector via insects was considered for NRW transformation pathways. This process includes the fattening of insects like mealworms (*Tenebrio molitor)* and black soldier fly larva *(Hermetia illucens)* and the processing of the inactivated and dried insects, yielding protein, lipids, chitin, and insect frass. Depending on the grade of refining and the lipid composition, insect oils can be a valuable source of functional lipids[49] [50] with applications in pet food and technical applications[51]

[46] Regional Employment Impacts of Biorefineries in the EU (wiley.com)
[47] https://news.fnr.de/fnr-pressemitteilung/gruene-chemie-polyurethane-mit-synthesebausteinen-aus-lignin (last accessed: 09.09.2024)
[48] Evaluation of organic fractions of municipal solid waste as renewable feedstock for succinic acid production (nih.gov)
[49] Microbial and insect oils: A sustainable approach to functional lipid (wiley.com)
[50] New lipid sources in the insect industry, regulatory aspects and applications | OCL - Oilseeds and fats, Crops and Lipids (ocl-journal.org)
[51] 288866 (wur.nl)



Organic fraction municipal solid waste (OFMSW)

Relevance for NRW

Collection via organic waste bin, organised by districts/cities
Commercial waste

Use:
- Composting
- fermentation/biogas, fertiliser
- Energy use: biomass cogeneration plant

Kennzahlen NRW/DE	
Emergence	1.92 M t (NRW,2022)
Composition (D, 2021)	
Organic waste bin	32 %
Garden/park waste	30 %
Agriculture/ Food processing	18 %
Food waste (HORECA)	4 %

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Figure 16: Information on the amounts and composition of OFMSW in NRW

Summarizing the information from the literature and expert interviews, mind maps were drawn in a semi-detailed form to aid in further stakeholder interactions and to prepare the multi criteria approach in the following stakeholder workshop. In general, the mind maps were structured in three sections including feedstock and preprocessing steps, the conversion (fermentation/ conversion via insects) and refinement and synthesis steps to yield final products.

For the next step, the multi actor approach including the multi criteria analysis, regional stakeholders were invited to review the collected pathways. The invitation for this workshop considered stakeholder with 1) knowledge of secondary feedstocks, 2) knowledge of products with impact for the chemical industry, 3) representatives of SMEs for the involvement in the pathway implementation, and 4) stakeholders with knowledge on tech transfer from academia and innovation networks. The workshops' structure included an introduction of the project BIOTRANSFORM, a presentation of the opportunities and challenges for NRW and the indicators derived from it as well as the considered feedstocks, conversion routes and possible products of the predefined transformation pathways.

Experts from the following sectors worked together on the co-definition of the transformation pathways:

- Research centers
- Academia
- Agricultural consulting
- Food and food tech network
- Food industry network
- Innovation management and sustainable business development
- State agency for energy and climate protection
- Regional development agency

The co-creation process of the considered feedstocks (Figure 17) met the interest of the regional stakeholders and sparked interesting discussion about possible mobilization and availability of biogenic feedstocks. Sugar beet cultivation has a special position in this context. Cultivation volumes and attractiveness are strongly linked to the price of sugar and are subject to the sugar market organization in Germany. Additional added value through the utilization of by-products can be an additional incentive and prevent farmers to switch to producing other agricultural products instead. The group commented on sugar being only one valuable ingredient of sugar beet and emphasized the importance of also using the other ingredients as materials. Dissolved substances in the process water of beet processing and sugar production can also be utilized in the future.

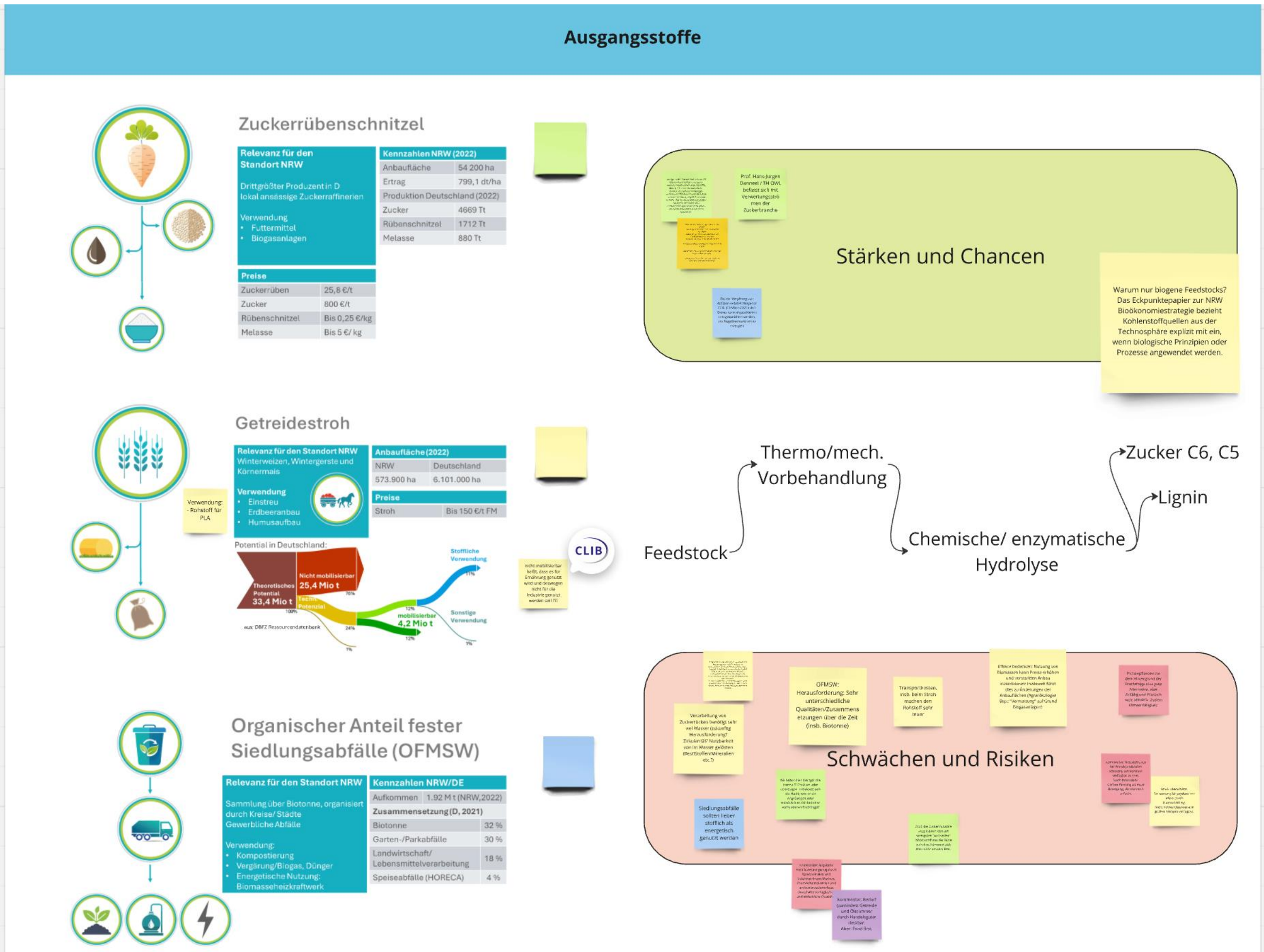

Figure 17: Miro online whiteboard-guided feedstock co-creation exercise in the stakeholder workshop of the NRW case-study.

While the outlook for the available quantities of wheat straw due to the increasing cultivation of wheat and comparable crops was seen as positive, it was emphasized that a proportion of this must also remain in the fields to form humus. This proportion must be kept in mind for all crops to ensure the fertility of the soil, especially with increasing production volumes. The discussion about the utilization OFMSW was dominated by regulatory challenges. OFMSW may still be classified as waste, subjecting it to stringent waste management regulations, rather than being recognized as a valuable feedstock for bioenergy or bioproducts. Establishing clear end-of-waste criteria for OFMSW is crucial for its utilization in biorefineries. Without defined criteria, the transition from waste to a usable resource can be hindered, affecting investment and operational decisions. In general, the group was agreeing on the unused potential of material utilization compared to energy utilization. However, the heterogeneity of OFMSW was pointed out as a major drawback that would have to be considered.

One issue connected to all feedstocks was connected to transport. While the infrastructure for the transport of the discussed feedstocks exists in the context of current utilization, alternative models will always incur additional costs due to transport, which stand in the way of profitability above a certain threshold value. However, local valorization or preprocessing steps, such as those partially integrated in sugar beet processing plants, are a great opportunity for such concepts.

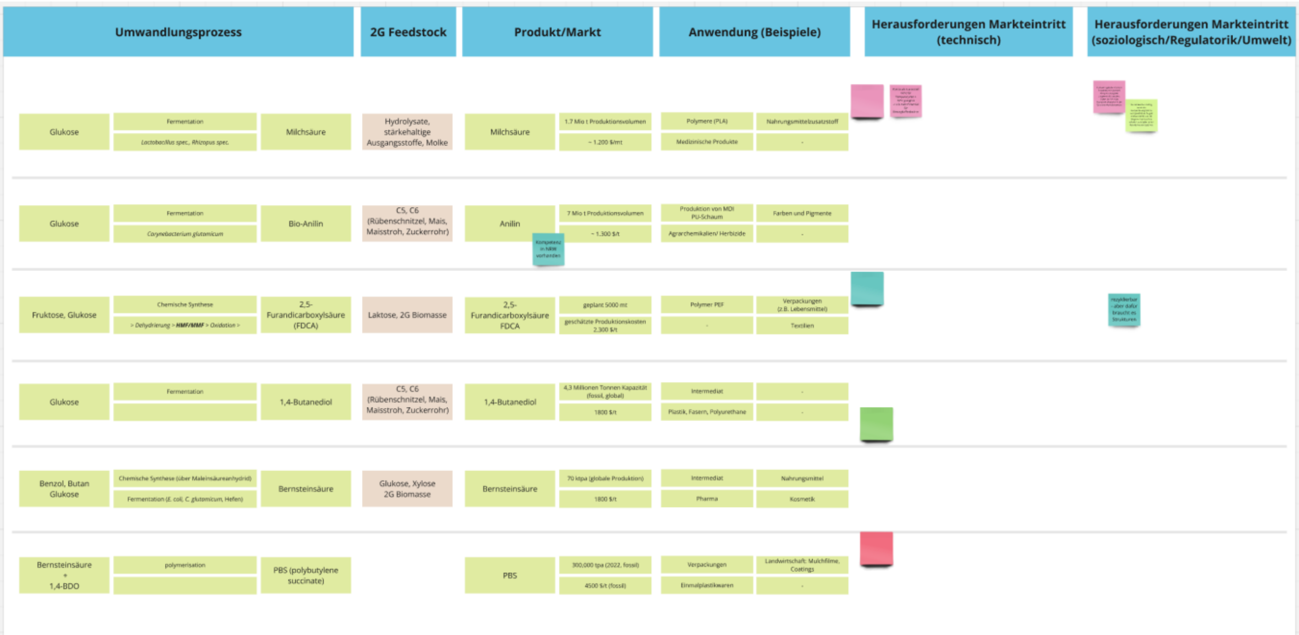

Figure 18: Miro board guided product co-creation in the stakeholder workshop of the NRW case-study.

The co-creation process of choosing products with the biggest impact for the chemical industry was more difficult. Despite the broad invitation, representatives of relevant industries and SMEs were absent, meaning that the assembled stakeholders did not have sufficient knowledge of industrial processes and the technical maturity of suitable processing routes. The products discussed were lactic acid, aniline, 2,5 furandicarboxylic acid (FDCA), 1,4 butanediol, succinic acid, and polybutylene succinate (Figure 18) and were identified as relevant for the NRW chemical industry as predefined via literature and expert interviews. Most of these products can be produces via fermentation and/or chemical synthesis based on first-generation biogenic feedstocks. The production on the basis of second-generation feedstocks, as discussed in the first part of co creation, is still hampered by a lack of feasibility and more research and industrial initiative is required. A valuable connection was, however, made to the cascading use of the structural components of plant-based feedstocks, as pectin and lignin (both structural component in plant cell walls) are considered valuable resources for several applications in the i.e. food industry or the polymer chemistry, respectively.

Instead of focusing on the chemical products, the co-creation moved one step further and challenges in the implementation were discussed. Here, the experts could provide valuable input. The importance of use cases and success stories was underlined as they create an additional incentive for the industry to shift to a stronger use of biogenic feedstocks. In turn, the market leading industry was named to carry the responsibility to spearhead the transformations as they can create the necessary impact on national and international markets. At the same time, the resource demand of the chemical industry is immense, meaning that the utilization of regional resources would need to be supported by international trade. On the regional level, knowledge transfer between the primary sector and the academia and SMEs should be fostered to create local solutions that are not too strongly influenced by negative factors such as transport costs. The strength of the bioeconomy is its multi-disciplinary character which includes all stakeholders along the value chain.

Following the co-creation workshop, bilateral meetings with industry experts were scheduled, to obtain the missing input and get commitment to providing the data necessary for the assessment tools. The three pathways were defined that match the technical readiness and could be considered for an implementation in the near future. They also address the request for more success stories, as had been voiced in the co-creation workshop. These pathways are depicted in Figure 19.

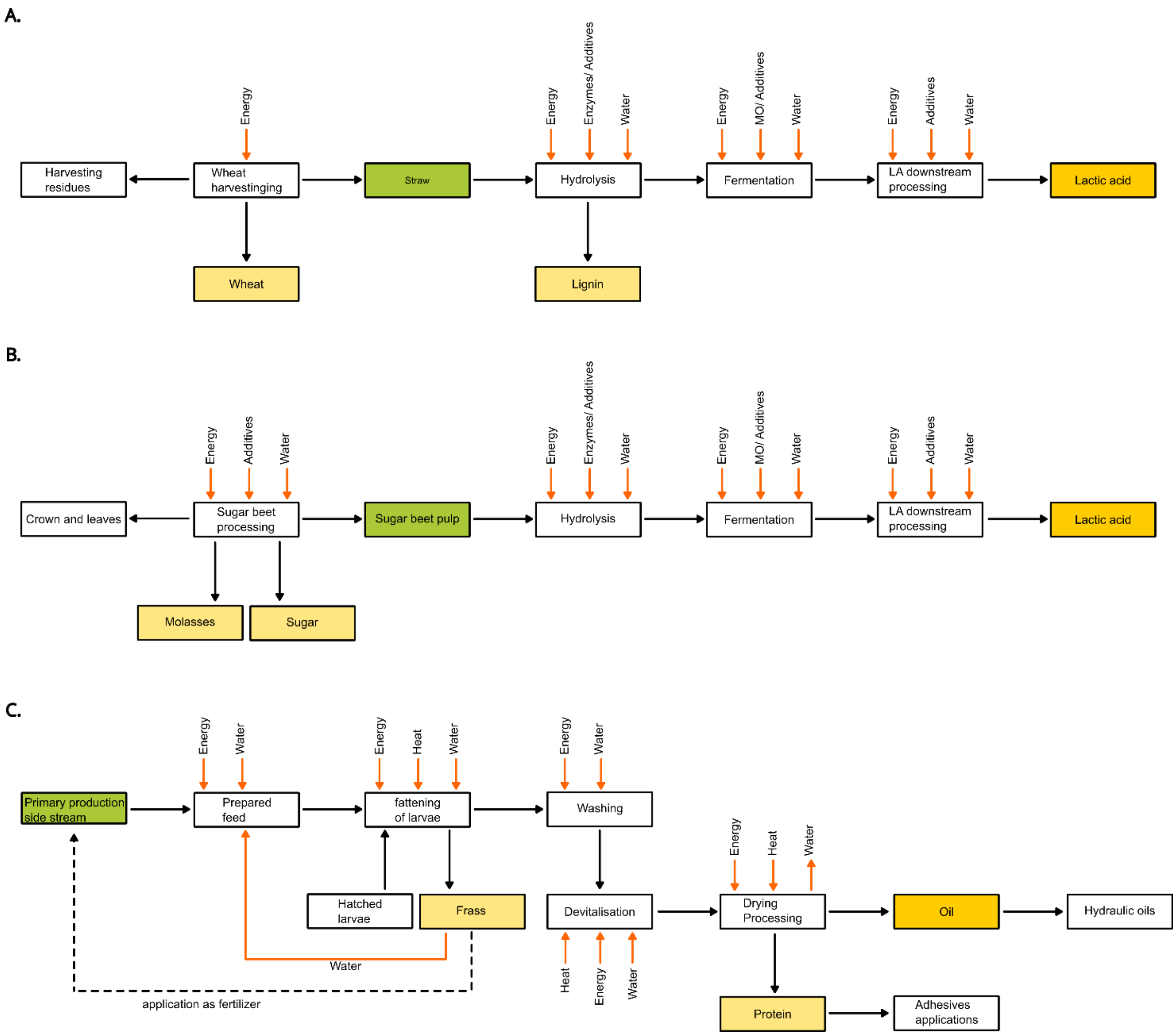

Figure 19: The three defined pathways for the NRW case-study.

A. Valorization of straw to lactic acid. B. Valorization of sugar beet pulp to lactic acid. C. Conversion of primary production residues to lipids using black soldier fly larvae

As both sugar beet pulp and wheat straw were feedbacked as raw materials of high valorization value, these were considered or the pathways. As a connection of these feedstocks, the process of utilization includes a certain amount of mechanical and thermo-chemical preprocessing and the (enzymatic) hydrolyzation to yield fermentable sugars, the latter being one of the cost intensive parts of the process. Suitable products and therefore needed production chassis for the conversion were discussed in more details with experts from TU Munich, as Bavaria and NRW share similarities in terms of agricultural practices and the agricultural framework for sugar beet and wheat production. The bilateral discussion found the transformation route of sugar beet pulp to lactic acid (LA) the most promising path. Sugar beet pulp is a water rich substrate that already includes compounds that have a positive influence in the fermentation process. 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. As the production of LA depends on fungi and lactic acid bacteria as the producing organism, straw was also considered as a lignocellulosic feedstock to yield fermentable sugars for the process.

After the stakeholder workshop the utilization of OFMSW was discussed with experts from the industry of insect protein production. First applications in this field aim for the production of insect protein and lipids to be used in pet food. However, regulations are limiting the feedstock availability for food and feed applications. As insect lipids show interesting lipid profiles, technical use has long been the subject of research. The pathway analyzed in BIOTRANSFORM focuses on the transformation of residues of the primary production via the black soldier fly to yield lipids for technical lubricants. This can help reduce the amounts of fossil-based lubricants. As a major byproduct of this conversion route is insect protein, technical application in adhesives could also be considered. While the fattening and processing of BSF larvae in a centralized unit is an option (and established in case of the participating company), the use of decentralized units at the production sites of primary producers are an interesting concept to reduce transportation costs. The logistic concept of this use case is already being analyzed in another funded project and will not be part of the MooV tool analysis. The results however can be communicated as a part of the implementation strategy in the stakeholder engagement (Task 3.3) to support the use case. The concept of the decentralized units for larvae fattening and further processing in a centralized unit (Figure 19, C) can be an additional added value for local primary producers and an alternative for the installation of biogas plants.

For the NRW case-study the combination of co-creation and bilateral meetings led to a selection of three pathways of high relevance for the region. While the conversion of SBP or straw into LA is a known process, the industrial implementation is still lacking. Processes using fermentation for LA production generally use sugar as a feedstock. The switch to second-generation feedstocks is a challenge that is not fully solved and the analysis in BIOTRANSFORM can help identify chokepoints for the regional success of this transformation pathway. Similarly, the full utilization of OFMSW suffers from regulations and heterogeneity issues. Insects as the converting factor might be a part of the solution. However, based on the German Biowaste Ordinance (Bioabfallverordnung)[52], the conversion of biowaste via insects would be subject to certain regulations. While the valorization on biogas plants is already covered by legislature, insects as a relatively new conversion platform for

[52] Bio-waste Ordinance – BioAbfV

bio-based feedstocks are not mentioned in ordinances. The presented case can be a step towards the urgently needed amendment of the ordinance and thus a more effective utilization of waste.

Next steps will be the assessment of the presented cases with help of the tools of the BIOTRANSFORM assessment package followed by the selection of the most promising transformation pathway by expert stakeholders.

3.5.3 *Experiences with the co-definition approach*

The co-creation approach as proposed by the task 3.2 lead in the BIOTRANSFORM project generated interesting insights and valuable information from practitioners. These would not necessarily have been recovered in a top-down approach or desk research. Several challenges were encountered, such as the availability of relevant stakeholders. Due to several similar projects and initiatives currently underway, these are invited to several workshops and especially industry experts are not able to commit enough time to actively participate in all of them. Another challenge was the fact that the evaluation of the most promising transition pathways and especially their assessment via the BIOTRANSFORM toolbox requires sensitive business data, which experts were unwilling or not able to divulge. Both challenges were in part overcome by a modification of the co-definition approach, including more bilateral discussions. The question of data availability for the assessment however, limited the choice of pathways evaluated further in the project. Nevertheless, the three pathways chosen represent major transformation chances for NRW.

3.6 Western Macedonia (Greece)

3.6.1 *Identification of key indicators*

To identify key indicators for the Western Macedonia region, we conducted a thorough examination of regional characteristics and engaged with a range of experts, including local actors and stakeholders as well as policymakers. These interactions provided essential insights into the region's ongoing decarbonization efforts and helped shape our understanding of its transition strategies.

The mind map that was created for the next step to visualize all the possible pathways, and the circularity helped us see all the interactions and all the connections to start identifying the key indicators. Then, we conducted a thorough search of available data specific to the region based on the bioeconomy indicators by the European Commission, focusing on various indicators that could reflect the progress and impact of our proposed pathways. This data-driven approach ensured that our indicators were grounded in real-world evidence and relevant to the regional context. The indicators are shown in Table 11.

Table 11: Relevant indicators for the Western Macedonia case study (Greece)

Headline indicator / category	Case-study-specific refinement	Unit
Management of primary production	Ratio of annual fellings	[m3/ha/year]
	Net annual increment	[m3/ha/year]

Headline indicator / category	Case-study-specific refinement	Unit
Emissions from primary production	Net GHG emissions (emissions and removals) from LULUCF	[kg CO2 eq]
Value-added from primary sectors	Value-added per sector	[million €]
Employment in primary sectors	Persons employed per bioeconomy sectors	
Production of biomass	Roundwood removals	
	Ratio of annual fellings to net annual increment	[m3/ha/year]
	Fraction of primary residues remaining in forest	
Value-added from secondary sector	Value-added per sector	[million €]
Employment in secondary sectors	Persons employed per bioeconomy sectors	
Use of Biomass	Biomass consumed for materials	[ktons]
	Biomass consumed for energy	[ktons]
Environmental	SOx, NOx	[ppm]
	GHG emissions (during hydrogen production, during hydrogen use as a fuel)	[kg CO_2 eq]

Finally, the analysis of the criteria table, which is currently in progress to validate the pathways, will help in evaluating the potential indicators against set criteria, ensuring that the chosen indicators are robust, relevant, and capable of accurately tracking the region's progress in its decarbonization journey. The whole procedure is depicted in figure 20.

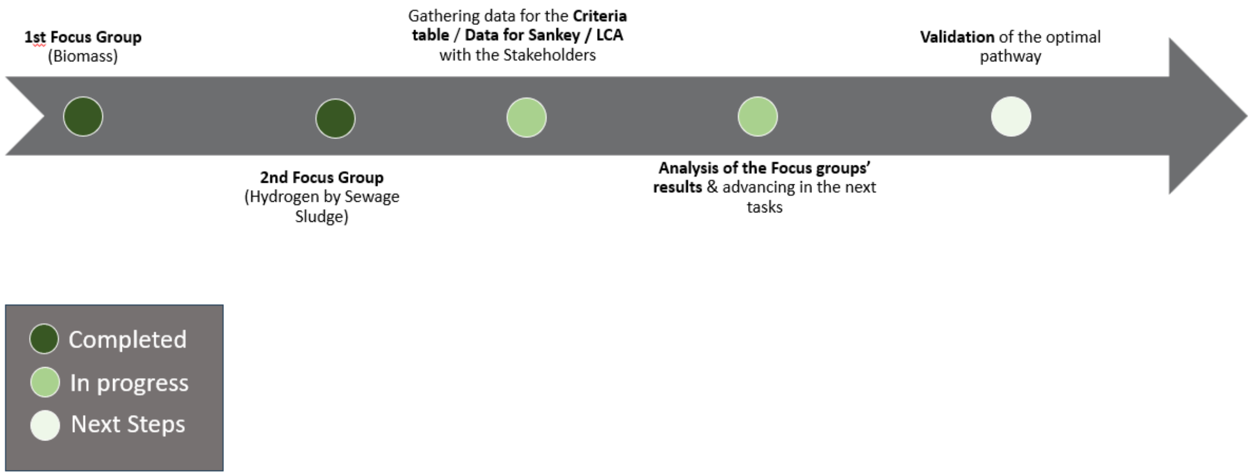

Figure 20: Pathway co-definition for the Western Macedonia case study (Greece)

The economy in the Western Macedonia region has long been reliant on fossil-based energy production, spanning over 70 years. However, the current shift towards decarbonization presents significant challenges, making it essential to explore sustainable energy alternatives. This case study is crucial as it examines the transition from sewage sludge to hydrogen production, offering a potential business model that could serve as an effective pathway for the region. By analyzing an innovative and sustainable sewage sludge valorization system, the project aims to innovate hydrogen production. This system is designed to incorporate additional raw materials to boost biogas production, showcasing a comprehensive approach to renewable energy generation.

In addition to sewage sludge, the case study investigates the scaling-up of the use of the region's abundant wood biomass as an alternative feedstock. This biomass can be processed into pellets for bioenergy or medium-density fiber boards (MDF) for the wood industry, illustrating the potential for diversified local resource utilization. The Western Macedonia case study highlights the critical need for exploring various energy transition pathways to ensure a sustainable future for the region, which has been adapting and evolving in recent years.

To effectively measure the impact and success of these initiatives, the selected indicators focus on both environmental-economic and social-economic aspects. Key indicators include biomass use and production, greenhouse gas (GHG) emissions, and employment rates in the primary and secondary sectors. The emphasis on environmental-economic indicators reflects the project's goal of achieving significant energy generation capacity to facilitate the energy transition while minimizing environmental impacts. These indicators provide a comprehensive overview of the project's contribution to reducing GHG emissions and promoting sustainable biomass utilization.

On the social-economic front, employment is a major challenge for the region, especially as the energy sector transitions away from fossil fuels. The project aims to address this need to provide training and upskilling opportunities for workers who may fear job displacement. By equipping the workers with the skills needed for new jobs in the bioeconomy, the workforce can be effectively relocated to roles related to new energy generation methods. This focus on human capital is crucial for maintaining social stability and economic resilience during the transition.

In summary, the selected indicators are vital for capturing the multifaceted impact of the case study, linking environmental sustainability with economic viability and social equity. They reflect the region's unique characteristics and challenges, emphasizing the importance of a holistic approach to the energy transition in Western Macedonia.

There were no significant changes to the indicators selected previously. At the moment, data is being gathered to support the conclusion of the analysis for the criteria table and Sankey diagrams. Focus is given to create a Sankey diagram where loops are closed. For this purpose, preliminary analysis was conducted based on the mind map created on a previous step. The Western Macedonia case study has data that complete the needs for the Life Cycle Assessment – LCA in the production step. Nevertheless, to complete the steps regarding its Life Cycle, data for other steps are being searched and this might lead to a slight change in the indicators in the future. The actors and stakeholders whose input we sought are experts from universities and companies, as well as policy makers.

3.6.2 *Co-definition of optimal transition pathways with regional actors*

The process of co-defining the region's pathways for Western Macedonia involved several methodical steps (depicted in Figure 20) to ensure comprehensive and relevant selection. Firstly, we identified some key stakeholders, local actors, policy makers, experts and industry representatives and had discussions with them for the decarbonization efforts being made in the region. Those discussions provided a foundational understanding of the region's transition initiatives.

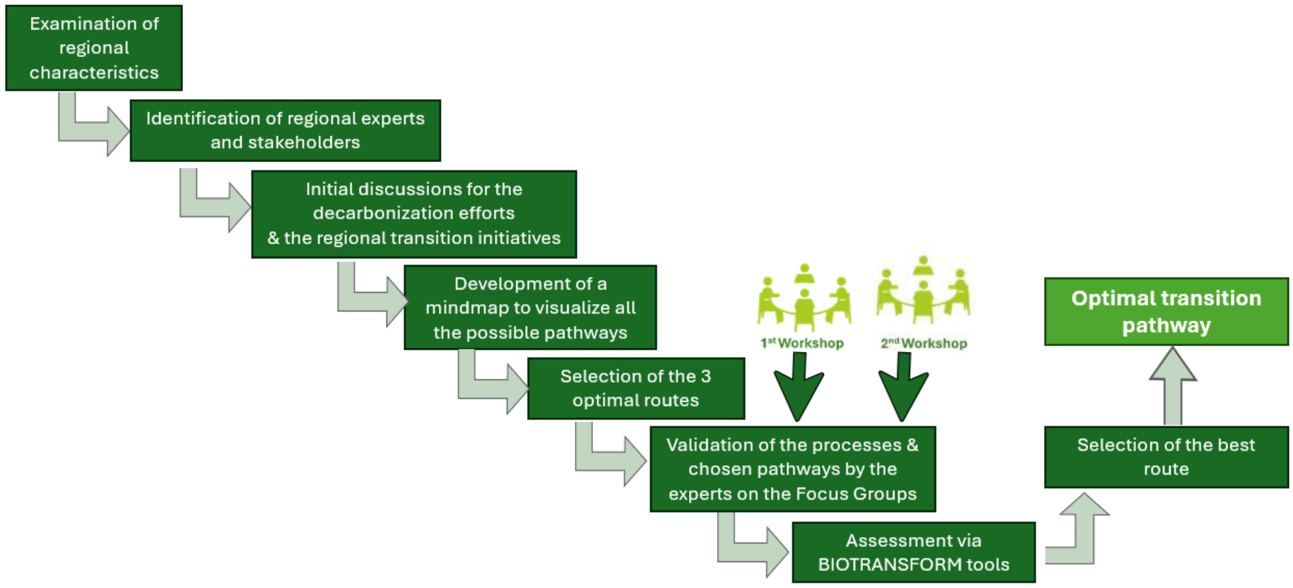

Figure 20: Co-definition of optimal transition pathways, Western Macedonia case study (Greece)

To enhance our understanding and visualization of the possible pathways for circularity, we created a detailed flowchart on resource availabilities with analysis of several value chains and emphasis on the return of nutrients to the forest (mind map-Figure 21). Also, a Miro board with sticky notes was created to help the knowledge exchange about current practices and their actors, perceived challenges, opportunities, current market trends, possible synergies and funding during the focus groups meetings that were organized. The mind map helped us see the interconnectedness of various processes (inputs and outputs) and identify critical points where interventions could be most effective.

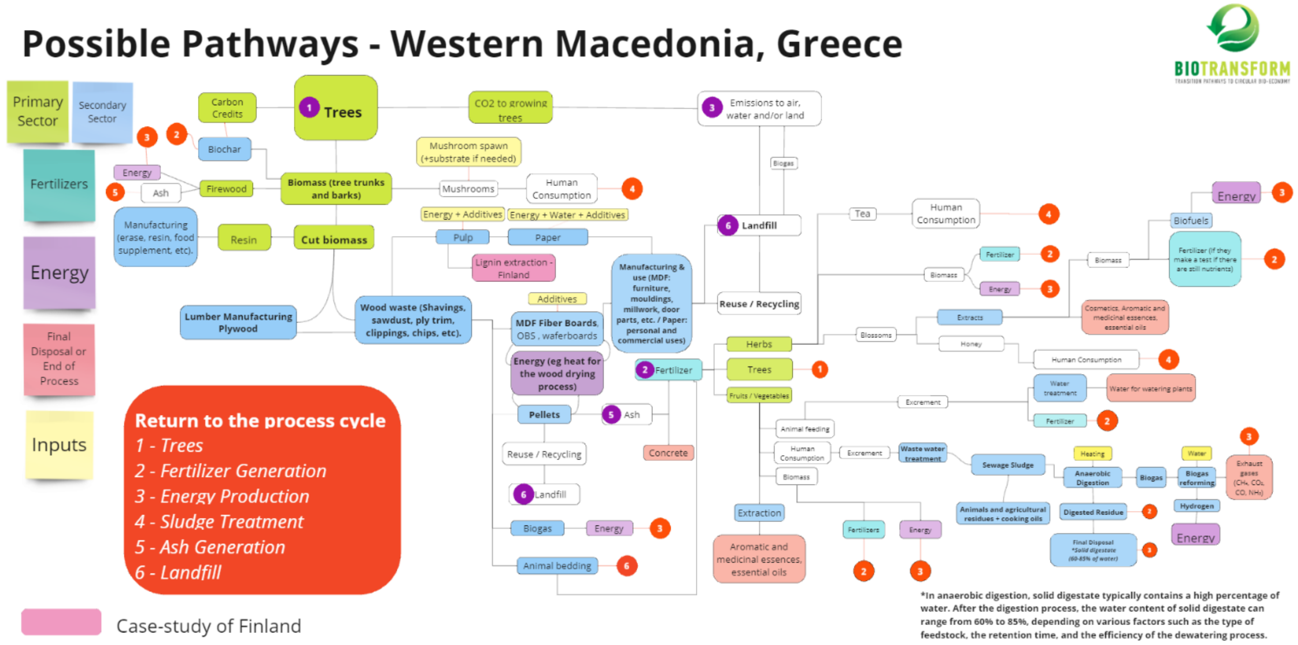

Figure 21: Mapping of the possible pathways for circularity on the Western Macedonia case study (Greece) through Miro. Selected routes depicted in bold.

During the next steps, we organized discussions on two separate focus groups, bringing together experts specializing in wood biomass and hydrogen production to evaluate the proposed pathways. The experts participated for deeper understanding and evaluation of the social, environmental, and economical aspects of these pathways, with a destination of the definition of the one pathway that has the most benefits for the region between the three proposed. These sessions provided valuable insights and allowed us to capture a diverse range of expert opinions and recommendations along with the validation of the proposed pathways via the analysis of a criteria table which is currently in progress to validate the pathways.

For the first focus group we invited experts in wood biomass including representatives from universities, associations of biomass and industries. For the second focus group, we invited regional experts in the hydrogen production by sewage sludge who are partners of Cluster of Bioeconomy and Environment of Western Macedonia (CluBE) and some of them participated actively in the study with the waste management company of Western Macedonia (DIADYMA).

The stakeholders provided an actual overview of the pathways, the final use and destination, policy challenges, actual and possible future social, environmental, economic impact, and aspects, as well as the possible paths to guarantee the circularity. All these points will be analyzed in a report and a comparison between all the results will be done to define the pathway with the most positive characteristics among the three.

There are ways in which the existence of centralized or decentralized refineries affects the case study. Stakeholders pointed out the following during the focus groups:

For the wood biomass:

- A holistic approach must be applied to both the way the biomass is transported and the way it is collected in order to obtain a sufficient quantity and make transport profitable, a sufficient size and composition to obtain the desired overall result. There is a problem because wood residues have a very low spatial density. The amount of these materials that can be transported by ordinary means of transport is too small, so that the value of the ton-kilometer (how much it costs to transport a ton for a kilometer) is greatly increased. Either we have to limit to short distances for collecting these materials or to suitable means of transport that e.g. pre-compress the material or remove their moisture. Otherwise, the cost of acquiring the raw material is so high that it makes the production of the final product prohibitive.

- Supply chain problems arise when the costs involved in either transport or utilization exceed the cost of direct consumption or the cost of using alternatives e.g. if a lot of oil must be consumed to transport biomass residues to make pellets and use them as a substitute for fossil fuels, this may not be profitable in the end. The cost per kilometer of transport for each specific biomass use should be calculated.
- Since we are talking about circular economy, the term “waste from a process” no longer applies. We must therefore ensure that we sort at the source, e.g. that forests are cleaned based on end use, pre-sorted and that the absolutely necessary raw materials are transported without transporting materials that add to the transport costs, as if no sorting is done, the costs are simply transferred to the next process. Better management exists when we have the possibility of parallel management e.g., transporting the biomass to a plant that can make both MDF and pellets in parallel. Management often depends on how ready and versatile the end user is. We need to investigate the real needs and the potential of the Greek market e.g., whether large investments are needed to exploit biomass of higher added value. First, we need to establish criteria for prioritizing needs so that we can see in the end which is the most preferable utilization, which is the second most preferable, etc.
- A small installation will have higher costs than a larger continuous flow installation. It is natural that the more production you have, the lower your production costs. There is a big range of the scale. For example, Alfa wood produces almost 40 times more tons than the Energy Community of Karditsa. Small industries that produce 1,000-1,200 tons of pellets per year should not only be concerned about increasing production per se but about how to increase the things they can do with that product.
- There is for sure a logistics problem and the use of MooV tool might be able to help the current situation. A meeting will be scheduled soon to discuss this with stakeholders. The concept of connected biorefineries and resource valorization routes is critical for the Western Macedonia region as it undergoes economic and environmental transformation. Historically dependent on fossil-based energy, the region needs to diversify its economy, and biorefineries offer new revenue streams and job opportunities by transforming local biomass into valuable products like green hydrogen and bioenergy. This transition supports sustainable development, enhances energy independence, and contributes to environmental restoration by efficiently utilizing local resources and reducing waste. Additionally, aligning with European renewable energy initiatives, this approach attracts funding and investment, fostering research and innovation, and positioning Western Macedonia as a leader in the bioeconomy.

For the hydrogen production:

- They haven’t examined the logistics. They believe that the collection of sewage sludge in a decentralized manner would be possible, but the production of H_2 in small units would be far more expensive and would incur significant logistics costs for H_2 production and transport to the end user.

Producing green hydrogen from sewage sludge has already been examined by the waste management company of Western Macedonia (DIADYMA), and a study has already been completed. The study outlines a comprehensive plan to utilize anaerobic digestion of sewage sludge to produce biogas, which is then converted to hydrogen. The study examined the use of hydrogen to fuel a fleet of 12 garbage trucks, aiming to significantly reduce carbon emissions. According to this study, this procedure is expected to generate substantial economic savings for local municipalities by reducing sewage sludge disposal costs and fuel expenses. The initiative aligns with regional and national goals for decarbonization and promotes sustainable waste management practices, contributing to a greener economy.

This production seamlessly aligns with the concept of connected biorefineries and the interconnection of resource valorization routes. This approach exemplifies the integrated resource utilization at the heart of connected biorefineries. By using sewage sludge, a material traditionally regarded as waste, as a valuable feedstock for hydrogen production, we enhance resource efficiency and significantly reduce waste. This integration supports circular economy principles by converting waste into a valuable product, thereby closing the resource utilization loop. The process also allows for the recovery of nutrients and other valuable materials from the by-products of hydrogen production, contributing to a holistic resource management approach.

Connected biorefineries benefit from the ability to process multiple types of biomass and waste, creating synergies between various processes. For example, a biorefinery could handle sewage sludge for hydrogen production while simultaneously processing other organic wastes for biogas or bioethanol, optimizing overall resource use. This setup leads to multiple output streams, enhancing economic viability and sustainability by producing hydrogen alongside co-products.

Moreover, interconnected value chains within a biorefinery optimize energy and material flows. Excess heat from hydrogen production can be utilized in other processes, improving overall efficiency. This interconnection also supports sustainability by reducing the environmental impact, cutting down on reliance on fossil fuels, and mitigating pollution from waste disposal.

The innovative and flexible nature of connected biorefineries allows them to adapt to different feedstocks and produce a variety of bio-based products. This adaptability fosters innovation and enhances the sustainability of resource utilization, making the production of green hydrogen from sewage sludge a prime example of how connected biorefineries can interlink various resource valorization routes to promote a more sustainable and efficient use of resources.

In conclusion, two focus groups sessions with experts of wood biomass and hydrogen production were conducted. The first meeting with the wood biomass experts indicated that the scaling-up of the pellet and MDF production using the excess wood biomass of the region would be possible but needs many changes to be profitable and worth the investment. The second focus group with the hydrogen production experts provided very promising data based on a study already conducted. This pathway seems to have very good prospects. However, experts will still need to answer some written questions and fill the criteria table, to confirm that this will indeed be the preferred pathway for the Western Macedonia case study.

After the definition of the main pathway, the planning of the feedback loops will be done, followed by a meeting with the policymakers and other stakeholders for gathering feedback.

3.6.3 *Experiences with the co-definition approach*

Engaging stakeholders effectively has proven to be a challenge, requiring numerous meetings to discuss all relevant subjects. Despite these efforts, it has been difficult to ensure active participation from all parties. Additionally, the lack of numerical data has hindered the ability to examine all proposed pathways in depth. While some data is available, it exists only at the national level, making it difficult to address regional-specific concerns.

4. Summaries of the regional case studies

4.1 Comparison of the key indicators chosen in the regions

Comparing the chosen key indicators of the five regions, it is evident that each region started with the headline indicators and refined them to a subset which best represent its trajectory towards a circular bioeconomy. All regions chose at least seven indicators (Finland), with a maximum of 23 (Charles Spa).

Some indicators are dictated by the transformation pathways and feedstock base chosen by the region, such as the focus on food waste in the Charles Spa region, or the focus on production of biomass in Andalusia, Northern Burgenland, and NRW. Others reflect the emphasis placed by local stakeholders and potentially regional policymakers, such as the focus on employment in the secondary sector (all case study regions except Finland), or value-added from secondary sectors (all case study regions except Finland). The indicator of emissions, either from primary or secondary sector was chosen by three regions (Northern Burgenland, NRW, and Charles Spa), while the Finnish region chose a more specific emissions indicator as forest-based GHG emission. This is perhaps not surprising, since emissions in CO_2eq are often taken as a general indicator of environmental sustainability.

The indicator chosen by all five regions was “use of biomass,” which is indeed the premise of the BIOTRANSFORM project.

4.2 Comparison of the favored transition pathways in the regions

Each region identified a locally important feedstock and elaborated a range of potential valorization routes. Table 12 presents an overview of the various conversion routes currently under evaluation in the case study regions. These examples include diverse approaches to valorizing local biomass resources across Europe.

- Andalusia capitalizes on olive pruning debris and pomace to produce polymers, antioxidants, and reinforced polymers, focusing on high-value bioproducts from agricultural residues.
- Charles Spa focuses on utilizing food waste to produce biogas and compost, reflecting a waste-to-energy and recycling strategy.
- Finland emphasizes the use of lignin, a by-product from forestry, for advanced applications like anode material in batteries, showcasing high-tech uses of biomass.
- NRW shows a versatile approach, using sugar beet pulp and straw for lactic acid production, while food waste is repurposed for insect oil and lipids, indicating a strong focus on bio-based chemicals and waste reuse.
- Western Macedonia utilizes wood biomass for traditional products like wood pellets and MDF boards, and transforms sewage sludge into hydrogen, aligning with both energy production and resource recovery.

These choices reflect different region-specific strategies where local feedstocks are utilized for innovative and varied bioeconomy applications, from energy production to advanced materials.

Table 12: Overview of the conversion routes currently under consideration in the case study regions.

Region	Feedstock	Product
Andalusia	Olive pruning debris	Reinforcement of polymers
Andalusia	Olive pruning debris	Polymers
Andalusia	Olive pruning debris	Antioxidants
Andalusia	Olive pomace	Antioxidants
Charles Spa	Food waste	Biogas
Charles Spa	Food waste	Compost
Finland	Lignin	Battery material
Finland	Lignin	Adhesive
Finland	Lignin	Plasticizer
NRW	Sugar beet pulp	Lactic acid
NRW	Straw	Lactic acid
NRW	Food waste	Insect oil, lipids
Western Macedonia	Wood biomass	Wood pellets
Western Macedonia	Wood biomass	MDF boards
Western Macedonia	Sewage sludge	Hydrogen

5. Conclusion

In BIOTRANSFORM, six different case-study regions across Europe took on the task of driving the transformation towards a bioeconomy in their respective region. Based on a solid database, which was created through intensive desk research in work package 1, the partner defined in task 3.1 region-specific indicators that are suitable for monitoring the progress of the transformation and can communicate the benefits of such a development clearly and comprehensibly to stakeholders and decision-makers. This process started from a common, EU-wide accepted set of indicators and went through a refinement of indicators, adapting them to each region via stakeholder discussions and research. Although the different case-study regions have different backgrounds in terms of industry, energy supply, economic performance, and sustainability commitment, their chosen indicators show an alignment with European standards and strategies for climate neutrality and sustainability.

In addition to the indicators, each individual case-study regions selected possible transformation pathways to replace or supplement linear (fossil- or bio-based) value chains with circular, bio-based value networks. Based on the BIOTRANSFORM methodology, all case-study regions were able to identify numerous pathways based on the data collected and further expert discussions. These were subsequently evaluated for their relevance and implementation potential using the BIOTRANSFORM multi-actor approach in co-definition workshops. This approach has revealed a range of challenges and experiences related to stakeholder engagement and data availability so that slight adaptations to the methodology were needed to collect the relevant feedback and motivate stakeholders to be part of the pathway implementation process.

The highly technical detail of the transformation pathways could be effectively broken down by the color-coded multi-criteria approach, which supported the evaluation of industrial processes by non-technical stakeholders. While these tools proved effective in promoting objective evaluations, challenges remained in accurately assessing economic aspects, underscoring the need for careful guidelines in their application.

A notable challenge across the experiences was stakeholder engagement. While stakeholders expressed high motivation during the workshops, contributing relevant content to the discussions, some entities relevant to the implementation were often reluctant to share sensitive business information or commit to implementing proposed transformation pathways. This hindered an early assessment of promising pathways by the BIOTRANSFORM tool kit and required reliance on public information, complicating discussions around financial considerations.

At the point of writing of this deliverable, each case-study region (with exception of Northern Burgenland) has identified three potential transformation pathways based on regionally available biogenic resources. These pathways are based on the economically dominant industries of the regions, but in some cases also break completely new ground for the valorization of side streams. It has been shown that novel approaches, such as the use of lignin in battery anodes, can make it possible to redefine side streams previously seen as low-value by using them in high-tech applications. These novel and highly specialized application examples have a high replication potential in economically similar European regions. Overlaps were also found within the BIOTRANSFORM case studies. The use of biogenic waste, such as residual streams from the primary sector and food waste from households and the hospitality industry, was identified as a common denominator in all regions. The selected solutions reflect the current political and socio-economic orientations of the individual regions. Both the regions Charles Spa and already NRW utilize food and other biogenic waste for energy, in industrial composting, and in the form of biogas plants. The challenge to find further material uses of this biogenic resource shows that holistic approaches are required in order to involve various stakeholders, decision-makers and the public. Only via this approach can regulatory hurdles be overturned and legislation enabling or supporting the innovative solutions (for example around end-of-waste definitions or cross-border collaboration on waste utilization) can be put in place.

In conclusion, the co-definition approach with multiple actors applied in the project offered a promising framework for stakeholder engagement and collaborative decision-making. The methodology of pathway identification and optimization proved to be a robust tool for all case-study regions. Depending on the focus of the pathways and the availability of experts, minor changes had to be made. This included, for some cases, several bilateral expert meetings and intensive literature research. While this might be a hurdle that similar EU regions might face when replicating this approach, it is part of the holistic nature of the BIOTRANSFORM methodology. Apart from this, the case study regions made good experiences with the multi actor approach, especially when engaging non-technical stakeholders. Their participation in choosing selected pathways from a larger set was well received and the discussions revealed interesting facts about the broader view of the regional bioeconomy readiness and personal involvement of the stakeholders. The use of MMA approaches such as the one used here therefore harbors great potential for replication in other EU regions. The case-study regions will now assess the chosen pathways using the BIOTRANSFORM tool kit, leading closer to the decision on the most beneficial transformation pathway. This deliverable therefore marks a mid-point in the regional transformation pathways as suggested by the project. The BIOTRANSFORM consortium already started task 3.3 which will bring together stakeholders necessary for the successful industrial implementation.

Annex

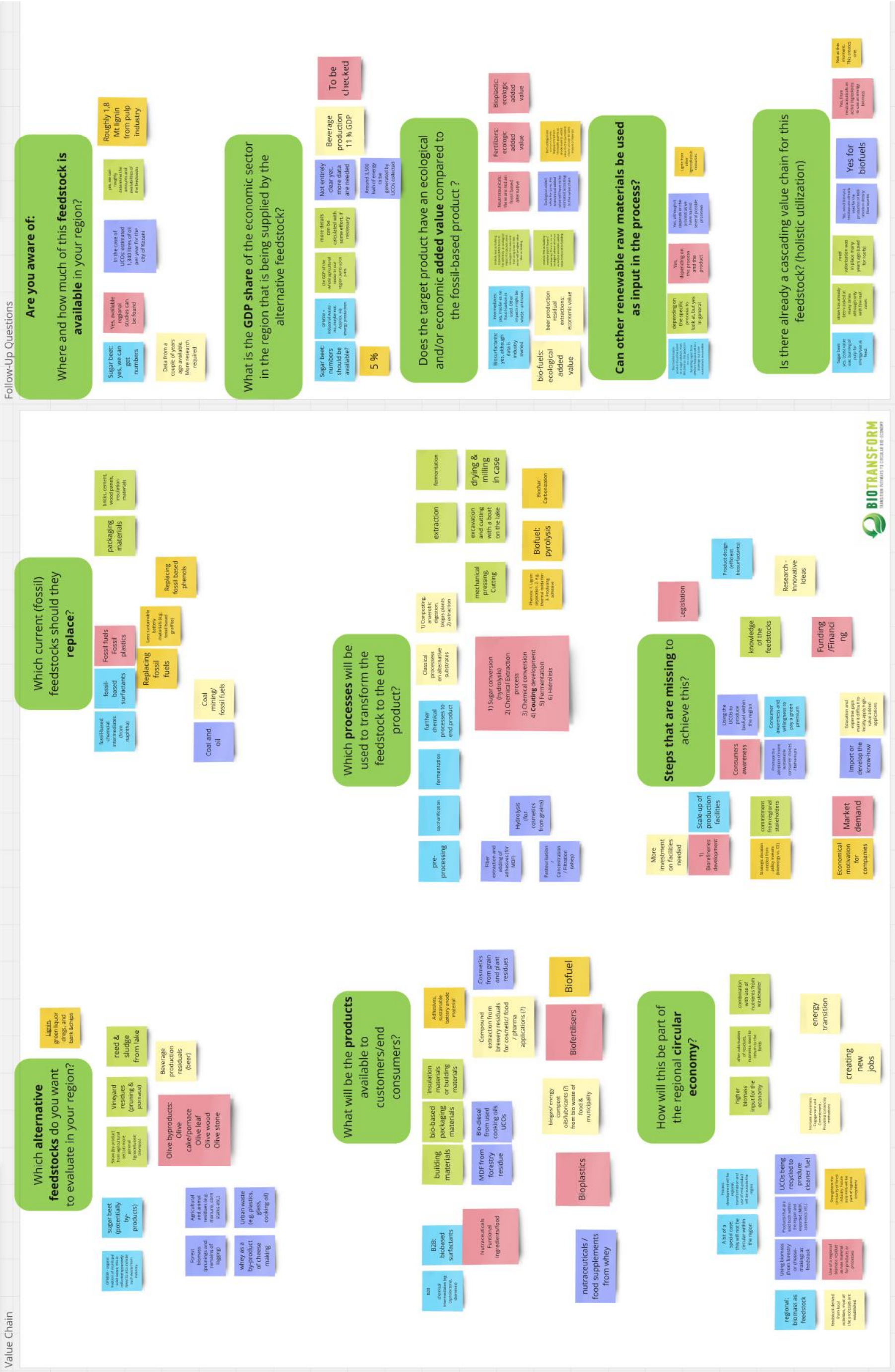

Figure 22: Documentation of the co-creation workshop to identify relevant regional indicators for the case-studies.

Residue	N°	Application	Processes	Combination	Resource availability	CO2 impact	Circularity potential	Water consumption	Freshwater quality impact	CAPEX	OPEX	Techn. Complexity	Economic relevance/feasibility	TRL	R&D needed	Utilisable infrastructures	Potential partners
Olive pruning debris	1	Reinforcement of polymeric materials	Colleting, shredding, sieving and chemical conditioning	Products 4 to 9	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	High	Medium R&D requirements to improve chemical conditioning of the pruning wood fibre	Collection systems, milling systems, sieving systems/compounding systems	Agricultural service companies/Cooperatives/companies that manufacture polymer materials/companies that transform polymer material into parts for industrial sectors
Olive pruning debris	2	Polymer production	Collecting, shredding and chemical synthesis	Products 4 to 9	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	Low	Medium R&D requirement to improve chemical processes	Collection systems, milling systems, compounding systems	Agricultural service companies/Cooperatives/companies that manufacture polymer materials/companies that transform polymer material into parts for industrial sectors
Olive pruning debris	3	Bioethanol production	Pretreatment•Enzymatic hydrolysis•Fermentation•Distillation	Products 5 to 9	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Medium	Medium R&D requirements on enzyme development and pentose fermentation	Biomass collection could be managed by existing	Agricultural service companies/Cooperatives
Olive pruning debris	4	Production of lignin	Fractionation•Separation•Purification	Products 3 to 9	Medium	Medium	Medium	Medium	Low	Medium	Medium	High	Medium	Medio	Medium R&D requirements	Biomass collection could be managed by existing	Agricultural service companies/Cooperatives
Olive stones	5	Xylitol production	Pretreatment•Enzymatic hydrolysis•Fermentation•Crystallization	Products 7 to 9	Medium	Medium	Medium	High	High	Medium	Medium	Medium	Medium	Low	Medium R&D requirements on microorganism development and purification systems	Both olive mills and olive pomace extractors infrastructure obtain separate streams of stones	Olive mills/olive pomace extractors/Researchers
Olive stones	6	Bioethanol production	Pretreatment•Enzymatic hydrolysis•Fermentation•Distillation	Products 7 to 9	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Low	Medium R&D requirements on enzyme development and pentose fermentation	Both olive mills and olive pomace extractors infrastructure obtain separate streams of stones	Olive mills/olive pomace extractors/Researchers
Olive pomaces	7	Hydroxytyrosol production	Pretreatment•Extraction•Separation•Purification	Ethanol or xylitol production	High	Low	Low	High	High	Medium	Medium	High	Medium	Medium	Medium R&D requirements on green extraction and purification systems	Olive mills infrastructure obtain separate streams of pomace	Olive mills/olive pomace extractors/Researchers
Olive pomaces	8	Triterpene production	Pretreatment•Extraction•Separation•Purification	Ethanol or xylitol production	High	Low	Low	High	High	Medium	Medium	High	Medium	Low	Medium R&D requirements on green extraction and purification systems	Olive mills infrastructure obtain separate streams of pomace	Olive mills/olive pomace extractors/Researchers
Olive pomaces	9	Oleuropein production	Pretreatment•Extraction•Separation•Purification	Ethanol or xylitol production	High	Low	Low	High	High	Medium	Medium	High	Medium	Medium	Medium R&D requirements on green extraction and purification systems	Olive mills infrastructure obtain separate streams of pomace	Olive mills/olive pomace extractors/Researchers
Olive pomaces	10	Tecoferol production	Pretreatment•Extraction•Separation•Purification	Ethanol or xylitol production	High	Low	Low	High	High	Medium	Medium	High	Medium	Low	Medium R&D requirements on green extraction and purification systems	Olive mills infrastructure obtain separate streams of pomace	Olive mills/olive pomace extractors/Researchers

Figure 23: Multi criteria analysis in Andalusian case study - version 1

Residue	N°	Application	Processes	Combination	Resource availability	CO2 impact	Circularity potential	Water consumption	Freshwater quality impact	CAPEX	OPEX	Techn. Complexity	Economic relevance/feasibility	TRL	R&D needed	Utilisable infrastructures	Potential partners
Olive pruning debris	1	Reinforcement of polymeric materials	Colleting, shredding, sieving and chemical conditioning	Products 4 to 9	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	High	Medium R&D requirements to improve chemical conditioning of the pruning wood fibre	Collection systems, milling systems, sieving systems/compounding systems	Agricultural service companies/Cooperatives/companies that manufacture polymer materials/companies that transform polymer material into parts for industrial sectors
Olive pruning debris	2	Polymer production	Collecting, shredding and chemical synthesis	Products 4 to 9	High	Medium	High	Medium	Low	Medium	Medium	Medium	High	Low	Medium R&D requirement to improve chemical processes	Collection systems, milling systems, compounding systems	Agricultural service companies/Cooperatives/companies that manufacture polymer materials/companies that transform polymer material into parts for industrial sectors
Olive pruning debris	3	Bioethanol production	Pretreatment+Enzymatic hydrolysis+Fermentation+Distillation	Products 5 to 9	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Medium	Medium R&D requirements on enzyme development and pentose fermentation	Biomass collection could be managed by existing	Agricultural service companies/Cooperatives
Olive pruning debris	4	Production of lignin	Fractionation+Separation+Purification	Products 3 to 9	Medium	Medium	Medium	Medium	Low	Medium	Medium	High	Medium	Medio	Medium R&D requirements	Biomass collection could be managed by existing cooperatives	Agricultural service companies/Cooperatives
Olive stones	5	Xylitol production	Pretreatment+Enzymatic hydrolysis+Fermentation+Crystallization	Products 7 to 9	Medium	Medium	Medium	High	High	Medium	Medium	Medium	Medium	Low	Medium R&D requirements on microorganism development and purification systems	Both olive mills and olive pomace extractors infrastructure obtain separate streams of stones	Olive mills/olive pomace extractors/Researchers
Olive stones	6	Bioethanol production	Pretreatment+Enzymatic hydrolysis+Fermentation+Distillation	Products 7 to 9	Medium	High	Medium	High	Medium	Medium	Medium	Medium	Low	Low	Medium R&D requirements on enzyme development and pentose fermentation	Both olive mills and olive pomace extractors infrastructure obtain separate streams of stones	Olive mills/olive pomace extractors/Researchers
Olive pomaces	7	Antioxidants production	Pretreatment+Extraction+Separation+Purification	Ethanol or xylitol production	High	High	Medium	Low	Medium	Medium	Medium	Low	Medium	Medium	Medium R&D requirements on green extraction and purification systems	Olive mills infrastructure obtain separate streams of pomace	Olive mills/olive pomace extractors/Researchers

Figure 24: Multi criteria analysis in Andalusian case study – version 2