BIOTRANSFORM
TRANSITION PATHWAYS TO CIRCULAR BIO-ECONOMY

Circular BIOeconomy TRANSFORMation for regions by enabling resource and governance networks

D2.1 Report on the framework for assessment and methodology

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Authors

First Name	Last Name	Beneficiary
Gitanjali	Thakur	LIST
Enrico	Benetto	LIST

In case you want any additional information, or you want to consult with the authors of this document, please send your inquiries to: chrysafi@qplan-intl.gr

Quality Reviewers

First Name	Last Name	Beneficiary
Kirsi	Kataja	VTT
Ruben	Guisson	VITO

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Summary

This report introduces BIOTRANSFORM's assessment package, essential for steering the shift towards a sustainable bio-based economy. This package comprises three synergistic tools: the Impact Assessment Tool (IAT by LIST), the Resource Flow Analysis Tool (RFA from ALCN), and the Logistics MOOV Tool (provided by VITO). By assessing regional sustainability goals aligned with regional challenges, the framework offers a comprehensive approach. The RFA and MOOV tools identify transition pathways, while the IAT delivers key performance indicators using sustainability and circularity metrics. These pathways are rigorously compared, revealing disparities between conventional linear (fossil-based) and emerging circular bio-based value chains in social, environmental, economic, and circular aspects. This valuable insight empowers policymakers and stakeholders to make informed decisions, guiding the holistic transition of the regional economy towards a circular bio-based model.

1. Introduction

In response to the climate crisis and the growing strain on natural resources, European Union (EU) policymakers are keen to expedite the transition of their economy from a linear (fossil-based) model to a circular bio-based economy with a commitment to address environmental challenges, reducing greenhouse gas emissions, and promoting circular bioeconomy. Current standards for measuring economic development and activity are in terms of Gross Domestic Product (GDP) (Marcus and Kane, 2007; McCalla and Smith, 2007, Ref). GDP as indicator but it has limitations when it comes to assessing the sustainability and overall well-being of an economy, especially in the context of circular bioeconomy (CBE) (Giannetti, B. F et al. (2015)). Circular bioeconomy models often aim to improve overall well-being, which may not be reflected in GDP growth alone as it measures economic output but does not directly measure the quality of life, well-being, or social equity within a society. In a linear, fossil-based economy, high GDP may be achieved by depleting finite resources quickly, which is unsustainable in the long term. In contrast, circular and bioeconomy models prioritize resource efficiency and sustainable resource management by emphasize the principles of reduction, reuse, and recycling of materials, while basing themselves on renewable raw materials. This can slow down GDP in the short term as less new production is needed, even though they are environmentally and economically beneficial in the long term. A circular-bioeconomy ambitions to minimize negative externalities associated with economic activity, such as pollution, habitat destruction, or climate change, but GDP does not reflect these improvements. To address these limitations, various alternative measures and indices have been proposed, such as the Genuine Progress Indicator (GPI), the Human Development Index (HDI), and environmental sustainability index (ESI) (Böhringer, C., & Jochem, P. E. (2007). These indicators attempt to provide a more holistic view of economic and social progress, accounting for factors beyond GDP at national level. These national-level indicators are not always adequate for a region which vary significantly in terms of their resources, economic activities, and sustainability challenges. Different regions may have distinct environmental, economic, and social characteristics, making it necessary to specify indicators that are tailored to reflect their unique context and challenges.

The current report focuses on a framework which aims to guide the holistic transition of the six-European regional industries of BIOTRANSFORM from linear (fossil based) to circular biobased economy. The case-study regions represent diverse industries and activities and differ in economic background and bioeconomy focus which the project aims to support. The six selected regions and their main bioeconomy topics are listed in Table 1.

Table 1: Country, region, and the main bioeconomy topic for BIOTRANSFORM

Country	Region	Main bioeconomy topics
Austria	Northern Burgenland	Vineyards, vegetation & sludge from lake, agribusinesses
Czech Republic	Charles Spa Region	Hot springs & associated spa tourism, beverages & food production
Finland	Country level	Forestry
Germany	North Rhine-Westphalia	Chemical industry / biogenic side & residue streams
Greece	Western Macedonia	Decarbonisation of energy production, agriculture, mining, fur & leather
Spain	Andalusia	Tourism, retail, transportation underdeveloped industry, agriculture

An extensive set of indicators is proposed as a robust assessment package providing a more comprehensive and holistic view of economic, environmental, and social progress. The aim of the assessment package is twofold. First to provide tools and indicators to design alternative, circular and biobased systems to replace the existing, linear (fossil based) ones. Second, to provide holistic indicators to assess the sustainability of the different alternative systems and provide insights on how to optimize them.

In the context of assessing the transition in the six-pilot regions, the assessment package will employ three established evaluation tools and a variety of indicators, offering a holistic perspective to policymakers. These indicators encompass resource efficiency, environmental impact, social well-being, and economic sustainability, aligning with the principles of bioeconomy and circular economy models. Such a multi-dimensional assessment approach better captures the overall progress and development in the region, reflecting the complex interplay of economic, social, and environmental factors allowing policymakers to make informed decisions by considering a range of factors beyond GDP.

The report is structured into three distinct chapters, each serving a specific purpose:

Chapter 2: This section lays the foundation for the report by introducing the tools and their subsequent benchmarking that will be central to the assessment method.

Chapter 3: This section delves into the regional context, offering insights into the challenges and limitations experienced in the specific regions.

Chapter 4: This pivotal chapter outlines the methodology framework that will be employed, offering a comprehensive list of indicators. It details how these indicators will be used to assess and guide the transition from linear and fossil-based systems to circular bio-based economies and also specifies the context in which the tools and methodologies will be applied.

2. Three existing tools

2.1 Resource Flow Analysis Tool – RFA (ALCN)

The Resource Flow Analysis (RFA) Tool focuses on assessing the flow of resources within the circular bio-based economy using a Sankey diagram. It is a visual representation that effectively showcases the movement of resources, energy, costs, or other measurable data. By utilizing distinct bands or streams, it visually illustrates the intricate inflows and outflows of data. This graphical tool proves valuable in making complex data flows more understandable and revealing patterns and inefficiencies, enabling a comprehensive understanding of the circularity of the system. It can highlight areas where resource efficiency can be improved, and waste can be minimized, contributing to the overall sustainability of the transition. The Sankey diagram is also used to define a scenario based on the resources available and describe which conversion plants can be used to convert this biomass into useful products. From this the feed can be estimated and the impact on indicators can be estimated. These diagrams play a crucial role in assessing the circular bioeconomy by:

1. Illustrating the movement of energy and resources it also helps in portraying the residual biomass stream, which allows us to track the movement of unused organic materials

2. Emerging as powerful instruments for visually mapping the circular economy concept. They effectively demonstrate the cyclical journey of materials, underscoring their role in enhancing sustainability through effective recycling and reuse.

3. Helping us visualize the environmental consequences of waste management processes. This sheds light on the potential for waste reduction through resource recovery strategies.

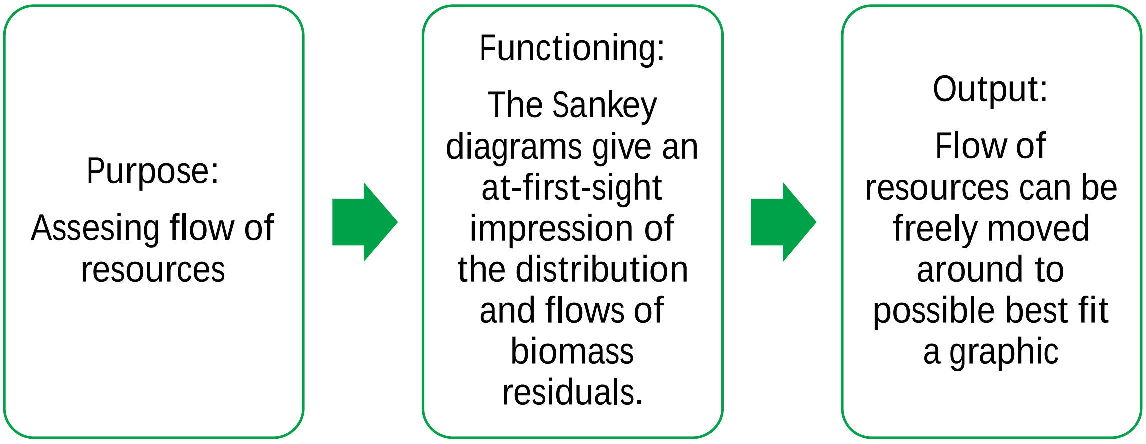

Figure 1: Purpose, functioning and output of RFA

2.2 Logistics MooV Tool – MooV (VITO)

MooV (https://MooV.vito.be) is a supply chain optimization service dedicated to optimizing the design of supply chains and supporting the rethinking of supply chain configurations independently and scientifically. MooV focuses on strategic and tactical decisions, such as determining the location of new activities, integrating new activities and products in chains, the right choice of transport fleet, etc. Within the project, the MooV tool focuses on the logistics and transportation aspects of the transition to a circular bio-based economy. MooV assesses the movement of materials, products, and information within the circular bio-based economy. It helps identify opportunities for optimizing transportation logistics, reducing emissions associated with logistics transport, and enhancing the overall efficiency of the transition process by considering all key decision parameters based on:

- Logistics & transport: location, multi-modality, hubs, peak & off-peak travel times
- Storage and processing: product flows, capacities, locations, process step costs
- Quality aspects: grades and standards, product specifications, process step
- Time effects: variations in time of supply & demand

The tool then finds the optimal supply chain network solution matching the set objective (e.g., cost minimization or maximum fleet emission reduction) and considering regional-specific constraints (e.g. production hotspots, low emission zones, loading capacities). As such, MooV provides decision support in transforming from fossil-based supply chains to circular bio-based ones. The ways to change the existing supply chain into a new one. MooV has been applied to be used by various sectors for turning their supply chain more efficient, which includes Agriculture, forestry, (green) Chemical chemicals and pharma, Construction & Building, Food and feed, construction, Forestry, Governmental authorities & services and Logistics & Transport logistics and transport. The client portfolio consists of private as well as public and non-governmental bodies. A pictorial representation of different activities and the decision criteria are shown in the figure below.

MooV combines linear programming and advanced analytics to address diverse strategic and tactical supply chain questions. It is an intelligent merger of in-house developed Python scripts combined with professional software packages such as GUROBI Optimizer, ESRI ArcGIS and Tableau.

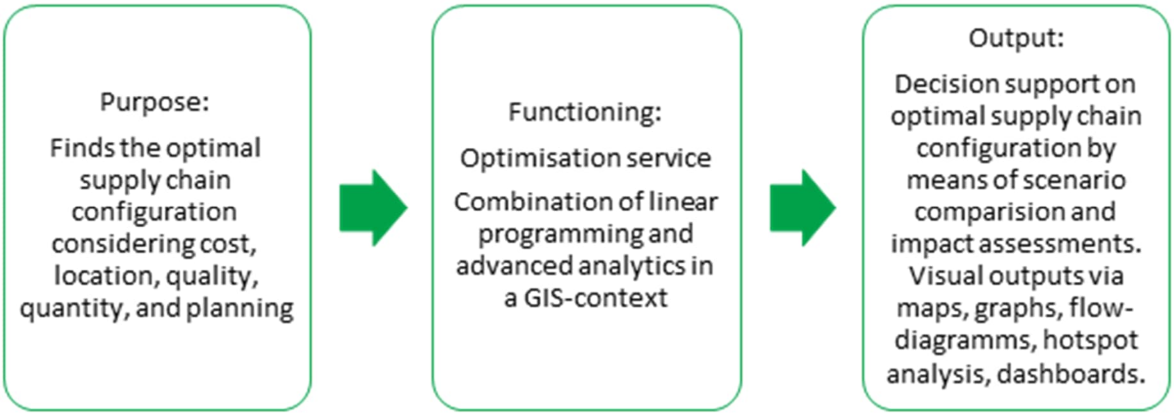

Figure 2: Purpose functioning and outcomes of MooV

2.3 Impact Assessment Tool – IAT (LIST)

The transition from linear fossil fuel-based system involves shifting from a model that relies heavily on finite fossil fuels and generates environmental degradation to one that is more sustainable, regenerative, and aligned with ecological boundaries. The impact assessment tool consists in a list of sustainability assessment indicators framed within the "Doughnut Economics" model of planetary and social boundaries (Raworth 2017). The indicators represent environmental, economic and social hotspots (e.g., renewable energy adoption targets, social equity measures) which must be assessed and monitored while imposing the objective of reducing the environmental burden in the six pilot regions. The framework can guide policymakers in designing and implementing policies that promote circularity and bio-based solutions.

The starting point is to quantify the GHG impact reduction target, compared to the current situation, to be achieved through a given transition scenarios towards a circular and sustainable bioeconomy. By identifying the leading sectors and activities which will be impacted by the transition scenarios and thereby will contribute to the targeted impact reduction, one or more prospective scenario(s) (relative to the status quo situation) are defined. The scenarios are associated to transition pathways that shall be crafted qualitatively and quantitatively, by modifying the main drivers of the status quo situation according to the prospective assumptions. For each of the prospective scenario, the resource and energy flows are quantified, and the associated environmental, economic and social aspects are assessed, based on the set of indicators.

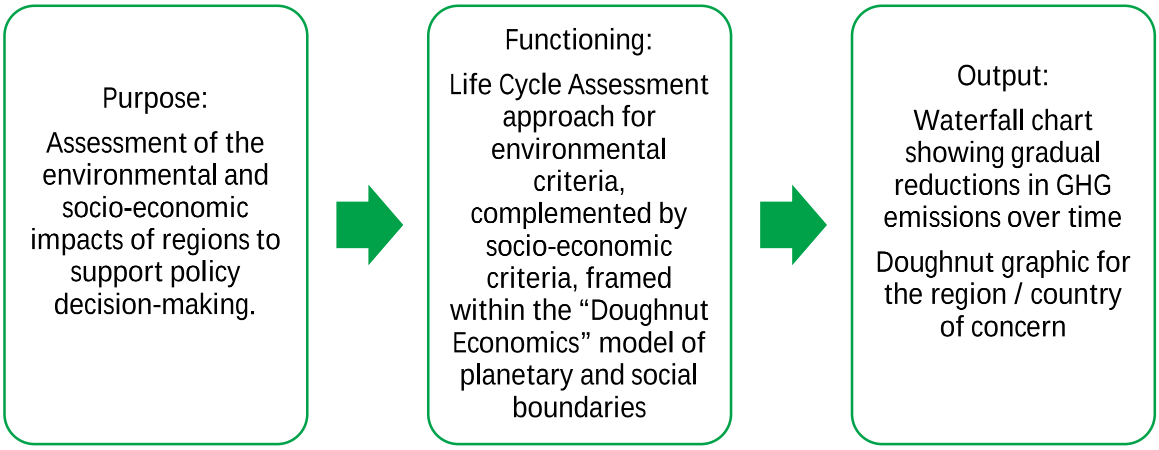

Figure 3: Purpose and outcome of IAT

2.4 Benchmarking of three tools

BIOTRANSFORM focuses on advancing the bioeconomy and circularity in six diverse European regions with varying industries and financial backgrounds. A critical aspect of the project involves benchmarking resource flow analysis (RFA), logistics optimization, and impact assessment tools to determine their suitability for specific applications within these regions. This benchmarking process aims to establish a comprehensive assessment framework by evaluating the tools against common criteria, considering the unique characteristics of each tool and region. Ultimately, the goal is to assess the tools' capabilities, effectiveness, and applicability in promoting sustainability during the transition from a linear (fossil based) economy to a circular bio-based economy. The information used for the benchmarking are shown in Table 2.

Table 2: Description and comparison between the three tools based on their generic information, data requirements, outcomes, and user interface.

Generic information	Resource Flow Analysis [ALCN]	Impact Assessment tool [LIST]	Logistics MooV tool [VITO]
Purpose	A resource flow diagram illustrates the inflow and outflow of resources within a system	The evaluation of environmental and socio-economic impacts within regions, for the purpose of informing policy decision-making, is conducted through the analysis of various consumption scenarios	Determines the optimal supply chain configuration, considering factors such as cost, geographic location, quality, quantity, and planning.
Type of tool (software (coding language) / model / Excel-based tool / other)	An Excel-based tool enriched with Python code for data visualization.	A methodological approach integrated with an Excel-based tool	The model is python coded (linear program). Supporting software a.o. ArcGIS (geographic context), Gurobi (solver), Excel (input-output files)
For software: indicate if open source	The open-source Python code is available on GitHub, providing the necessary knowledge and resources to utilize it seamlessly in conjunction with Aalchemia-Nova	n.a. (not a software yet)	No (supporting software is under license)
Methodology followed / Modelling approach	Resources are characterized by their inflow and outflow, with arrows denoting the directional flows, while nodes symbolize the processes involved.	Life Cycle Assessment (LCA) emphasizes a comprehensive evaluation of environmental factors, enriched by the incorporation of socio-economic criteria. This holistic framework is firmly rooted within the 'Doughnut Economics' model, which emphasizes the recognition and management of planetary and social boundaries	Focuses on determining the optimal locations for facilities, such as warehouses, distribution centers, or production plants, while considering capacity constraints
Developed in house	Yes	Yes	Yes

The tool is used internally in your institute, or is it open to external users/clients? Or both?	The tool is employed for internal purposes	For internal utilization, as a user interface has not been developed yet	The tool is offered as a service to maximally unburden clients and to reduce implementation/use complexity at the client's end.
Licensing scheme	The tool was initially developed to serve the needs of Aalchemia-Nova. While it is openly accessible, the repository of knowledge primarily resides within the institute	No specific licensing scheme is in place, and distribution to external parties is not currently facilitated	None (offered as a service)

Foreground Data required	Resource Flow Analysis [ALCN]	Impact Assessment tool [LIST]	Logistics MooV tool [VITO]
Quantitative or Qualitative	To articulate this expression effectively, a comprehensive understanding of both qualitative insights into processes and quantitative data pertaining to the magnitude of arrows is necessary	Both qualitative and quantitative aspects	Quantitative
Type of data (e.g. bill of material / bill of energy / process data / process description / location of stakeholders along supply chain / …)	Every process scheme can be modelled with this tool. It can show energy, nutrients, water, biomasses, carbon or whatever else one wants to show as mass flow scheme	Market data, consumption data, bill of mass, bill of energy	5 different types of data: 1) Cost data: on transport and activities in the supply chain 2) Location data: GIS coordinates of the available supply chain locations. 3) Quantity data: mass-flow between different activities in the supply chain 4) Quality data: to differ between material types, quality grades… 5) Planning/time data: to reflect offer/de
Sources of data	Quantities of resources = arrows, processes = nodes	National/ Regional/Sectorial statistics & inputs from stakeholders	Combination of customer-provided and extended with manually sourced data by us.
Type of data	Numeric	Numeric	Numeric

Sources of data: Background database(s) used	Knowledge on inputs and outputs necessary	EXIOBASE (Stadler, K., et al.(2023))	Case dependent.

Outcomes / type of results	Resource Flow Analysis [ALCN]	Impact Assessment tool [LIST]	Logistics MooV tool [VITO]
Quantitative / Qualitative	Both	Both - some indicators are quantitative (life cycle based), some are qualitative (e.g. socio-cultural) in case of lack of inputs for quantitative assessment.	Quantitative
List of indicators / criteria released	Masses of resources, conversion efficiencies, side streams	Set of indicators relevant to the assessment of circular bio-based systems and comparison with linear (fossil based) systems: **Environmental:** GHG emissions (production-based, consumption-based, biogenic carbon); Marine and freshwater eutrophication (kg N, kg P); Blue water withdrawal (fresh surface water used for human activities); Air pollution (combine nitrogen oxides, sulphur oxides, particulate matter emissions (2.5 µm) into disability-adjusted life years) Material use and circularity (tons of material, assess circularity of materials qualitatively); Land use, land use change (carbon sequestration potential); Biodiversity (using case-specific metrics, such as share of organic agriculture) **Social:** Job loss and creation; Wages; Training needs; Resource efficiency; Conversion rates and costs of equipment; Sizing and scaling; Influence on trades, logistics, infrastructure and related costs; Social and environmental costs **Socio-Cultural:**	Standard KPI's are: cost (€), mileage (km), CO2-emissions (ton), vehicle movements, vehicle loading rate and the location of the activities. However other KPI's can be customised depending on the client's request.

		Life satisfaction literature providing variables like employment, income, work-life balance, housing, health, education, governance, environment, security, self-reported life satisfaction	
Assessment / Evaluation method	Often numbers rely on assumptions or literature values, evaluation should compare with real regional data (once this is measured)	Life Cycle Impact assessment (Environmental indicators), combined with statistics for the socio-economic indicators.	Impact assessment – comparing different supply scenarios – based on the KPI's. .

User interface	Resource Flow Analysis [ALCN]	Impact Assessment tool [LIST]	Logistics MooV tool [VITO]
Existing for entry data (yes/no)	Yes, excel data file	So far the Excel data file is for expert in sustainability assessment. The tool could be replicated in Python with the addition of a user interface.	Yes, excel data file template
Possibility to define several scenarios / Sensitivity Analysis -	Yes, either time rows or scenarios are generated	Yes	Yes
Existing for results visualisation	Yes, the Python code directly shows the flow diagram, where the nodes can be freely moved around to possibly best fit a visually appealing graphic	Not yet - Graphs are hand made	Dashboard (on demand) visualising maps, graphs, tables (customised to client's need)
Type of visualisation	Sankey diagram	Waterfall chart showing gradual reductions in GHG emissions over time Doughnut graphic for the region / country of concern	Maps, graphs, tables..

Support to interpretation: contribution analysis, sensitivity analysis, multicriteria assessment	With any changes of underlying excel or adding of a scenario, the Python code can be run again to immediately show an updated version. Possibly each scenario can apply a different set of solutions, which can also be assessed through the multi-criteria assessment	Yes	Yes – MooV is offered as a service. An experienced MooV-team guides clients through the results to better understand and organize their chain.

3. Study regions and their limitations (results from WP1)

This section presents a summary for each case-study region in the WP1 and discusses the limitations associated with the existing linear and fossil-based economies. The analysis is based on literature and insights from interviews with relevant policymakers and stakeholders, exploring opportunities for utilizing renewable biological resources, fostering innovation in bio-based industries, and developing policies to promote a more circular and sustainable economic model. By identifying these common limits and issues, the study aims to shed light on broader challenges pertinent to the individual regions and resonate at the European Union (EU) level. The various stakeholder interviewed to assess the regional sustainability barriers, especially in view of the sectors in scope of the BIOTRANSFORM project as show in Table 3.

Table 3:Interviewee details from each region

Region	Interviewee details
Charles Spa	Regional officer, director of business development agency Member of regional research and development Representative of small regional business Policy makers and relevant stakeholders (exclusive details not found)
Austria, Burgenland	Chairwoman of an association (NGO) Professor of Innovation and Sustainability (Research institution) Model region manager for a KLEM region (Other) Regional manager for a KLAR region (Other) Specialist advisor in the regional administration of the state of Burgen-land (Political decision maker)
Andalusia, Spain	Research organisation Policymakers Public administration Environmental and forest administration
Finland	Policy maker (municipal level) Policy maker in ministry Circular economy and environment manager Ecosystem leader in public organisation
Germany	Experts/associations in waste management, Food processing start-up support, Policymaker
Greece	Policymaker in regional level Policymaker in municipal level related to the geotechnical field. Policymaker in regional level related to rural development. Policymaker /project officer at a local public authority

1. Burgenland and Northern Burgenland Region, Austria:

Economic Growth is characterized by commuting. A large portion of the population still commutes to Vienna and surrounding areas for employment suggesting external job markets and larger industries in the region rely on fossil fuels.

Environmental Limits: main hotspots include CO_2 emissions, nutrient loading from agriculture, habitat loss, impacts on biodiversity, and water resource challenges. Climate change's effect on wine production and soil degradation from agricultural activities are also highlighted.

Economic Limits: The availability and prices of raw materials due to dependency on imports. However, there's also a growing demand for eco-friendly products and services.

Social Limits: An influx of population strains from the local ecosystem due to increased resource demands, while at the same time, younger and more skilled individuals are leaving the region. Lack of awareness, creativity, openness, and innovation.

2.Charles Spa Region:

The main economic activities are centred around traditional crafts like glass and porcelain manufacture, textiles, building materials, and musical instruments, which have been losing importance due to high energy demands, raw material needs, and workforce requirements. Efforts have been made to transform key companies to compete globally, with foreign investment playing a role but only a few have successfully adapted to new markets due to the following challenges:

Environmental Limits: The region faces environmental challenges, including pollution of watercourses critical for the spa industry, ecological burdens of brownfields, air pollution from heating, and solid fuel usage, and soil and forestry pollution.

Economic Limits: Economic constraints include a dependency on imported raw materials and reliance on fossil fuels for energy. The region's industries also need more specialized personnel, making adaptation to market changes difficult. A lack of an environment for start-ups and a low innovation culture.

Social limits: Lack of skilled individuals due to migration to other regions for employment and a mismatch in education offerings. Low social responsibility by companies and citizens.

3.Finland:

The Finland forestry sector contributes by 15 per cent to the world's paper and paperboard exports. It plays an essential role in Finland's commitment to become climate-neutral by 2050 (European Green Deal) by increasing biomass extraction while minimizing waste, optimizing resource use, and creating value from by-products and waste streams.

Environmental Limits: The pulp and paper industry is responsible for substantial nutrient discharge. Biodiversity loss is observed from forestry activities, and eutrophication from phosphorus and nitrogen used in forestry.

Economic Limits: Fluctuations in energy prices, large number of forest owners makes it difficult to ensure a steady wood supply for the industry. Lack of recycled fibre as most of the fibre-based products are exported and are not returned to Finland for recycling.

Social Limits: Lack of skilled professionals in rural areas, Lack of funding and other incentives to create circular models, considering forests of human well-being needs.

4.North Rhine-Westphalia (NRW) Region – Germany

NRW has a robust industrial sector, with the chemical industry significantly contributing to its economic power. The chemical sector heavily relies on fossil resources, particularly petrochemical

raw materials and is an energy-intensive industry. Its output is essential for a wide range of other industrial sectors in Germany and other countries.
Environmental Limits: Degradation of ground and surface waters due to lignite mining, reduction in biodiversity, high CHG emissions, and use of fossil carbon raw materials.
Economic Limits: Dependence on the import of raw materials (fossil and renewable), high electricity cost for the chemical industry, and environmental regulations that will require changes in the operations of the chemical industry.
Social Limits: High interest of consumers in ecologically produced food and ingredients, and investment to companies perceived as sustainable grows. Citizens aim for a greener and more sustainable lifestyle.

5. Region of Western Macedonia – Greece
Western Macedonia consistently experiences high unemployment rates, especially among youth, and has one of Greece's lowest per capita GDPs. Small companies, traditional industries, and low competitiveness characterize the local economy. De-industrialization and the migration of labour-intensive industries to neighbouring low-cost countries have further weakened the economy. The region's power stations are scheduled to shut down by 2028 due to the limitations and negative impacts of the current financial system, particularly in the lignite industry.
Environmental Limits: Lignite extraction process causes loss of biodiversity, contamination of groundwater by chemicals, land degradation, dust, noise and water pollution, air pollution, soil and water acidification.
Economic Limits: Low innovation performance, import of raw materials (smaller local producers), stopping lignite mining.
Social limits: Loss of jobs due to stopping lignite mining, elderly population with a low level of education, and lack of advanced and up-do-date skills.

6. Andalusia Spain:
Andalusia significantly contributes to Spain's national GDP and economy. However, the use of fossil resources, primarily for energy purposes, negatively impacts the regional environment. The Government of Andalusia has recognized the need for an energy transition due to the limits and impacts of the linear economy.
Environmental Limits: Ecological agriculture, tourism, construction, loss of beaches and biodiversity, air pollution from transport and retail business, and CHG emission from energy production and consumption
Economic Limits: Dependence on raw materials and imports - main imported category is crude petroleum oils. Increased prices of imported raw materials (oil), and price of water needed for irrigation in the agriculture sector.
Social limits: Increased population in the region, citizen choosing to be more environmentally responsible and putting pressure on the industries for eco-friendly products.

The challenges faced by the six regions are summarized in Figure 4. These highlights are then considered in the definition and deployment of the assessment framework in the next chapter.

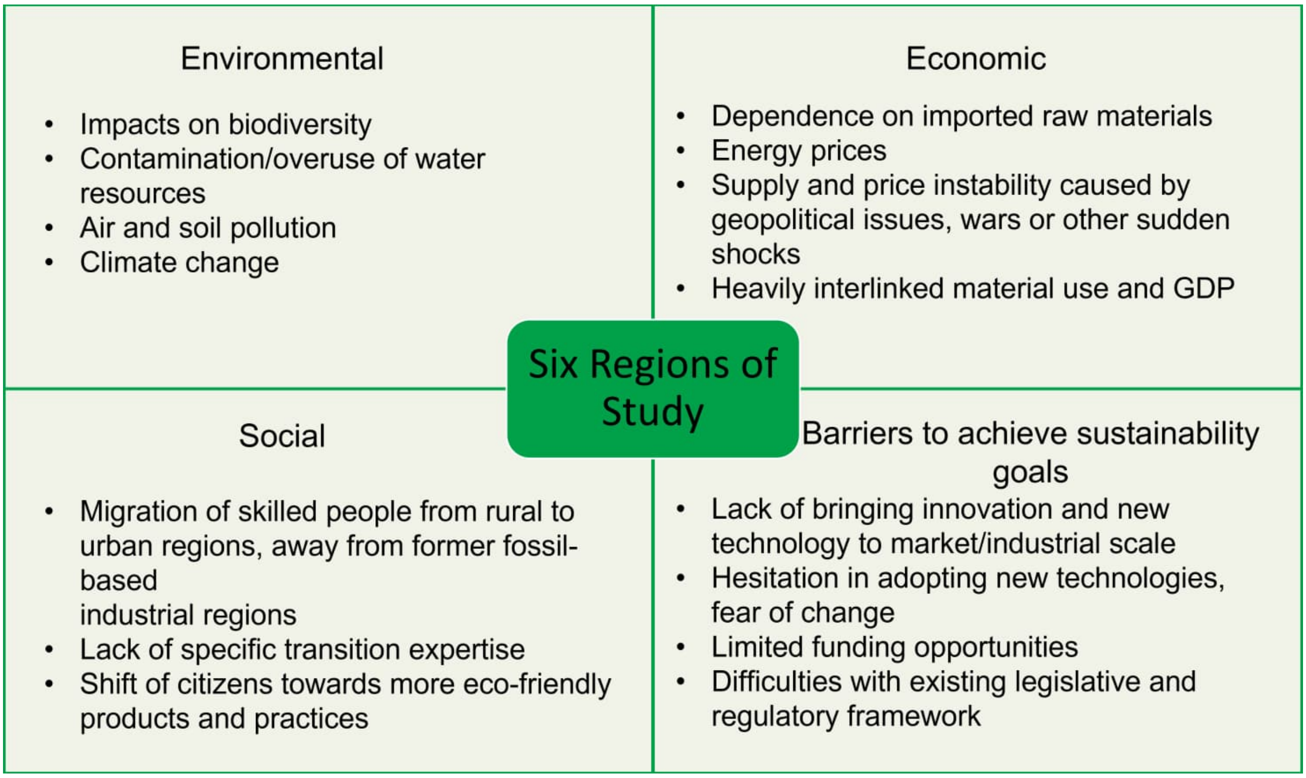

Figure 4:Summarising the challenges faced by various regions, revealing common limits and barriers that are indicative of the broader situation of linear economies at the European Union (EU) level.

4. Assessment framework

This chapter outlines a structured framework for addressing sustainability challenges in the six regional economies, which is depicted in Figure 5. First step is the setting of sustainability goals, based on the regional challenges previously identified for each region. This revolves around two key aspects: reducing greenhouse gas (GHG) emissions and advancing the circular bioeconomy in the regional industrial sector. In a second step, the improvement actions to reach the goals are identified through the optimization of supply chains and the enhancement of biomass circularity using the RFA and MooV tools. The data required for the tools will be provided by the industrial partners. In a third step, the assessment of the improvement actions is performed. Two approaches can be used: 1) a simplified one, where technical and economic data on the improvement actions are collected to calculate the circularity indicators listed in Table 6, considered as proxy of environmental and socio-economic impacts; 2) a detailed assessment, where a comprehensive inventory for each activity and material flows characterizing the improvement actions is performed, which includes quantitative data for all inputs and outputs at each life cycle stage of the actions. This means looking at all stages, from raw material extraction, production, transportation, use, and recycling to then calculate the environmental, social, and economic impacts listed in Table 4. In the final step, data and findings are visualized, using Sankey diagrams illustrating resource and energy flows for various scenarios, bar plots displaying effect of supply chain optimization on the GHG emissions, a waterfall chart demonstrating gradual reductions in GHG emissions over time, and a Doughnut graphic portraying regional target, ceiling values and constraints.

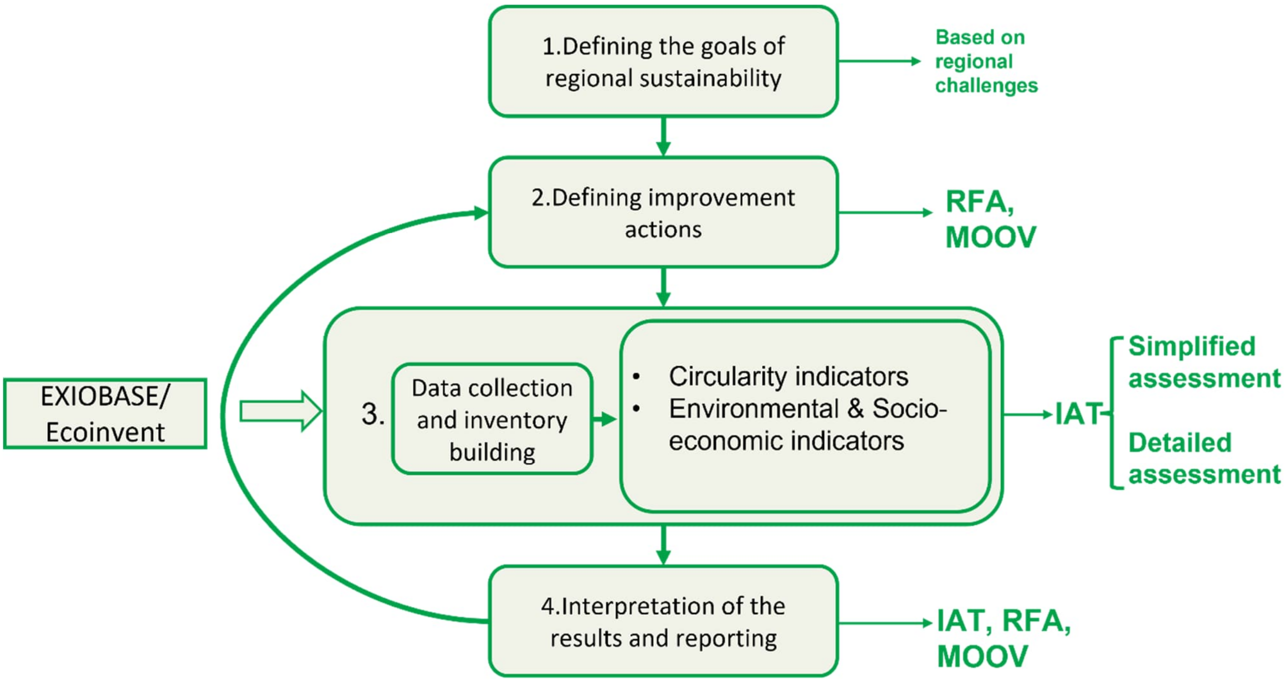

Figure 5: Flowchart showing comprehensive approach consisting of four steps to assess the regional transition by using IAT, RFA and MooV

4.1 Defining the goals of regional sustainability

By identifying regional barriers to sustainability in terms of their geographical characteristics, resources available, and challenges to bioeconomy and circularity (discussed in Chapter 2) provides a deep understanding of the specific issues and constraints in each region. These barriers are categorized into environmental impacts, economic dependencies, social shifts, and regulatory hurdles as shown in Table 4. This step provides a comprehensive understanding of the challenges at hand and suggests which assessment should be done (simplified or detailed). We have aligned the specific regional challenges with the appropriate tools as shown in Annex 2 with required input and regional sustainability targets. Results demonstrate how the three tools will be effectively used to address and evaluate the identified barriers to sustainability.

Table 4: Barriers to sustainability and tools that can be used to address them.

Study Regions	Barriers to sustainablity/ Bio-economy			
	Socio-economic	Technical	Legal/Administrative	Environmental
Andalusia, Spain	Insufficient financial resources	Supply of raw materials, High generation of waste in manufacturing, Inadequate waste management	Poor inter-administrative coordination, regulatory frameworks related to tourism, bureaucratic obstacles, lack of political interest	Regional orography, Impact on biodiversity due to rise in sea level
Burgenland, Austria	Competition for land use, Highest number of cars per household in Austria, Loss of workers and retraining, Lack of well-developed public transportation	Limited research	Lack of enforcing laws, Energy price	Increasing water requirements for wineyards, drying up of lake Neusiedl due to surface sealing revitalization of fallowland excessive use of petrochemical fertilizers has led to contamination of ground water with high level of nitrates, animal farms

Charles Spa region	Less educated people, Distrust on circular economy	Limited research and technological innovation, Poor transport not connecting supply and customer chain	Need for legislative framework that might not be conducive to sustainable practices, small investment in new technology	
Finland	Need for funding and support to create circular models for commercializing new concepts and technologies.	Shortage of wood	Environmental permits, EU regulations, Sustainable forest management	Decreasing harvested forest area, regeneration of forestry, environmental impacts on water bodies, Regulation on nature conservation and land use
NRW Germany	Lack of skilled workforce	Conversion complexities in the chemical industry	Low investment, regulatory framework issues	
Region of Western Macedonia-Greece	Reduction in primary sector employment	Lack of technical knowledge, Lack of solid supply chains between biomass providers, transporters and end users, Lack of control mechanisms	Lack of public and private financing resources and limited infrastructure	

4.2 Defining improvement actions

To define the ways to improve the sustainability of the study regions, the two existing tools will be used.

4.2.1 Using RFA

The Sankey obtained from the RFA about the energy and resource flows in the region is instrumental in guiding improvement actions for a sustainable regional transition as it provides a clear picture of resources being used and wasted. The diagrams can highlight opportunities for waste reduction and recycling. This information can be used to integrate biobased resources into the existing value chains. Continuously updating and analyzing Sankey diagrams will also allow for the monitoring of progress in terms of resource and energy efficiency during the transition.

4.2.2 Using MooV

MooV will analyze the current supply chain configurations in the region and will identify areas where resources are underutilized or where inefficiencies exist. For instance, if storage facilities or distribution centers are not optimally located, this could lead to unnecessary resource consumption. MooV can simulate the effects of changes in product demand on the supply chain which will help to plan for fluctuations in demand and adjust the supply chain accordingly. Based on the demand patterns the capacity of storage facilities will be optimized. This optimization will have an impact on the existing use of resources. The details of MooV methodology followed is shown in Annex 4.

4.3 Inventory, emission profiles and assessment

The first phase will focus on circularity indicators, as presented in Table 5. This approach will enable to gauge how much the activities align with circular economy principles, emphasizing resource efficiency and reduced waste. In the second phase, we will conduct a comprehensive analysis using a detailed list of sustainability indicators. This approach ensures a thorough examination of environmental, economic, and social factors, as illustrated in Table 6.

4.3.1 Simplified assessment

Biomass residues offers a transformative opportunity for regional economies to transition towards a circular bioeconomy model by repurposing bio-waste as a replacement for virgin materials, such as by removing chemicals using organic feedstocks. This way a profound shift towards sustainability and circularity can be achieved, reducing dependence on finite fossil resources, and mitigating environmental impacts. The conversion of biomass residues into organic feedstocks promotes resource efficiency, minimizes waste, and fosters a closed-loop system where materials are continuously reused and recycled. This shift may also stimulate economic growth by generating new avenues for bio-based industries, ultimately contributing to a more resilient and environmentally responsible regional economy. The below table provides the regional biomass residue (obtained from WP1) sources that can be focused for the regional transition.

Table 5: Regional biomass residue sources

Region	Biomass residue sources
Northern Burgenland – Austria	-Municipal waste -Lake: reed & sludge -Agriculture
Charles Spa Region – Czech Republic	-Agriculture & Forestry, Tourism
Finland	-Forestry
North Rhine-Westphalia – Germany	- Agricultural, agri-food/feed and forestry sector -Municipal waste -Industrial waste
Western Macedonia – Greece	-Fur and leather -Municipal waste biomass -Forestry -Agriculture
Andalusia – Spain	-Agriculture waste -Industrial waste -Energy crops -Urban waste

By conducting a thorough inventory of available biomass residue sources in the region and analysing the composition and properties of the biomass residue the circularity potential of biomass residue can be assessed using four categories as shown in Table 6. The circularity indicator then can be related to the social, economic, and environmental impacts.

Table 6: Macro level circular economy indicators (Geng et al., 2012) based on EASAC policy report 30 (2016) and its overlap with sustainability (social, environmental, and economic) indicators. The calculation formulation for each indicator is given in Table 11

Category	Indicator	Env.	Social	Eco.
Resource output rate	Output of main mineral resource	✓		✓
	Output of energy	✓		✓
Resource consumption rate	Energy consumption per unit of GDP		✓	✓
	Energy consumption per added industrial value		✓	✓
	Energy consumption per unit of product in key industrial sectors		✓	✓
	Water withdrawal per unit of GDP	✓	✓	✓
	Water withdrawal per added industrial value	✓	✓	✓
	Water consumption per unit product in key industrial sectors	✓	✓	✓
	Coefficient of irrigation water utilization	✓		
Integrated resource utilization rate	Recycling rate of industrial solid waste	✓		✓
	Industrial water reuse ratio	✓		✓
	Recycling rate of reclaimed municipal wastewater	✓		✓
	Safe treatment rate of domestic solid wastes	✓	✓	✓

	Recycling rate of iron scrap		✓	✓
	Recycling rate of nonferrous metal	✓	✓	✓
	Recycling rate of wastepaper	✓	✓	✓
	Recycling rate of plastic	✓	✓	✓
	Recycling rate of rubber	✓	✓	✓
Waste disposal and pollutant emissions	Total amount of industrial solid waste for final disposal	✓		✓
	Total amount of industrial wastewater discharge	✓		
	Total amount of sulphur dioxide emissions	✓		
	Total amount of COD discharge	✓		

4.3.2 *Detailed assessment*

Data on each activity in the considered value chains regarding resource use and material use, along with the data on each stage of the emissions, will be estimated using EXIOBASE and ecoinvent (Stadler, K., iet al.(2023), Wernet, G et al.(2016)) These stages typically include raw material extraction and processing, manufacturing and production, transportation and distribution, use and operation, and End-of-life (disposal, recycling, or waste management). The environmental indicators quantify the environmental impacts, the economic indicators will assess the financial aspects of the transition, and the social and cultural dimensions will be evaluated using social indicators as shown in Table 5. These helps quantify the multifaceted aspects of sustainability, providing a holistic view of the transition's impacts and ensuring that it aligns with the goals of environmental preservation, economic development, and social well-being. It also provides a way to track and evaluate whether the desired direction is at the expected pace required for the transition. The primary list of environmental indicators based on the ecological footprint method of the European Commission (Manfredi, S et al. (2012)) is given in Table 5. The social and economic indicators are chosen based on the common economic and social challenges in Figure 4. Additionally, a detailed list of indicators obtained from the literature review is given in Annex 1

Table 7: List of social, environmental, and economic indicators.

Proposed EF impact category	Unit (environmental impact category indicator)	Source	Included environmental flows
Climate change, total	GHG emissions, GWP100 (kgCO2eq)	Intergovernmental Panel on Climate Change (2007), Beylot (2019, 2020)	CO2, CH4, N2O, SF6, HFC, PFC
Ecotoxicity,	Comparative Toxic Unit	Rosenbaum et al.,	Benzo(a)pyrene, Indeno(1,2,3-cd) pyrene, PCDD_F, HCB, As, Cd, Cr

Proposed EF impact category	Unit (environmental impact category indicator)	Source	Included environmental flows
freshwater	for ecosystems (CTUe)	(2008), Beylot (2019, 2020)	Hg, Cu, Ni, Pb, Benzo(k)fluoranthene, Se, Zn, B(a)P, Indeno, PCDD/F, NMVOC, PAH, B(k)F
Water use	Water stress (m*3 of H2O equivalents)*	Frischknecht et al. (2008), Cabernard (2019)	Water consumption
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	Struijs et al. (2006), Beylot (2019, 2020)	NH*3* - air, P
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (kg N eq)	Struijs et al. (2006), Beylot (2019, 2020)	NH*3*, N
Material footprint	Material footprint (tonnes of cultivated biomass, extracted mineral ore and fossils)	Cabernard (2019)	Extraction Used
Acidification	Accumulated Exceedance (mol H+ eq)	Seppälä et al. (2006), Posch et al. (2008), Beylot (2019, 2020)	SOx, NOx, NH*3*
Eutrophication, terrestrial	Accumulated Exceedance (mol N eq)	Seppälä et al. (2006), Posch et al. (2008),	NH*3*, NOx

Proposed EF impact category	Unit (environmental impact category indicator)	Source	Included environmental flows
		Beylot (2019, 2020)	
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	Rosenbaum et al., (2008), Beylot (2019, 2020)	Benzo(a)pyrene, PCDD_F, HCB, As, Cd, Hg, Ni, B(a)P, Pb, PCDD/F
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	Rosenbaum et al., (2008), Beylot (2019, 2020)	HCB, As, Cd, Cu, Hg, Ni, Pb, Zn
Particulate matter	Impact on human health (DALYs)	Humbert (2009), Cabernard (2019)	PM*2.5*, CO, SOx, NH*3*, TSP
Photochemical ozone formation, human health	Tropospheric ozone concentration increase (kg NMVOC eq)	Van Zelm et al. (2008), Beylot (2019, 2020)	CH*4*, SOx, CO, NMVOC
Land-use related biodiversity loss	(Global m3 PDF years)	Cabernard (2019)	Land use, crop, forest, pasture
Ionising radiation	Human health effect	IPCC 2013; Joos et al. 2013	Change in radiative forcing

Proposed EF impact category	Unit (environmental impact category indicator)	Source	Included environmental flows
Resource use, fossils	kg oil-eq	Jungbluth and Frischknecht 2010)	Heating value
Resource use, mineral and metals	kg Cu-eq	Vieira et al. 2016a	Increase in ore extracted
Ozone depletion	kg CFC-11 equivalent	WMO 2011	Stratospheric ozone decreases

Proposed social impact category	Unit	Source	Included flows
Gender-related development index	-	Bilbao-Ubillos, J. (2013)	HDI
Job creation and loss	h/jobs*year	Pillain, B et.al (2019)	Working hours, Biomass availability
Skill development initiatives	% of GDP	Husgafvel, R et al.(2015)	Hours of training

Proposed economic impact category	Unit	Source	Included flows
Emerging investment ratio	dollar	Karwowski, E., & Stockhammer, E. (2017)	GDP%
Imports and export prices of raw material	dollar	Sheinbaum-Pardo, C. et al. (2012)	Domestic extraction, imports of raw material

4.4 Reporting of insights

4.4.1 Using MooV

In general, MooV applies a three-step approach (Define, Design, Deliver) towards reporting of insights/outputs (Figure 6):

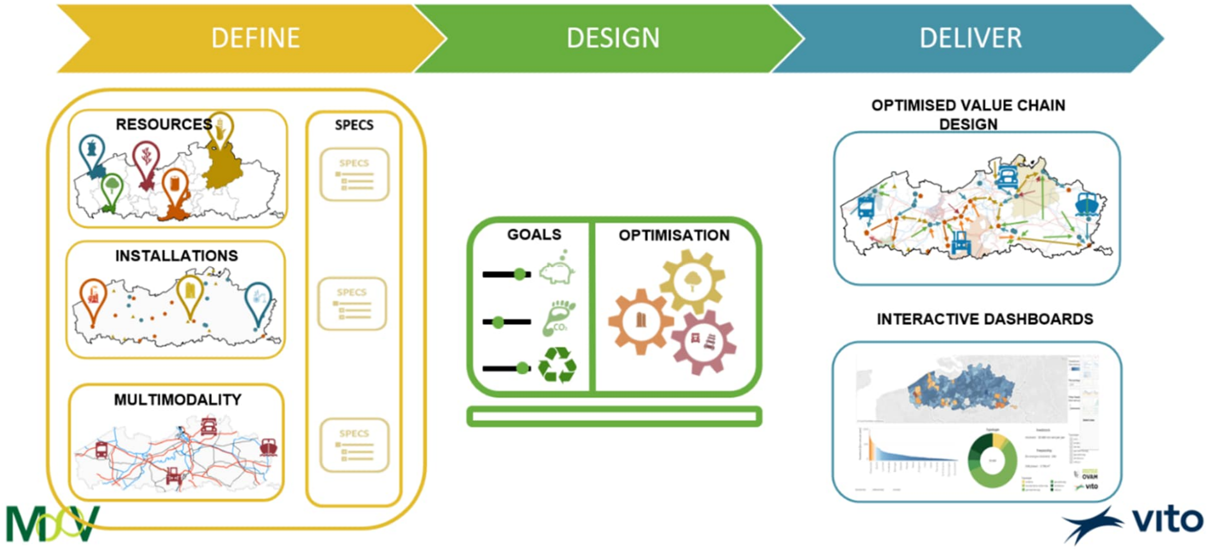

Figure 6:MooV's three-step methodology

Define phase: in which all scenario specifics are discussed with the client.

Design phase: in which the MooV model is customized reflecting the client's specific needs (defined in the Define phase).

Deliver phase: in which the MooV scenarios are ran – and outputs/results are presented and discussed with the client (Figure 7).

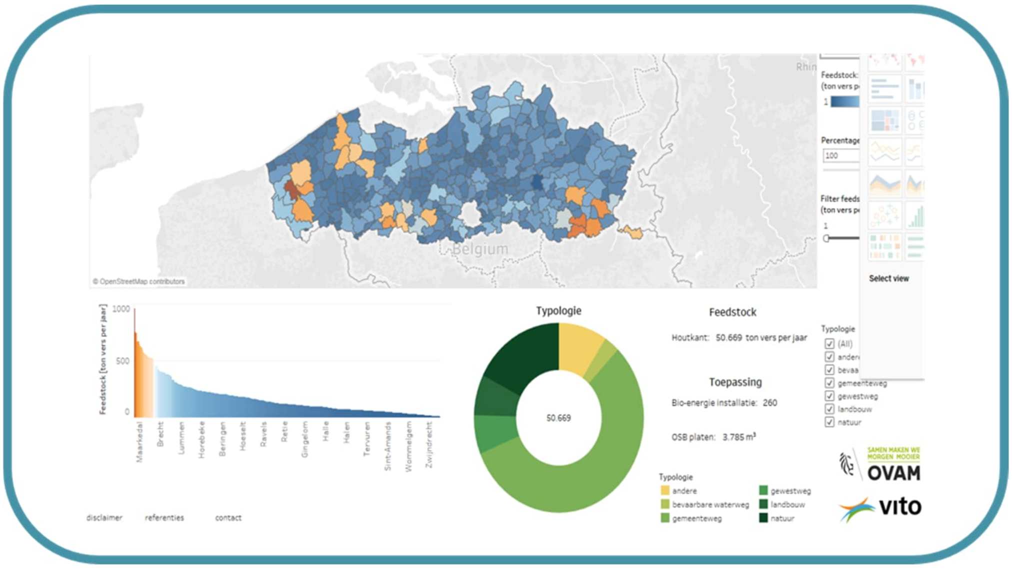

Figure 7:Dashboard with MooV output

Figure 7 shows a visual of a dashboard with MooV outputs. Such dynamic online dashboards are developed on demand and allow clients to compare results of the different supply chain scenarios side-by-side. The dashboard is intended to visualize the results of the simulated/optimized scenarios. However, it also might give the opportunity to the client to perform limited network simulations (e.g., changes in supply/demand). The dashboard format is customizable to client's needs.

4.4.2 *Using RFA*

Sankey diagrams provide a visual and accessible way to communicate the transition plan to stakeholders, garnering support from businesses, government agencies, and the community. We will use these diagrams to explain the policy makers the various ways in which an existing bio-waste can be integrated in the existing linear system while phasing out fossil fuel dependence. For instance, straw, in the current state, is mainly used as bedding residue and afterwards it gets composted. In a future scenario, further value chains would be introduced to convert these flows. For example, they can be utilized as insulation material and the leftover from this conversion process will be used in furnace application. Due to the increase of conversion facilities, additional environmental impacts must be calculated. This enables stakeholders to assess whether the goals of reducing fossil fuel dependence and enhancing circularity are being achieved.

Figure 8: Straw scenario description using Sankey (RFA: first Sankey diagram shows the initial state of straw usage, and the second Sankey diagram shows the projected evolution of resource flows over time, highlighting potential areas for residue valorisation, as depicted in the subsequent diagram

4.4.3 *Using IAT*

Results from the circularity assessment can be visualized in a simple table. Results from the application of the detailed assessment framework are represented within the Doughnut Economics model. This provides a visual representation of the inner boundary (socio-economic foundation) that represents the minimum standards for human well-being, and the outer boundary (environmental ceiling) that represents the environmental limits of the region. The area between these boundaries is a "safe and just space for the region." The regional targets are specific to the unique characteristics and challenges of each region. An illustrative example of the Doughnut model is given in Figure 8.

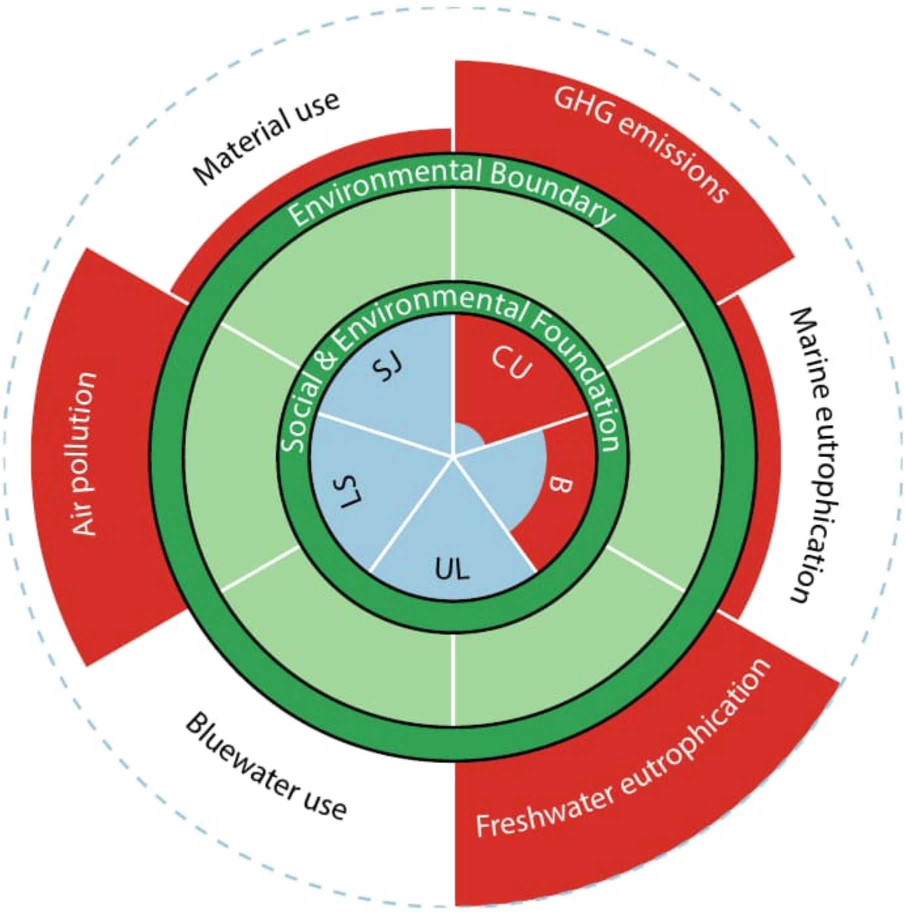

Figure 9: CU - carbon uptake, B - biodiversity, SJ - social justice, LS - life satisfaction, UL - unbuilt land. A red area represents an overshoot from the ceiling (for environmental boundaries) or a failure to meet a threshold (for social foundations). E.g., Bluewater use is deemed sustainable, as it is under the ceiling, while freshwater eutrophication is the indicator that overshoots its boundary by the highest margin.

ANNEX 1

Table 8: List of various aspects and sustainability indicators

Categories systematically considered	Aspect	Related indicators	Unit	Sources
Environmental	Climate change	Ozone depletion potential (ODP)	Kg CFC-11 eq	Wozniak et al. 2021
		Global warming potential	kg CO_2 eq	Skytt, T., Nielsen et al. (2020)
		Fossil fuel dependence	MJ	Solarin, S. A. (2020)
	Water quality and quantity	Eutrophication of freshwater	kg N(or P) cap^{-1} yr^{-1}	Li, Y., Shang et al.(2021).
		Water resource consumption	m3 water equivalent of deprived water	Alamdari, N et al. (2020).
		Ecotoxicity of fresh water	CTUe	Mainardis, M et al. (2021).
	Air quality	percentage of population exposed to PM 2.5	–	Gustafsson, M et al.(2018)
		nitrogen oxide (NOx)	ppm	Orellano, P et al.(2020)
		sulphur oxide (SOx).	ppm	Orellano, P et al.(2020)
		PM 2.5,		Orellano, P et al.(2020)
	Land use land use changes	Land degradation	m2/a(occupation or transformation)	Mainardis, M (2021)
		Land cover change	m2/a(occupation or transformation)	Karvonen, J et al.(2017)
	Soil pollution	Use of pesticides	kg/ha	Weissmannová et al. (2017)
	energy use	Share of renewable mix, intensities	% of electricity coming from renewables	Cucchiella, F et al. (2017).

Categories systematically considered	Aspect	Related indicators	Unit	Sources
	Biodiversity	Expenditure on biodiversity	% of GDP	Seidl, A. et al. (2021)
		Biodiversity Habitat Index	N/A (0-1)	Chaudhary, A. et al. (2018)
Social	**Governance**	Price regulation for biomass	USD	Popp, J. et al. (2021)
		Bio-economy focused legislation	no of Policies	Wang, Q., & Zhang, F. (2020)
		GDP investment on research and development	Currency of the country	Adedoyin, F. F. et al.(2020)
	Employee empowerment and employment conditions.	Temperature level at working stations		Coca, G. et al. (2019)
		Employee health and safety training hours	hr per year	Popovic, T. et al. (2018)
		Working hours	hr per year	Popovic, T. et al. (2018)
		Added value		Asheim, G. B. (2017)
	Gender-responsive	Gender-related Development index		Calicioglu, Ö., & Bogdanski, A. (2021)
Circular	**Transition from linear (fossil based) to circular bio based system**	Replacing non-renewable feedstock by biomass		Rosenboom, J. G., Langer, R., & Traverso, G. (2022)
		Substitution share indicator		Jander, W., & Grundmann, P. (2019)
		Sub-raw index	no dimension	Wolfslehner, B. et al. (2016)
	Reduce	Recycling for specific waste streams (RSWSI)	% (ratio of same units, namely tonnes)	Sub-indicators: Recycling rate of total packaging waste. Recycling rate of plastic packaging waste. Wood packaging recycling rate. Recycling rate of electrical and electronic waste (e-

Categories systematically considered	Aspect	Related indicators	Unit	Sources
				waste). Recycling of bio-waste per capita. Recovery rate of construction and demolition waste.
		Recycling rates (RRI)	% (ratio of same units, namely tonnes)	Sub-indicators: Municipal waste recycling rate Recycling rate of total waste excluding mineral waste
	Repair	Revenue from upgrade, repair and maintenance services	US Dollar ($)	Kravchenko, M. et al. (2019)
		Specific energy consumption in operations	kWh/m2.a	Kravchenko, M. et al. (2019)
	Remanufacture	Energy intensity	Joules/ US Dollar ($)	Hegab, H. A. et al. (2018)
	Material circularity	Material circularity indicator	between 0-1	Niero, M., & Kalbar, P. P. (2019)
		Material utilization score	%	Moraga, G. et al. (2021)
		Eco-efficient value ratio	Ratio (no unit)	Figge, F. et al. (2018)
Economical		Emerging investment ratio		Karwowski, E., & Stockhammer, E. (2017)
		Share of SMEs		Regmi, M. B. (2020)
		Value added		Ronzon, T. et al. (2020)
		Jobs in bioeconomy		
		Import and export prices of the sector		Sheinbaum-Pardo, C. et al. (2012)
		Innovation intensity		Velasco-Muñoz, J. F. et al.(2021)
		Return on investments		Velasco-Muñoz, J. F. et al. (2021)

ANNEX 2

Table 9: Regional transition theme, regional target, input required.

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
MooV + LIST +ALCN	Main purpose(s)+C2:C15C2:C14C2:C13C2:C2:C31	Tourism, Mobility, Agriculture, Industry	Agriculture, wine and recreational activities regarding lake Neusiedl, Commuter Traffic	Decarbonisation of energy production, agriculture and wine, mining, fur & leather	Forestry	Spa industry, glass and porcelain manufacture, building materials, textiles and musical instruments manufacture, ignite mining (loosing siginifcance) , Quarries	Chemical Industry
	Geographical scope: Area of concern	Andalusia	Northern Brugenland NUTS AT 112	Western Macedonia	Finland entire country	Charels Spa Region	North Rhine-Westphalia
LIST	Transition themes, e.g. Energy transition, agroecology, Post-growth economy, … etc.	Resource efficiency and energy transition.		Energy transition	Energy transition, biodiversity preservation/regeneration	Energy transition: The biggest employer in the region is in coal mining industry	
	Quantified target for one or several socio-economic, environmental impact(s)	- Increase employment - Sustainable local food production / agriculture - Energy and resource efficiency (including Reduce Waste generation, Increase Waste recycling, energy sources for industry) - Shift to sustainable mobility / transport & logistics - Reduce impact of tourism on biodiversity	Indicators: - Utilized material flows of secondary raw materils - employment bioeconomy - Turnover bioeconomy => if too ambitious Bioeconomy companies - Car/Capita -used biobased carbon -used CO2	- The Municipality of Kozani's Action Plan: 100% CO2 emissions' reduction in 2030 compared to the base year 2010. - The Green City Accord: - A significant improvement in air quality moving closer to respecting the WHO's Air Quality Guidelines	Improve the valorisation of forestry side streams, switch to renewable energy sources, . - target for renewable energy is 51% by 2030 (2019 NECP - National Energy	Indicator Ideas: - Area treated Brownfield - educational rate - population development -quantity R&D facilities	- "Bioökonomiestrategie": - more efficient resource management - the introduction of value circles - cascade use of resources: the food first, energy second approach, when using biomass, so (food) waste side streams should be considered specifically.

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
		(exploitation of coastal area)		- Improve the quality of water bodies and the efficiency of water use - Progress in conserving and enhancing urban biodiversity, including through an increase in the extent and quality of green areas in cities, and by halting the loss of and restoring urban ecosystems. - Significant improvement in the management of household municipal waste, an important reduction in waste generation and landfilling, and a substantial increase in re-use, repair, and recycling - Significant reduction in noise pollution, moving us closer to the levels recommended by the World Health Organization. Indicator ideas: - Bioeconomy employment - Bioeconomy turnover - Bioeconomy companies	and Climate Plan), considering a share of 37% in 2019. - For transport, the proportion of renewable energy must be 14% in each Member State by 2030. - Finland's Distribution Obligation Act will increase the share of biofuels in transport from 18% to 30% in 2021–2029. (Finnish Ministry of the Environment 2022) - Achieve carbon neutrality by 2035 and to halt the decline in biodiversity by 2030. (Finnish Ministry of Finance 2023) -		- "Innovation strategy NRW" and the "Carbon Management Strategy": that the regional change to more sustainability and the commitment to the environmental goals has high priority. - NRW's sustainability strategy: - Use resources economically and efficiently - Increasing economic efficiency in an environmentally and socially responsible way - Increase employment levels, especially among women - Create new solutions for the future - Support sustainable lifestyle and consumption - Increase share of sustainable production - Increase share of sustainable public procurement - Reduce GHG emissions - Protect sustainable forestry - Protect ecosystems, ecosystem services and habitats

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
				- Energy decarboni-sation			
MooV + LIST	Time horizon to which the target shall be reached / Total period for which the assessment is carried out	Depends on the pathway			2030	2033 (away from coal)	
	Planning period: shortest time span at which time related decisions can be made by the model. This allows to capture seasonal variations in e.g., supply or demand.	Annual for most pathways	Annual	Annual (?)			
MooV + LIST	Main sectors / main processes contributing to the impact under focus	- Services (including mainly tourism) (75% GDP) - Industry (12% GDP), - Construction (7% GDP), - Agro-fishing (6% GDP)	- Primary Production i.e. wheat, soy, reed and Wine - Lake Mud (differnt to sewage sludge)	- Energy production - Agriculture - Wine - Fur & leather	Forest management (stock and flows) Forestry products industry	Spa Tourism industry, Manufacture of metal structures and fabricated metal products, except machinery and equipment - 37 % GDP Beverage production - 11 % GDP Manufacture of other non-metallic mineral products - 10% Textile - 8% vehicles - 8%	- Lignite mining - Chemical industry - Crop production - Energy production

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
	Main raw materials or products of concern / reference flow	- Agriculture and food products flows -	- straw - sludge - Wine residues (pomace and prunings)	- Manure, solar power, biomass - Cereal crops, fruit trees - Grapes - Animal skins	Wood resource, wood products, Forestry side streams, Water consumption and treatment, use of chemicals in pulp and paper industry (highly significant for the country).	Bio-waste from restaurants, catering and hotel industry, Biodegraadable municipal waste	- Chemicals (naphta feedstock?) - Rapeseed (for chemicals) ?
LIST	Main drivers towards the target / Identified transition pathway (main actions)						
	Technical transition (infrastructures development / technology switch, ...)						
	Policy incentives	• The 2021 Andalusian Climate action Plan • The 2018 Andalusian Circular Bioeconomy Strategy • The 2018 Strategy for Sustainable Development 2030 • The 2019 Integrated Waste Plan of Andalusia • The 2022 Circular Economy Law • Andalucía energy strategy 2030		• National Strategy for the Circular Economy 2018-2030 • National Energy and Climate Plan 2030 • Long-term Strategy 2050 • National Air Pollution Control Program 2020 – 2029 • National Development Program 2021-2025 • National Biodiversity Strategy • Development Plan for the Greek Economy • National Recovery and Resilience Plan • National Waste Management Plan	- Recovery and Resilience Plan of Finnish Government - enhance the economy of Finland through green technologies. - EU's target to reduce net greenhouse gas emissions by at least 55% by 2030. - EU forest strategy for 2030 - EU biodiversity strategy for 2030 - 'Fit for 55' -	Development Programme of the Region 2021-2027	

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
				• Regional Waste Management Plans • Regional Social Inclusion Strategy • Digital Transformation Bible • Operational Plan for the Sustainable Urban Development Strategy of Western Macedonia, Municipality of Kozani, Municipality of Florina • Integrated Spatial Investment for the Utilization of the Lakes of Western Macedonia	proposals for transformation from linear to circular economy in Finland, (proposed changes to EU Emissions Trading System (ETS), and Land Use and Land-Use Change Forestry). - Finnisch ministry of the environment (2023) strategic programme for circular economy - objectives for use of natural resources to promote circular economy model and to assist accomplishment of the targeted carbon neutrality by 2035.		
	Societal (consumer behavior, market shift forecasts, …)	Concern of population about environmental issues related directly or indirectly to their consumption model (food, energy, natural	Concern of unemployment Concern of the enivronmental crisis with the neusiedler lake	Concern of population about decarbonization increasing unemployment and reducing income in a region already struck	nature and forest cover 75% of the land, and the emotional connection of	Brain drain, reluctance to adopt new technologies, education gap regarding CBE	

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
		environment). Concern of population about unemployment.		hard by the crisis	population is fully part of their culture and daily life.		
	Economic (investments, costs and revenues, subsides, taxes, …)	Low support from public funding - lack of stability of the regional public support instruments				Low funding support and investment on R&D and education	
MooV + LIST + ALCN	Value chain (from raw materials generation, to intermediate product, end product, use and end of life) description through detailed processes/stakeholders nodes available	General processing for food, drink and milk, from materials reception to post processing operations	- Primary Production processes, Lignocellulose based, residues from pomace (esp. vine), Sludge	Sustainable energy production Agriculture	General processing steps available for transformation of wood in sawnwood, woodboards, pulping, paper making, textile	Processing of food waste & bio-waste from the tourist industry for energy conversion, separation, biogas plants, composting, oils for the production of technical oils and lubricants	
MooV	Potential geographic location for each node/stage is available	Probably available, depending on the node/stage	is available	probably available	available	Partly available	
	Transportation options between the different stages	Depends on the pathway	depends on transformation pathways	depends	depends on the selected material case	Depends on the pathway	
	Special constraints that apply to specific stage or to the supply chain as a whole (e.g. timing: like raw material needs to be processed within X hours/weeks/...; biomass availability during the year (seasonal crops), impossible combination of processing steps; quality aspects: processing step X requires fresh biomass Y which is not older than Z, etc...)	For agricultural pathways, there could be seasonal production (affecting biomass availability) and seasonal storage constraints. For tourism, seasonal issues need to be considered.	- primary production def. timing (storage issues) availability (seasonal) - Sludge different more constant	?	depends on the selected material case	Seasonality of the tourist industry (most and least busy period?)	
	List of proposed interventions and where they impact the supply chain.		- harvesting time reed (only winter months due to natural law restrictions)				

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
	Availability of background data required for each assessment tool						
MooV + ALCN (mainly material capacities)	For each stage of the value chain:						
	Location	Partly available, it might be difficult for some primary production linked pathways	Difficult for primary production, secondary production adresses available	GIS coordinates available	GIS coordinates available	Partly available	GIS coordinates available
	Processing capacities					Partly available	
	Material balance equations					estimations	
	Processing Costs (OPEX)					estimations	
	Investment cost (CAPEX)					unknown	
	For each transport option:						
	Transportation capacities					Road & train?	
	Costs (per trip, per ton transported, per km)…					?	
	Other (optional): Criteria to narrow down the list of potential locations, Environmental impacts (e.g., CO2/km transported or CO2/ton processed, ...) for each activity, Market offer and demand						
LIST + ALCN	Production and/or Consumption-based quantification (euros) of significant flows (energy and materials per type), per sector. >> Market data, consumption data, regional / national statistics, bill of mass, bill of energy.	Figures available for most pathways, specially for materials flows. As for the energy flows, there could be global figures for the region/macro level per pathway		- Average of 6,000 tonnes of woody biomass per year from a government-sponsored programme - 9,000-12,000 tonnes of residual forest biomass per year - 1,500 tonnes per year of residual biomass from lavender cultivation - 45 tonnes per year from walnut shells	Global number available	Partial data for the catering, hospitality sector. Biodegradable waste from kitchens and catering establishments in 2021 was 635.3 t, more research on energy consumptions required	- sugar beet (and potato) have an area under cultivation of 61.000 to 81.000 hectares
	Variation of the consumption / production considering each intervention. >> Estimates and forecasts officially published.	Some figures linked to % that could be found in regional strategic agendas or plans				No	

Required for tool:	Inputs required:	*Andalusia (Spain)*	*Northern Burgenland (Austria)*	*Western Macedonia (Greece)*	*Finland*	*Charles Spa Region (Czech Republic)*	*North Rhine-Westphalia (NRW-Germany)*
ALCN	As detailed as necessary classification system for bioeconomy commodity classes	Certain pathways identified, with further exploration possible	Defined value chains, transformation pathways			Certain pathways identified, with further exploration possible	
	Quantities of resiudal bio based resources derived from primary and secondary production systems	Available for some pathways linked to agri-food/primary sector	Available for Primary sector not for secondary sector			partly available data from secondary food production	
	Composition of residue (protein , starch, polymers, sugars, lipids, polyphenol)	Few information only for some agricultural biomass residues				mixed waste	
	Temporal availability	Seasonal production				Seasonal fluctuations of the tourism sector	
	Wet content	Few information only for some agricultural biomass residues				?	
	Transformation platform / concept (Biorefinery)	Just a few biorefineries available in the region				composting, biogas plants etc	
	Current usage of the secondary biomass (byproduct)	Landfill or energy; for some pathways, value added products				Landfill or energy	

ANNEX 3

Table 10:Regional main drivers, desired policy incentives and identification of new value chains

Related Requirements	Identify the main driver for the transition and final targets (e.g. reduce by X% GHG footprint by 2030/increase by Y% the amount of renewable energy for all sectors)	Main actions on contextual arguments/
Northern Burgenland (Austria)	•Creation of local value chains rising regional business. Expressed as business gross product generated in the region NUTS 112 •Increasing employment in the region. Allocated to the bioeconomy •The increase in the number of young adults living in the region •Water level of the Neusiedler lake (important for tourism) •Reduced commuting km •Northern Burgenland is a top performer in terms of GHG emissions and renewable energy share	•Public data needed of producers in the Nace C and Nace A sector •Estimation of how much farmers produce biomass themselves (This type of biomass utilization fails the common statistics) •Quantification of biomass and conversion abilities, identification of stakeholders and assessment of the willingness to cooperate
Western Macedonia (Greece)	•Decarbonisation and climate neutrality of the region (emission reductions). Creation of new local value chains in bioeconomy	•Identification of local stakeholders, their needs, main barriers

Finland	• According to the Recovery and Resilience Plan (EU), Finland aims to achieve carbon neutrality by 2035 and to halt the decline in biodiversity by 2030	• Circular economy targets and renewable energy targets must be optimized and quantified together, since wood-based energy (mainly from the incineration of forest industry side streams and logging wastes) represents 77% of the total renewable energy in Finland. The renewable energy share of all energy was 37% in 2019, and the same year Finland reported that its target for renewable energy is 51% by 2030.
Charles Spa Region	• Decarbonization and circular valorisation of waste from existing value chains like the Spa industry, Food & Beverage production • Charles Spa is a Just Transition Funding Region and following the EU plan for the regions in transformation.	• Proposal for concrete steps for transformation in a multi actor approach, i.e. with the direct involvement of regional stakeholders, securing funding resources, invest in CBE related education and R&D centres, research added value applications for waste streams other than energy

Germany	• Reduction of GHG by 65 percent in contrast to 1990 (according to the Klimaschutzgesetz NRW from 2021). Climate protection goals shall be raised in the amendment of the climate protection law, which is in preparation. • Climate protection should act as driver of innovation and modernization. • NRW is within transition from a region partly influenced by lignite mining (ends 2030) to fostering the development of innovative and sustainable companies and enterprises. A subregion of NRW, the Rhenish Mining Region, wants to become a model region for bioeconomy. • The chemical industry in NRW has set itself decarbonization targets, including a shift from fossil based to renewable feedstocks	• Improvement of end-of-waste and transportation legislation to facilitate the use of additional feedstocks. • The creation and expansion of scale-up facilities. • Invest in infrastructure, R&D, novel technologies to close loops and create innovations needed for the transition. • Statistics exist on national and state level (eg on economic sectors or biomass or waste production). A more detailed monitoring of biobased feedstocks at the producer level is needed to manage availability.
Andalusia - Spain	• Increase in the number of companies using the by-product or waste streams of others as feedstock, making the benefits of industrial symbiosis evident. • Large contribution of renewable energies to the Andalusian energy mix, due to favourable environmental conditions. • Creation of new jobs.	• Increasing the availability of sustainable biomass for utilization through innovative treatment. • To increase the number of biorefineries in Andalusia. • Facilitating the flow of information between the different stakeholders • Development of biohubs where sustainable biomass management can be realized.

ANNEX 4: MooV methodology

Goal and scope definition (Define)

When setting up a new supply chain or changing an existing chain, the supply chain options can be numerous. This phase has the objective to define the potential supply chain configurations in function of existing components and potential additional components, the requirements to be considered and the questions to be answered. This phase sets the boundaries of the MooV analysis or in other words, it defines the borders of the virtual supply chain to experiment in. Different components are at stake which are not necessarily performed in a chronological order:

1. Concept definition

• Sketching the problem statement

• Defining the overall objective (minimise cost, maximise profit, minimise environmental impact, … or combination of objectives)

2. Time Context

• Define the time related context

1. Seasonal product fluctuations, historic trends, future projections…
2. Storage & transport period
3. Planning horizon and planning period

3. Products

• Define all relevant products in the value chain

1. Primary product/resources/feedstock (roadside grass…)
2. Intermediate product (chopped grass, baled grass…)
3. End-products (biogas, building materials, landscaping materials…)

4. Activities

• Define all relevant activities in the value chain

1. Pre-processing (pressing, chopping…)
2. Storing or transferring (silage, bales…),
3. End-processing (compounding, digesting, extruding…)

4. Transport modes (truck, train, ship…)

5. Supply Chain Diagrams

• Diagrams serving as a blueprint of the supply chain design and defining the system boundaries:

1. Block flow diagram representing all relevant interconnections between products and activities

2. Network flow diagram representing all possible product flows between locations (i.e. location of resources and activity sites)

6. Geographic Context

• Define geographical and spatial parameters:

1. Boundaries of the study area

2. Potential or actual location of resources

3. Potential or actual location of activity sites

4. Transportation/Logistics network(s)

7. Conditional Context

• Define specific conditions based on expert knowledge (via survey), scientific literature (via review) and empirical (via demo-cases);

1. Regulatory conditions: conditions can limit (negative) or favour (positive) certain products, activities, interconnections, configurations…

2. Physical conditions: economic, technical, environmental, social… constraints or preferences.

8. Competitive/Cooperative Context

• Define relevant third-party value chains in view of competition (risk) or cooperation (opportunity).

• Define how the new value chain interacts with the existing value chains.

Specific MooV-shell development (Design)

MooV's core-shell architecture is developed with a focus on flexibility for application on any type of activity, product, condition or objective. An important prerequisite is that this flexibility is offered without the need to question the system's fundamental logics (i.e. MooV-core), nor the need for major additional model developments for each individual case. This phase has the goal to customise the MooV-shell to meet the specific needs and objectives as described in the define phase.

9. MooV database-design

• Design the Database structure to match the Case specifics

• Datafication - collect quantitative/qualitative data relevant for the cases:

1. Physical data: masses, volumes, density… of products…

2. Technical data: storage and processing capacities, transport capacities, quality requirements…

3. Economic data: costs, revenues…

4. Environmental data: greenhouse gas emissions, sustainable transport, land-use change

5. Time data: growth models, transport times, production speed, (un)loading times…

6. Geographical data and analysis: locations of resources, activities, transport network…

10. MooV model-design

• Tailor the MooV-model – Mixed Integer Linear Programming (MILP) coding to match the Case specifics

1. Programme the objective(s): minimise costs, emissions, mileage… or maximise revenue, storage use, production volume…

2. Programme the possible interconnections and network configurations (based on 4)

3. Programme additional constraints and requirements

Supply chain analysis and optimisation (Deliver)

MooV supports in defining the best supply chain configuration by comparing alternative scenarios side-by-side and assess the impact of critical decisions on the efficiency and configuration of the overall chain by performing sensitivity analyses.

11. Scenario or 'what if' analysis

• Experiment with the virtual supply chain: by running 'what-if' scenarios MooV shows the impact of strategic value chain choices on the value chain performance and allows comparing different value chain scenarios with each other:

1. Greenfield analysis, "what if", policy changes, etc.

2. Identification and budgeting of critical hurdles

3. Analyse the impact of proposed mitigation measures

12. Sensitivity analysis

• Examine the robustness of the value chain by performing sensitivity analyses on critical parameters. These sensitivity analyses are performed by using multiple what-if analyses to see how the configuration and efficiency of the chain varies by influence of a parameter.

13. Interpretation and discussion of the results

ANNEX 5: Calculation of circularity indicators

Table 11:Calculation formulation for the circularity indicators

No.	Calculation formula	Explanation
1	Output of main mineral resource ¼ GDP/total consumption of main mineral resource (Unit: 10,000 U/ton)	A higher value means more efficient use of mineral resource. The main types of mineral resources include iron-, copper-, lead-, zinc-, tin-, antinomy-, tungsten-, molybdenum-, pyrite-, and phosphate ore, etc
2	Output of energy ¼ GDP/Energy consumption (Unit: 10,000 ¥/ton sce)	A higher value means more efficient use of energy. The energy source includes coal, oil, natural gas, nuclear power, wind power and hydro power
3	Energy consumption per unit of GDP ¼ Energy consumption/GDP (Unit: ton sce/10,000 ¥)	The total energy consumed per 10,000 ¥ produced. The lower value means more efficient energy consumption.
4	Energy consumption per added industrial value ¼ Industrial energy consumption AVI(Unit: ton sce/10,000 ¥)	The lower value of this indicator means more efficient energy consumption.
5	Energy consumption of key industrial product ¼ Energy consumption of steel (copper, aluminium, cement, fertilizer, paper)/steel production (copper, aluminium, cement, fertilizer, paper) (Unit: ton sce/ton)	Key industrial sectors include mining industry, manufacturing industry, water, electricity and gas production and supply industry. Main products include steel/iron, copper, aluminium, cement, fertilizer, paper etc. The lower value means more efficient energy consumption
6	Water withdrawal per unit of GDP ¼ total amount of water withdrawal/GDP(Unit:10,000 m3 /¥)	Water withdrawal includes all kinds of fresh water sources, such as surface water, groundwater, recycled wastewater, rainwater, desalinated seawater etc, but excludes the directly used seawater. The lower value means more efficient water consumption.
7	Water withdrawal per added industrial value ¼ amount of industrial water withdrawal/AVI(Unit:10,000 m3 /¥)	Water withdrawal means water consumption. Water withdrawal here is the water consumed during the industrial processes, such as manufacturing process, cooling process, air conditioning and purification processes. Fresh water consumption value here

No.	Calculation formula	Explanation
		does not include any recycled water. The lower value means more efficient water consumption
8	Water consumption of key industrial sector product ¼ total amount of fresh water consumption/total amount of steel production (copper, aluminum, cement, fertilizer, paper)(Unit:10^8 m3 /ton)	Water consumption efficiency in key industrial sectors.
9	Coefficient of irrigation water utilization ¼ actual amount of irrigation water consumption/total amount of irrigation water consumption	Ratio of actual amount of irrigation water consumption to total amount of irrigation water consumption. The higher value means more efficient water use in agricultural sector
10	Recycling rate of industrial solid waste ¼ (industrial solid waste integrated utilization Q/Industrial solid waste generation) x 100%	Ratio of amount of integrated utilized industrial solid waste to total amount of industrial solid waste.
11	Industrial water reuse ratio ¼ (industrial repetitive water use Q/Industrial water consumption) x 100%	Industrial water reuse includes both recycled water reuse and cascaded water reuse. Industrial water consumption includes water consumption for both industrial and living purposes.
12	Recycling rate of wastewater ¼ (Treated wastewater reuse Q/Total treated wastewater Q) x 100%	The reuse of treated wastewater includes both treated domestic wastewater and industrial wastewater that is qualified with the national recycling water standard. The total treated wastewater is the actual amount of wastewater treated in the wastewater treatment plant, including physical, biological and chemical treatment.
13	Safe treatment rate of municipal rubbish ¼ (total amount of safely treated domestic waste/total amount of domestic waste cleaned up) x 100%	Ratio of total amount of safely treated domestic rubbish to total amount of domestic rubbish.
14	Recycling rate of iron scrap ¼ (Amount of recycled iron scrap/total amount of iron production) x 100%	Ratio of amount of recycled wasted iron scraps to total amount of iron production.

No.	Calculation formula	Explanation
15	Recycling rate of non-ferrous metal ¼ (Amount of recycled non-ferrous metal/total amount of non-ferrous metal production) x 100%	Ratio of amount of recycled mom-ferrous metal to total non-ferrous metal production.
16	Recycling rate of paper ¼ (Amount of recycled paper/total amount of paper production) x 100%	Ratio of amount of recycled paper to total amount of paper produced
17	Recycling rate of plastic ¼ (Amount of recycled plastic metal/total amount of plastic production) x 100%	Ratio of recycled plastic to total amount of plastic produced.
18	Recycling rate of rubber ¼ (Amount of recycled rubber/total amount of rubber production) x 100%	Ratio of recycled rubber and total amount of rubber produced.
19	Industrial solid waste for final disposal (Unit: ton)	Total amount of industrial solid waste for final disposal.
20	Industrial wastewater discharge (Unit: ton)	Total amount of discharged industrial wastewater.
21	SO_2 emissions (Unit: kg)	Total amount of SO_2 emission
22	COD discharge (Unit: kg)	Total amount of chemical oxygen demand (COD)

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