CEE2ACT

Empowering the Central and Eastern European Countries to Develop Bioeconomy Strategies and Action Plans

D2.3 - Report on sustainability assessment of the bioeconomy concepts

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EXECUTIVE SUMMARY

The bioeconomy is a cornerstone in achieving the 17 Sustainable Development Goals (SDGs), particularly "Zero Hunger" (SDG1), "Good Health" (SDG2), "Industry and Innovation" (SDG9), "Responsible Consumption" (SDG12), and "Climate Action" (SDG13). The CEE2ACT initiative aims to assist Central and Eastern European (CEE) countries in transitioning to a circular bioeconomy by promoting sustainable biomass use and converting it into value-added products. Tailored strategies are necessary to ensure bioeconomy solutions meet the sustainability needs of each target country, taking national conditions and public acceptance into account from the outset.

To maximize the bioeconomy's potential, all sectors—including agriculture, forestry, aquaculture, and biotechnology—must be equally considered, along with their respective products such as food, feed, wood, and biobased goods. Evaluations of bioeconomy strategies must align with national frameworks and account for diverse stakeholder interests. A collaborative approach was adopted to assess relevant options and indicators, identifying challenges and potentials in each of the 10 target countries through a baseline assessment. Feasibility and sustainability of options were evaluated using nine indicators covering environmental, social, and economic dimensions. Environmental indicators utilized Life Cycle Assessments, while quantitative assessments analyzed renewable energy and biomass production. Social indicators like consumer acceptance and economic factors like willingness to pay were gauged through surveys.

Key findings highlighted that locally tailored solutions yield varying results. On average, the most sustainable options included central and small-scale heating plants, food waste reduction, sustainable diets, and nature tourism. Options like insect farming and inland aquaculture had lower feasibility due to limited acceptance or biomass yield.

Recommendations for specific countries include:

- **Bulgaria:** Sustainable diets, nature tourism, and biogas plants.
- **Croatia:** Sustainable diets, nature tourism, and bio-plastic production.
- **Czech Republic:** Food waste prevention, biogas plants, and multi-feedstock biorefineries.
- **Greece:** Sustainable buildings, nature tourism, and food waste prevention.
- **Hungary:** Sustainable diets, nature tourism, and biogas plants.
- **Poland:** Nature tourism, biofuels, and food waste prevention.
- **Romania**: Nature tourism, sustainable buildings, recycling of organic waste
- **Serbia:** Biogas plants, nature tourism, sustainable healthy diet
- **Slovakia:** Food waste prevention, sustainable diets, and biofuels.
- **Slovenia**: Sustainable healthy diet, biogas plants, nature tourism

CEE2ACT facilitates a shift toward diversified green economies while addressing social and economic challenges. It will provide national roadmaps to support CEE countries in developing bioeconomy strategies, addressing re-skilling needs, and attracting investment for smarter growth.

DISCLAIMER

The CEE2ACT project is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

1 Introduction

1.1 Position in the CEE2ACT project

The evaluation within workpackage 2 (WP2) is situated in the project CEE2ACT next to separate evaluation works in other workpackages, for details see Table 1. Each of the evaluation frameworks have different aims and thus different indicators are foreseen for quantifying corresponding criteria.

Table 1: Evaluation concepts within CEE2ACT

CEE2ACT Workpackage (WP)	Aim of the evaluation	Corresponding deliverables	Due Date
WP2	Evaluation of options to measure the implementation of bioeconomy	D2.2 "Set of sustainability criteria and indicators for bioeconomy implementation" and D2.3 "Report on sustainability assessment of the bioeconomy concepts"	Dec 2023 (M16) Aug 2024 (M24)
WP3	Evaluation of stakeholder engagement	D3.3 Impact evaluation report	Aug 2025 (M36)
WP5	Evaluation of knowledge transfer	D5.2 Evaluation and recommendations from CEE and EU perspective	July 2025 (M35)

1.2 Aim of the evaluation

CEE2ACT is empowering countries in Central Eastern Europe and beyond (Bulgaria, Croatia, Czech Republic, Greece, Hungary, Poland, Romania, Serbia, Slovakia and Slovenia) to develop circular bioeconomy strategies and action plans through innovative governance models.

Bioeconomy is expected to contribute to all 17 Sustainable Development Goals (SDGs) and in particular to SDGs 1 and 2 (Zero Hunger & Good Health and Well-Being), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Bioeconomy at project level shall include and interlink:

- land and marine ecosystems and the services they provide;
- all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries, and aquaculture) and other sources (insects, algae, yeasts, fungi, microorganism etc.)

- and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services.

This involves not only the extraction of renewable raw materials (Principle 1: the avoidance of fossil carbon sources and scarce, non-renewable raw materials) but also the utilisation of biogenic waste and residues (Principle 2: the circular orientation) in a sustainable way (Principle 3: the recognition of ecological and social framework conditions).

There are several solutions (hereafter called 'options') that can contribute to an implementation of bioeconomy from a bottom-up perspective in different member states (MS) in the EU.

According to Mubareka et al. (2023), the bioeconomy is "a set of intertwined interconnections of various degrees of strength and with directionality and thus challenging to quantify". However, we should "think about how to identify the most critical nodes and connections in order to focus on indicators in those areas, or to attribute weights to indicators". Therefore, the clear benefit of the evaluation is to improve understanding of interactions within the bioeconomy.

The objective of the evaluation is to achieve informed decision-making processes, societal engagement and innovation, building on the practice of partners from contributing countries (Austria, Germany, The Netherlands, Belgium, Spain, Finland, Sweden), and addressing relevant economic, social and environmental aspects. As part of the project, questions arise on how to implement bioeconomy, which alternative scenarios are feasible for bioeconomy implementation and which measures to consider in an action plan of a bioeconomy strategy.

2 Methodology

2.1 Assessment framework and definitions

The objective of the evaluation is the implementation of a sustainable bioeconomy. The sub-objectives are therefore based on "triple bottom line" (Elkington 1994) to track economic, environmental and social imperatives towards a sustainable bioeconomy.

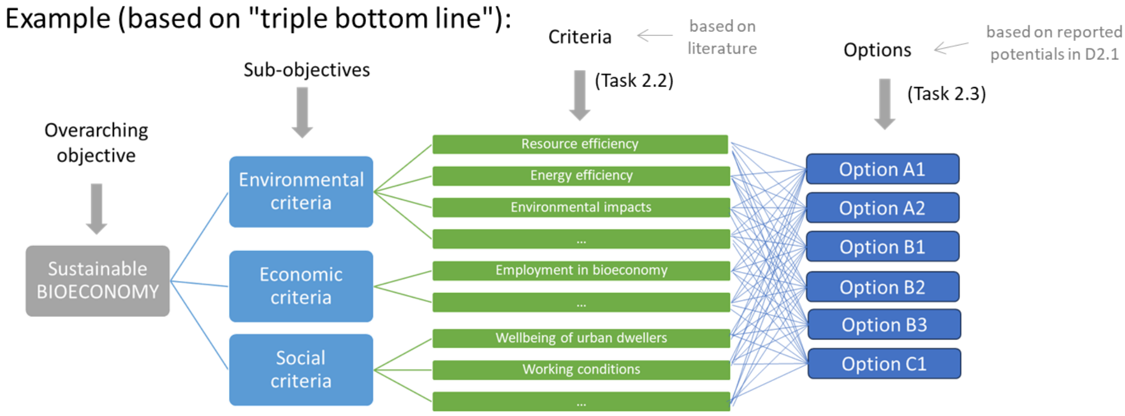

Figure 1: Target hierarchy based on the sub-objectives of sustainability

These objectives need to be represented by appropriate criteria that are made measurable by indicators. Therefore, criteria and indicators have to be found for each of the sustainability pillars. To ensure sustainable bioeconomy strategies the evaluation of options must be carried out against the respective national framework conditions. This applies to both national circumstances and political preferences. Different stakeholders have most often divergent preferences that need to be considered as well. With this in mind, all options, criteria, indicators and stakeholder preferences are combined in a multi-criteria-decision-analysis (MCDA). The process and structure of the MCDA are both shown in Figure 1. Stakeholders, that are persons working in the bioeconomy field but beyond the CEE2ACT consortium, have been included in the selection of options as well as the selection of indicators to enable an understanding of trade-offs and a classification of options for future action plans of the national bioeconomy strategy.

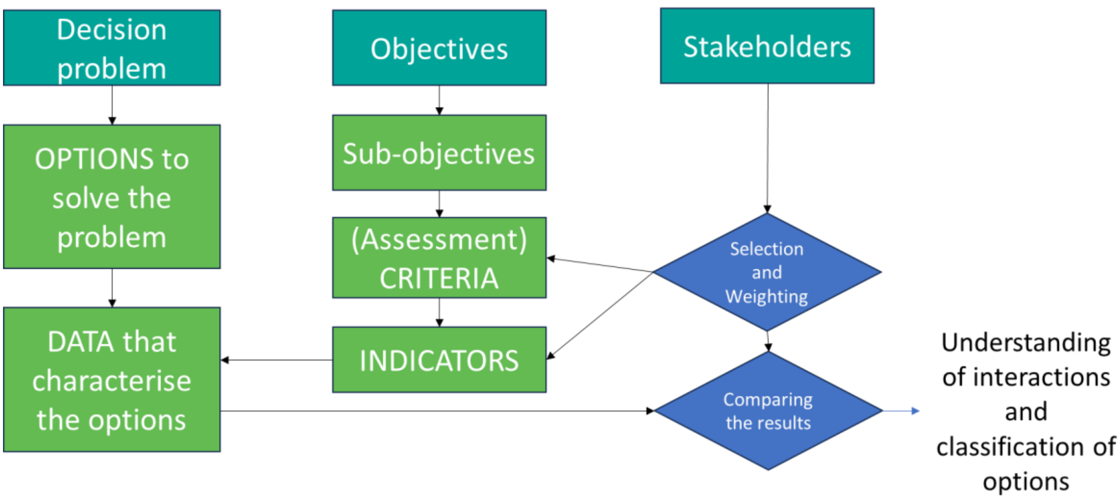

Figure 2: Process and structure of a multi-criteria decision analysis (MCDA) based on Kühmaier (2023)

To ensure a common understanding of frequently used terms for evaluation processes, the most important terms are described in more detail in Table 2.

Table 2: Glossary of terms used in the evaluation

Terms	**Definition**	**Examples**
Criteria	Criteria are derived from the goals. They assess activities and measures for their performance to achieve the goals	*Energy efficiency* *Gender equality* *Investment*
Functional unit	The unit that allows quantification of the function that is defined. It should represent the performance of the functional outputs of the product system.	*1 kg fish, 1 MJ heat*
Indicator	Indicators are defined for criteria that specify observable characteristics of target achievements. The indicators show if, and to what extent, the target is met.	*GHG emissions in kg CO_2e* *Share of women with jobs in %* *Jobs created in Full Time Equivalents*
Options	Options refer to measures or actions that are necessary to implement bioeconomy in a country; referred also to bioeconomy-related options or bioeconomy options	*agricultural waste for biogas production* *biodegradable plastic mulch films* *multi-feedstock biorefinery processes* *microalgae for biofuels* *food residues for food or feed ingredients*
Scaling	The value of the indicators needs to be transferred into scaled values	*By ordinal scale*
Scenarios	Scenarios are outlined for each bioeconomy option to better describe/or to narrow down the option by considering all process steps, flows and assumptions	*Prevention of clear cuts in forests*
Situation	Describing the situation before and after the transition to bioeconomy	*'Status Quo Situation'* *'Bioeconomy Situation'*
Upscaling	The value of the indicator per functional unit is upscaled at the country level.	*Value multiplied with production volumes from national statistics*

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2.2 Stakeholder engagement procedure

Using a multi-actor approach, the decision-making process actively included not only the core WP2 team but also other CEE2ACT partners and external stakeholders. Figure 3 illustrates the evaluation process, highlighting the stages where the involvement of CEE2ACT partners and stakeholders is anticipated.

To ensure that stakeholder perspectives and preferences are fully integrated into the evaluation methodology, stakeholders were engaged in the selection of criteria and indicators, as well as in identifying options for evaluation. Additionally, CEE2ACT partners contributed to the data collection efforts necessary for the assessment.

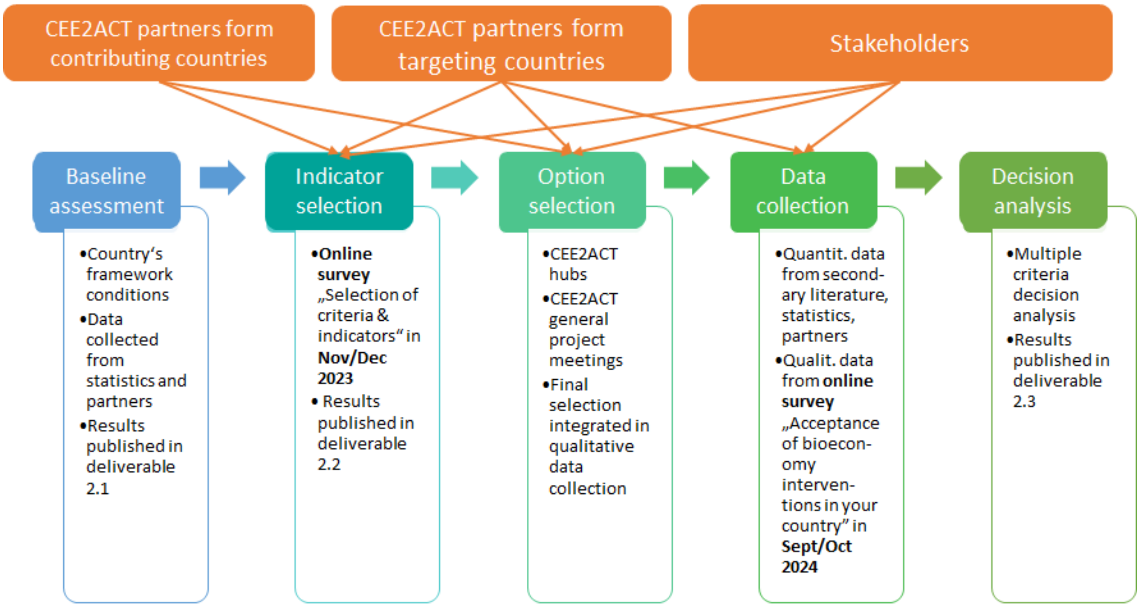

Figure 3: Procedure of the evaluation within WP2

The first online survey with the title "Selection of criteria & indicators for the evaluation of bioeconomy-related options on country level" was completed by in total 70 out of 128 participants (dropout rate: 45%) in November/December 2023. The majority of the participants were stakeholders (63%), from Poland, Greece, Slovakia, Romania, Bulgaria and Serbia. Most of the participants work in Research and Development, followed by non-governmental organisations and voluntary organisations, small and medium enterprises, public service and higher education. The biggest sectors were agriculture, food and feed, forestry, and ecosystem services.
The second online survey with the title "Acceptance of bioeconomy interventions in your country" was answered by 68 participants and completed by 49 participants (dropout rate 28 %) in September/October 2024. About half of the participants have been external stakeholders and no consortium members (47%). Most participants (39%) come from Serbia, followed by Poland (22%), Bulgaria and Slovakia (10% each), no answers from Slovenia, only one from Greece and Croatia. For Slovenia therefore the mean value of other answers was taken for the assessment. By far most answers came

from persons working in the Research and development sector, (43 %) followed by public sector (24%) and SMEs (16%). There were responses from representatives of all Sectors. 22 % of the answers were given by stakeholders from agricultural sector and 20 % came from forestry. At 11 to 14% also the sectors ecosystem services, food and feed as well as organic residues and waste were also well represented. The responses were gender-balanced, with around half (51%) coming from women. Around 50% of respondents stated that their main area of expertise was in sustainable, circular and bio-based activities. 17% of participants felt that they belong to the food and feed sector, 20% came from wood and 13% from bioenergy and biofuel sector.

2.3 Evaluation procedure

For the evaluation of bioeconomy options in CEE2ACT, the method of rational decision making was applied. In this method individuals use facts and information, analysis, and a step-by-step procedure to come to a decision. For the evaluation of the options each alternative is evaluated on the basis of a coherent set of selection criteria. These can include both quantitative and qualitative factors, such as costs, consumer acceptance or environmental impacts. The aim is to arrive at a well-founded assessment of which alternative promises the best results. The decision process and system components of rational decision making are illustrated in Figure 4. The analysis of the object system is based on objective information; in our case it is about activity options (bioeconomy options) and the subject system based on subjective selected information by including interest, demands, opinions of stakeholders (which are the within the stakeholder process selected evaluation indicators).

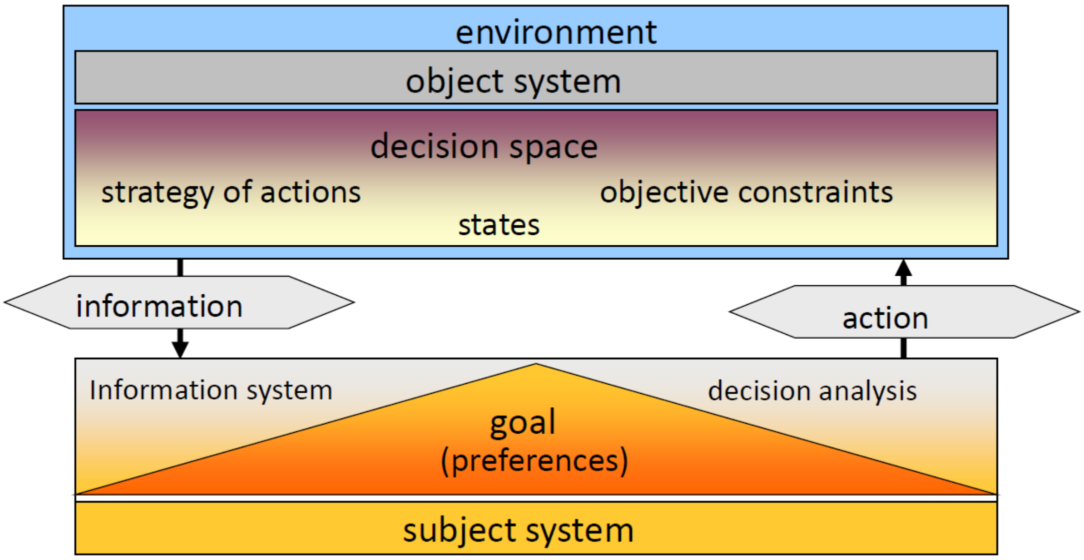

Figure 4: Decision process and system components of rational decision making (Bamberg & Coenenberg, 1996)

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2.3.1 Goal of the decision analysis

The evaluation aims to provide a **decision support on a national level**, especially **for policy information** by identifying bioeconomy options with the largest impact potential. Based on the focus areas of bioeconomy the following main objectives have been identified:

- Increased biomass mobilization
- Increased efficiency/productivity
- Sustainable production
- Circular instead of linear product chains
- Creation of new bio-based products
- Replacement of fossil based fuels

2.3.2 Selection of bioeconomy options (object system)

The selection of relevant options to be included in the roadmaps of the target countries for the implementation of a sustainable bioeconomy in the future was based on a correspondingly broad and comprehensive basis. Based on around 90 options that were summarized from the BIOEASTup country reports, as well as a further 40 options that were also considered relevant to the current regional CEE2Act Hubs, a completion was carried out on the basis of the literature, in order not to leave out any options that had not yet been mentioned. These original 180 options were then analysed for redundancies and feasibility, resulting in a set of around 45 options. The final selection of specific options to be included in the assessment was carried out in close cooperation with the partners from target countries to ensure the relevance of the topics. For this purpose, the partners were asked in a joint workshop in Zagreb in September 2023 to select from a pre-selection of possible options based on the outcomes of Deliverable D3.1 those that should be considered a priority in their country and to add any missing options.
In order to maintain an overview of the spectrum of possible options and to ensure that no area of action is left unconsidered, attention was paid to assign options to each bioeconomy sector and objectives of bioeconomy. All options promote the implementation of bioeconomy in a country, addressing either food, feed, wood, energy, sustainable activities or bio-based products.

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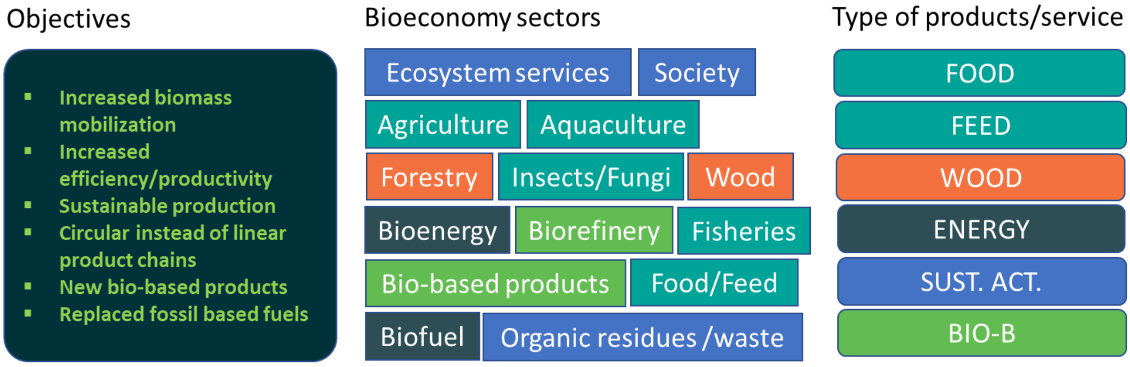


Figure 5: Coverage of bioeconomy options - Objectives (left), bioeconomy sectors (middle), type of products/service (right). Colours represent possible connections between sector and type of product/service

As an assessment is only possible on the basis of tangible data, a specific scenario was defined for each option in a final step, which was assessed as representative of the entire option. It was not possible to define suitable scenarios for all options. Mainly due to the availability of data, 24 specific scenarios, which nevertheless represent all bioeconomy sectors and the different types of products and services, were ultimately selected for evaluation.

The final set of options including the corresponding scenario is shown in Table 3. The description of each option as well as the reasoning for the selection is presented in chapter 3.

Option IDs consists of the product or service considered in the scenario and a consecutive number:

- "FOOD": Food in tonnes
- "FEED": Feed in tonnes
- "WOOD": Timber in solid m3
- "ENERG": Bioenergy (Electricity and/or heat, fuel) in MJ
- "SUST": A mixture of sustainable, circular activities
- "BIOB": Bio-based products in tonnes

Table 3: Set of bioeconomy options selected for decision analysis

Product Service	Option ID	Option-Name	Scenario-Name	Bioeconomy Sector
WOOD	WOOD1	Sustainable wood supply	harvesting via chain saw and long-distance transport by train	Forestry
	WOOD2	Sustainable forest management	preventing clear cuts	Forestry
	WOOD3	Cascade utilisation of wood	virgin wood to glue laminated timber to particleboard to refined lignin oil & bioethanol	Wood products
BIOB	BIOB1	Fungi farming	mycelium for packaging	Other biomass production
	BIOB2	Bio-plastic	PLA (polyactic) food packaging	Bio-based products
	BIOB3	Biodegradable plastic	biodegradable mulch films for agricultural production practices	Bio-based products
SUST. ACT.	SUST1	Nature tourism	agritourism	Ecosystem services
	SUST2	Sustainable buildings	use of secondary raw materials in construction	Bio-based products
	SUST3	Consumer behaviour change to more sustainability	Repair bonus for electronic equipment (laptop)	Society
	SUST4	Recycling of organic waste	commercial and municipal composting	organic residues and waste management
FEED	FEED1	Insect farming	insects protein for feed	Other biomass production
	FEED2	Valorisation of food by-products	animal feed from food by-products	Food and Feed
FOOD	FOOD1	Agrosilvicultural agroforestry practices	woody perennials with crop production	Agriculture
	FOOD2	Modernisation of agricultural sector	Precision/smart farming, predictive modelling	Agriculture
	FOOD3	Organic farming	avoiding the use of synthetic fertilisers	Agriculture
	FOOD4	Small-scale fishing	sustainable harvesting of fish and seafood within short supply chains	Fisheries
	FOOD5	Sustainable inland aquaculture	lake aquaculture	Aquaculture
	FOOD6	Food waste prevention and reduction	low-waste food supply chain	Food and Feed
	FOOD7	Sustainable healthy diet	Non animal protein sources from fungi	Society
BIOEN ERGY	ENERG1	Central and small-scale heating plants	from biomethane	Bioenergy incl fuels
	ENERG2	Biogas plants	combined heat and power	Bioenergy incl fuels
	ENERG3	Biofuel	from biomethane in form of compressed natural gas (bio-CNG)	Bioenergy incl fuels
	ENERG4	Boiler <20kW	from wood chips and pellets	Bioenergy incl fuels
	ENERG5	Multi-feedstock biorefinery process	fatty acid production and bioenergy production	Biorefinery

There was a range of options/scenarios that had to be omitted from the evaluation. They are listed below including the reasoning for the exclusion:

- 'Rehabilitation of lignite coal mines (repair of damage caused by mining activity)': Difficulty to assess the creation of the necessary surface layer with adequate soil; no literature data for modelling found. Moreover, scenario-building presented additional difficulties: defining a baseline scenario (coal mine operations?) versus bioeconomy alternatives (agriculture or forest restoration?). The lack of clear parameters and baseline assumptions prevented inclusion of this scenario.
- 'Carbon capture and storage': There is currently an incredible number of possibilities and more or less well-developed methods (da Cruz, 2021), of which a method could be selected. Without detailed background knowledge of the target countries (is there an abandoned, suitable coal mine, is there the expertise to implement the necessary processes, etc.) the necessary assumptions for this scenario are not fulfilled.
- 'Biomass from abandoned (uncultivated) land': Building scenarios for this option requires specific knowledge about the types and characteristics of abandoned land available, which is currently missing. For instance, does the land have the potential for biomass cultivation, or would it require significant intervention? Without such data, it is difficult to establish baseline or bioeconomy scenarios. Literature references provide some insight but lack the granular data needed for modelling specific cases (Vera et al., 2022; Winberg et al., 2024).
- 'Algae farming (biofuel from algae)': Literature showed still uncertain results; biofuel from algae is still on laboratory scale, as energy efficiency of algae biofuels compared to other biofuels of fossil fuels is still very low; even demanding more energy for its production then the energy they can deliver. (Braud et al., 2023; Carneiro et al., 2017)
- 'Microorganism production': There are numerous emerging technologies in this field, but most are still in the early implementation phases. This nascent stage of development is reflected in a lack of comprehensive data for modelling and unclear pathways for scaling these technologies. Additionally, it remains uncertain which specific scenarios (e.g., protein production from hydrogen-oxidizing bacteria, biofuel production) are relevant to target countries without more detailed input (Jarvio et al., 2021; Keasling et al., 2021).
- Scenarios in the pulp and paper sector: Scenarios for this sector were not requested by the partners

2.3.3 Selection of indicators - subject system

The subject system includes the analysis of the preferences of the stakeholders from participating countries. Interests, demands, wishes, opinions from stakeholders have been considered for applying systemic and rational decision making. For this purpose, a detailed collection of indicators followed by a survey to assess their level of measurability and importance was conducted and described in D2.2 (Scherhaufer et al., 2023).

Initially about 400 indicators were collected based on literature sources (details are listed in Scherhaufer et al., (2023). By removing redundant entries and indicators that are not relevant to the study, retained indicators were reduced to a number of 61. A

stakeholder survey conducted in Task 2.2 resulted in a reduction of the number of indicators from 61 to 28 indicators. The impact level (importance) was defined as a key criterion for the selection of indicators. As a second step the level of measurability is another criterion, because even if the indicator is defined as important (necessary condition) it is possible that it is not likely to be measurable (sufficient condition). In a data-driven approach that we have foreseen in the project, it is crucial to select indicators that fulfil both: importance and measurability. For this reason, a further selection regarding the level of availability of data as well as significance of the indicators for the selected options was carried out and reduced the number again to 9 indicators.
The final set of indicators selected for the analysis of the bioeconomy options is shown in Table 4. The indicators were measured with different methods including both quantitative and qualitative assessment. In total four indicators were measured by means of life cycle assessment (ENV1, ENV2, ENV3, ENV4). For another two indicators quantitative assessment was applied based on desktop research including the renewable energy production as energy-based indicator (ECO3) and the domestic biomass production as mass-based criteria (ECO2). Three indicators were measured by a qualitative survey to stakeholders (SOC1, SOC2, ECO1).
The selected indicators have different characteristics: some can be measured by continuous scale (Life cycle impact assessment results, produced mass, produced energy), some can be measured by ordinal scale (1-10 or verbalized categories) The Indicator ID is aligned to the sustainability pillar the indicators can be allocated to: environmental pillar (ENV), social pillar (SOC), economic pillar (ECO).

Table 4: Set of indicators selected for decision analysis

Indicator ID	Indicator name	Measuring method	Scale	Preference direction*
ENV1	Fossil resources savings	LCA	Continuous	↗
ENV2	Water resource savings	LCA	Continuous	↗
ENV3	Greenhouse gas savings	LCA	Continuous	↗
ENV4	Soil condition	LCA	Continuous	↗
SOC1	Consumer acceptance	Survey	Ordinal	↗
SOC2	Willingness to pay	Survey	Ordinal	↗
ECO1	Job creation potential	Survey	Ordinal	↗
ECO2	Domestic biomass production	Desktop research	Continuous	↗
ECO4	Renewable energy production	Desktop research	Continuous	↗

LCA… Life Cycle Assessment
*Preference direction refers to the orientation or trend that indicates how a decision-maker's preferences evolve with respect to a particular criterion/indicator. It defines whether higher, lower, or specific values of a criterion are considered more favorable or desirable.

For the indicator description, it is referred to Annex I of this document.

Table 5: Omitted indicators

ID	Indicator name	Importance >4	Measurability	Quantification method
A.1.2	Material Circularity for bio-based products	4.3	5	
A.1.6	Material and waste recycling and recovery rate	4.4	5	excl.
A.2.3	Change in carbon stocks / Carbon sequestration	4.2	3.3	excl.
A.3.1	Climate change adaptation: Diversity of tree species	4.0	3.7	excl.
A.3.2	Deforestation	4.4	4.3	excl.
A.3.3	Forest biodiversity	4.0	3.7	excl.
A.3.6	Forests under management plan	4.1	4.1	excl.
A.3.7	Change in carbon stocks / Carbon sequestration	4.3	3.2	excl.
B.1.3	Education and knowledge: technical awareness	4.1	3.1	excl.
B.1.5	Participatory process: involvement to decision making	4.1	3.4	excl.
B.2.3	Household equality: Access to separate waste collection	4.2	3.7	excl.
C.1.5	Land cover: Agric. area, forest area, aquacultural area	4.1	4.6	excl.
C.2.3	Private and public spending on research and develop.	4.2	4.0	excl.
C.2.4	Bio-based research and innovation activity			excl.
C.3.2	Turnover of bioeconomy sectors	4.2	3.7	excl.
C.3.3	Contribution of bioeconomy sectors to GDP	4.4	3.7	excl.
C.3.4	Value added (bio-based sectors)	4.4	3.4	excl.
C.5.2	Renewable energy share in total final energy consumption	4.5	4.0	EB
C.5.3	Import dependency ratio	4.1	4.0	MB

The indicators listed in the table were excluded from the analysis for several reasons tied to the methodology and criteria defined in the project. These exclusions are rooted in the systematic decision-making process that emphasized both **importance** and **measurability** as primary criteria, as outlined in the introduction. Here's an explanation for the exclusion of the specific indicators:

(1) Low Measurability

Even though many excluded indicators were deemed important (e.g., deforestation, contribution of bioeconomy sectors to GDP), their **measurability** scores were relatively low. This reflects challenges in reliably obtaining, quantifying, or modeling data. For example:

- **A.2.3 and A.3.7 - Change in carbon stocks / Carbon sequestration**
  These indicators scored well on importance but had measurability challenges (3.3 and 3.2, respectively). Quantifying changes in carbon stocks or sequestration often requires detailed, location-specific data that may not be readily available or reliable for the selected countries.
- **B.1.3 - Education and knowledge: Technical awareness**
  This indicator was considered important (4.1) but challenging to measure (3.1). Measuring technical awareness in a comparable and meaningful way across diverse stakeholders or countries requires extensive and uniform survey efforts, which were beyond the project's scope.
- **C.3.4 - Value added (bio-based sectors)**
  This indicator faced similar issues. While crucial for understanding economic contributions, its measurability (3.4) suggests a lack of harmonized data across all countries or sectors/sub-sectors/options included in the analysis.

(2) Data Availability

For certain indicators, even if they were considered measurable in principle, the **availability of data** was insufficient to allow reliable evaluation. For example:

- **C.2.3 - Private and public spending on research and development**
  While spending data exists (related to bioeconomy sectors), accessing it at the level of detail required for bioeconomy-specific projects (and in all participating countries) proved impractical.
- **C.3.3 - Contribution of bioeconomy sectors to GDP**
  Although important (4.4), GDP contribution by bioeconomy sub-sectors/narrow areas is not uniformly reported, and accurate data disaggregation not exist for all regions under study.

(3) Insufficient alignment with selected bioeconomy options

Some indicators were excluded because they were **not directly significant** for the specific bioeconomy options analyzed in the project. These include:

- **A.3.1 - Climate change adaptation: Diversity of tree species**
  While important (4.0), this indicator primarily pertains to forestry-related activities, which may not have been a focus for all bioeconomy options under evaluation. Similarly, its measurability (3.7) further limited its inclusion.
- **C.1.5 - Land cover: Agricultural area, forest area, aquacultural area**
  While this indicator scored highly on measurability (4.6), it may not have been deemed critical for evaluating the bioeconomy options selected for this project. It is difficult to measure the potential change calculated by country.

(4) Overlap with Selected Indicators

Some indicators were excluded due to redundancy with others already selected, where overlapping metrics or outcomes would result in duplicative efforts. For example:

- **A.3.3 - Forest biodiversity**
  This may overlap with other biodiversity or environmental health indicators already selected, such as ENV1-ENV4 (measured through life cycle assessment).

(5) Preference for Quantifiable Indicators

Indicators requiring qualitative assessments or complex stakeholder input were deprioritized in favor of more **quantifiable** metrics. For instance:

- **B.1.5 - Participatory process: Involvement in decision-making**
  While important (4.1), this indicator relied heavily on subjective stakeholder surveys, making it less suitable for quantitative modeling or direct comparison across regions.

2.3.4 Data collection and decision analysis

The decision analysis follows the principles of rational decision making. However, the specific approach (decision making procedure) was different for qualitative and quantitative indicators.

The procedure of the decision analysis for qualitative and quantitative indicators is shown in Figure 6.

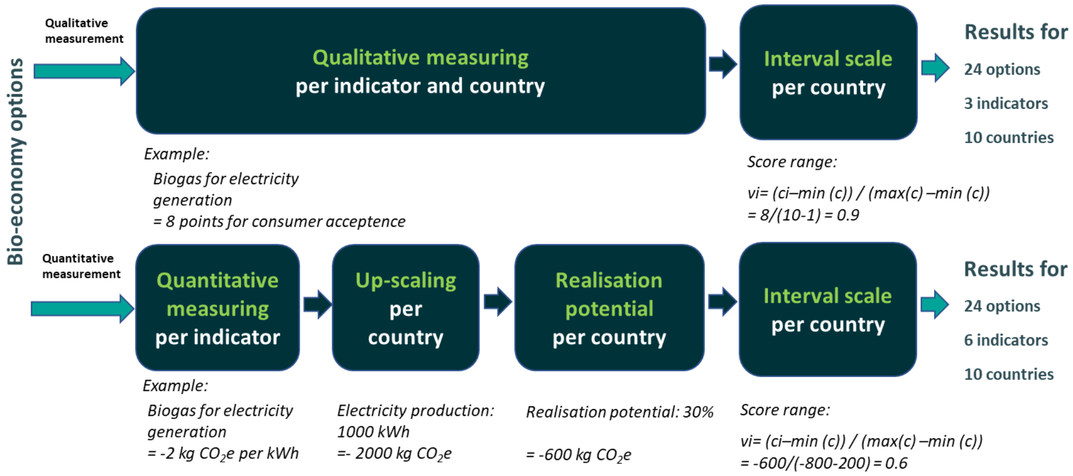


Figure 6: Procedure for the decision analysis – qualitative (top) and quantitative (bottom) measurement

Data for the qualitative indicators was collected in an online survey called “Acceptance of bioeconomy options in your country” (see chapter 2.2). For he indicators consumer acceptance (SOC1) and willingness to pay (SOC2), stakeholders in the target countries were asked to give their assessment using a 10-point Likert scale in an online survey The assessment of the job creation potential (ECO3) was based on a six-point scale, with each scenario requiring an estimate of whether less than 20, 20–100, 101–1,000, 1,001–5,000, 5,001–10,000, or more than 10,000 jobs would be created by a nationwide implementation.

For the quantitative measurement, the functional unit was defined for each scenario as it forms the framework for making different products, processes or services comparable. It serves as a reference against which environmental impacts are measured and evaluated. The functional unit makes it possible to compare different products or processes with each other by creating a common basis. It defines which function the product or service fulfils and to what extent, so that the environmental impacts in relation to this function can be quantified. Example: When comparing the environmental footprint of two different packaging, the functional unit could be “1 kg of product protected”, meaning that the environmental impact of the packaging is assessed in relation to the protection of the product. Following the life cycle approach for all quantitative criteria the impact of the implementation of each of the selected bioeconomy scenarios was assessed against the status quo before this implementation. Therefore, the two states are compared:

- ‘Status quo situation’: Situation before the implementation of bioeconomy related measures and actions (referred to bioeconomy options); such as fossil-based systems and/or linear systems.
- ‘Bioeconomy situation’: Situation after the implementation of bioeconomy related measures and actions (referred to bioeconomy options); such as bio-based systems and/or circular systems.

The differences between status quo and bioeconomy scenarios were eventually focused on. Only the differentials are considered and modelled. So, absolute results are not evident, only the change is measured. This change either towards improvement or deterioration was calculated in the first step, based on the functional unit (e.g. 1000 kg biomass). In a second step based on a stakeholder consultation via online survey the respective realisation potential in the individual countries was taken into account. Based on the existing status quo situation and the specific realisation potential for each scenario an upscaling of the indicator values on country level was performed. In a final step the results were scaled for each quantitative indicator on country level to be able to classify the relevance of the results. Data from International (FAO), European (EUROSTAT) or complementary National Statistics were used for the up-scaling step. Sources and values used for the up-scaling are listed in Annex II and results for the realisation potential from the survey are shown in Annex III.

For the final evaluation of all 24 scenarios using the selected 9 indicators at the level of the 10 target countries, the indicator results were transferred to a 10-point scale using interval scaling, to express each value in relation to the maximum value of the specific indicator for all scenarios and transfer it to the scale from 0 to 1. This enables a direct comparison of all scenarios at the country level, so that the most relevant scenarios can be identified in each case.

3 Bioeconomy options

The selected bioeconomy options are described in the following sub-chapters in a format as fact sheets to provide a better overview.

3.1 Bio-based products (BIOB)

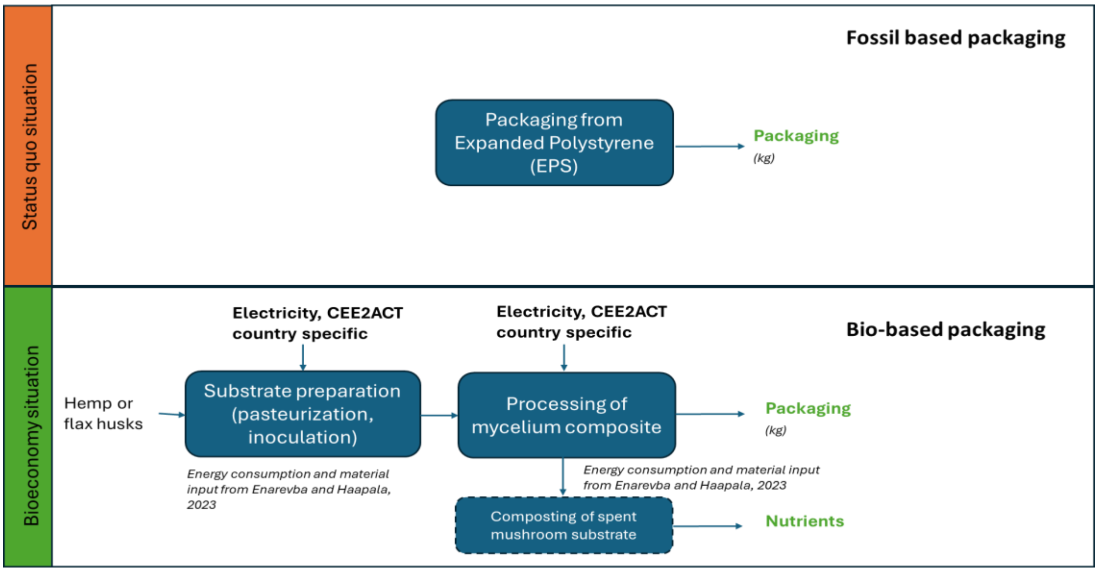
3.1.1 BIOB1 "Fungi farming"

Option ID, short name:	BIOB1 "Fungi farming"
Bioeconomy sector:	**05_ Other biomass production**
Bioeconomy objective:	New bio-based products
Scenario name:	Mycelium for packaging
Scenario FU:	Packaging [1 ton]
Up-scaling:	Total packaging mass in use per country
Goal:	to enable a reduction of fossil resources by using bio-based products and promoting circular economy: Forestry and agricultural residues are used to cultivate mushrooms with conversion into high value agricultural products, food, medicine, mycelium materials and mycoprotein. Spent mushroom substrate (SMS) is reused as compost for plants, animal feed, etc.
Reasoning for the selection: Currently, there is a growing interest in the cultivation of fungi as a means of supplementing or replacing wild harvests. This can be attributed to the growing recognition of the nutritional value of various species and the realisation of the income-generating potential of fungi through trade. Lignocellulosic waste, abundant in agricultural residues and forestry by-products, represents a significant untapped resource. Mushrooms can be cultivated with forestry and agricultural residues transforming it into an agricultural goods, food, medicines, and other items, including mycelium material and mycoprotein (a meat alternative). The agricultural sector produces a large amount of waste each year. Approximately half of these agricultural residues are used for purposes such as animal feed, packaging materials and fuel, while the remainder is often burned in the fields as this is the easiest method of disposal. Using of agricultural residues to cultivate mushrooms not only reduces the release of pollutants into the atmosphere, but can also provide an economic support to farmers. In addition, instead of being disposed of, spent mushroom substrate, can be reused to make a compost, biochar, feed, medicine, etc. It can also be used as a substrate for cultivating another types of mushrooms.	

<u>Scenario description:</u> The production of mycelium composite for packaging was chosen as a scenario because it is already available on the market (e.g. https://www.grown.bio/de/pilz-verpackung/). An alternative scenario would be mycelium for textiles (Williams, 2022). Myzel for insulation in the construction sector seems to be only in laboratory and pilot stage. Fungi for food was considered in the scenario "sustainable healthy diet" (FOOD7).

'Status quo situation':	Packaging from expanded polystyrene (EPS)
'Bioeconomy situation':	Forestry and agricultural residues are used to cultivate mushrooms with convertation of l into high value agricultural products, food, medicine, mycelium materials and mycoprotein. Spent mushroom substrate (SMS) is reused as compost for plants, animal feed, etc

<u>System diagram:</u>



<u>Limitations of the modelling:</u>
EoL stage: comparing EoL would be benefial but due to lack of data of composting quality of mycelium composite, it was not possible to include (possibly to include: composting of bio-waste?) to decide
More importantly: Loss of mass during drying is not included in the Life cycle inventory of Enarevba!
Mushroom mass was modelled with flax husks. Why? In the study they stated "Due to a lack of information for the production of hemp hurd, flax husks were used as a proxy, as both materials share similar characteristics", so they used flax husks as a feedstock/substrate, but they mention additional flax husks for mushroom biomass (a mistake?); exclude it for mushroom biomass?

3.1.2 BIOB2 "Bio-plastic"

Option ID, short name:	BIOB2 "Bio-plastic"
Bioeconomy sector:	**05_ Other biomass production**
Bioeconomy objective:	New bio-based products
Scenario name:	Polyactic (PLA) food packaging
Scenario FU:	Food packaging [1 tonnes]
Up-scaling:	Total food packaging mass in use per country
Goal:	to enable a wide range of economic, social and environmental benefits by promoting sustainable and circular practices and driving innovation.

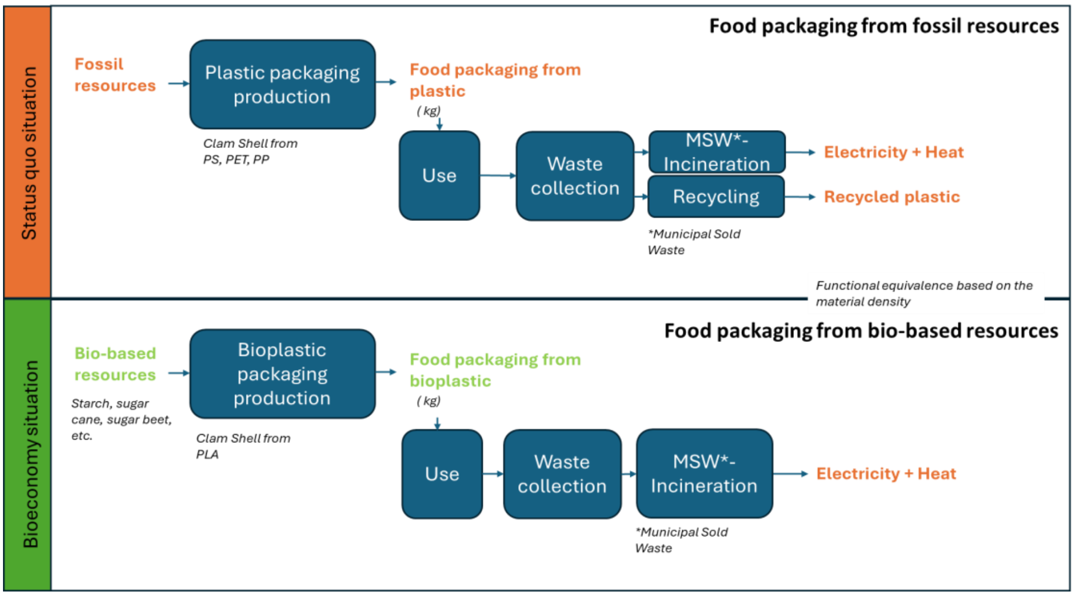
Reasoning for the selection: Bioplastics are becoming a critical component in the drive to create a fully sustainable and circular bioeconomy. Of the more than 400 million tonnes of plastic produced each year, bioplastics currently account for around 0.5%. Bioplastics are being used in an increasing number of applications, including packaging, which remains the largest market segment for bioplastics. Bio-based plastics are made in whole or in part from biological resources, rather than from fossil raw materials. PLA is a bioplastic made from renewable, plant-based materials such as corn, cassava and sugar cane. The advantages are significant when we compare PLA bioplastics with conventional plastics. PLA bioplastics are made from rapidly renewable plant starch, whereas virgin PET plastic is mostly made from limited fossil resources. PLA plastic is certified for industrial composting (AS4736, EN13432), whereas PET can be recycled. Bio-based products are products derived in whole or in part from biological materials (e.g. plants, animals, enzymes and micro-organisms). It is usually characterised by its bio-based carbon content or bio-based content, and it can be an intermediate, material, semi-finished or final product. Reasoning for the selection of the scenario: Bio-based products are made from renewable raw materials and can therefore offer a number of advantages, such as helping to reduce CO_2, lower toxicity and novel product characteristics such as biodegradability. They have potential for replace or improve fossil product. Through the use of fermentation and bio-catalysis instead of traditional chemical synthesis, higher process efficiencies can be achieved, resulting in energy savings, reduced water consumption and less toxic waste. Furthermore, biobased products can help relieve pressure on ecosystems by diversifying feedstocks.

Scenario description: Clam shells are small volume containers (body and lid), rigid thermoformed, transparent, with a volume of 500 ml, and serve to pack food ready for take-away at the retail outlet. Clam shells are usually made of polypropylene (PP), oriented polystyrene (OPS) and polyethylene therephtalate (PET). NatureWorks is a large scale producer of polyactide (PLA) made from renewable feedstock. Secondary products are methanol, electricity, thermal energy as well as recycled plastic granulates in case of PP, PS and PET. DATA is taken from (Detzel, 2006)

'Status quo situation':	Linear system in which raw materials are transformed into plastic products with low levels of re-use or recycling. They are usually disposed of at the end of their life
'Bioeconomy situation':	Bioplastics play an important role by replacing the use of fossil resources with bio-based raw materials materials such

	as starch (corn), sugar cane, sugar beet, tapioca. PLA bio-based plastics are biodegradable and compostable, proving sustainable end-of-life solutions..

System diagram:



Limitations of the modelling:
MSW because no differences in emissions from burning PLA and other polymers can be modelled.
Collection and sorting of plastic waste is omitted.
Process waste from extrusion and forming is omitted.
Only PS as status quo scenario is modelled.

3.1.3 BIOB3 “Biodegradable plastic”

Option ID, short name:	BIOB3 “Biodegradable plastic”
Bioeconomy sector:	**Bio-based products**
Bioeconomy objective:	New bio-based products
Scenario name:	Biodegradable agricultural mulch film
Scenario FU:	Agricultural area [1 square metres]
Up-scaling:	Total available agricultural area per country
Goal:	to use biodegradable material made from natural resources to avoid plastic pollution.

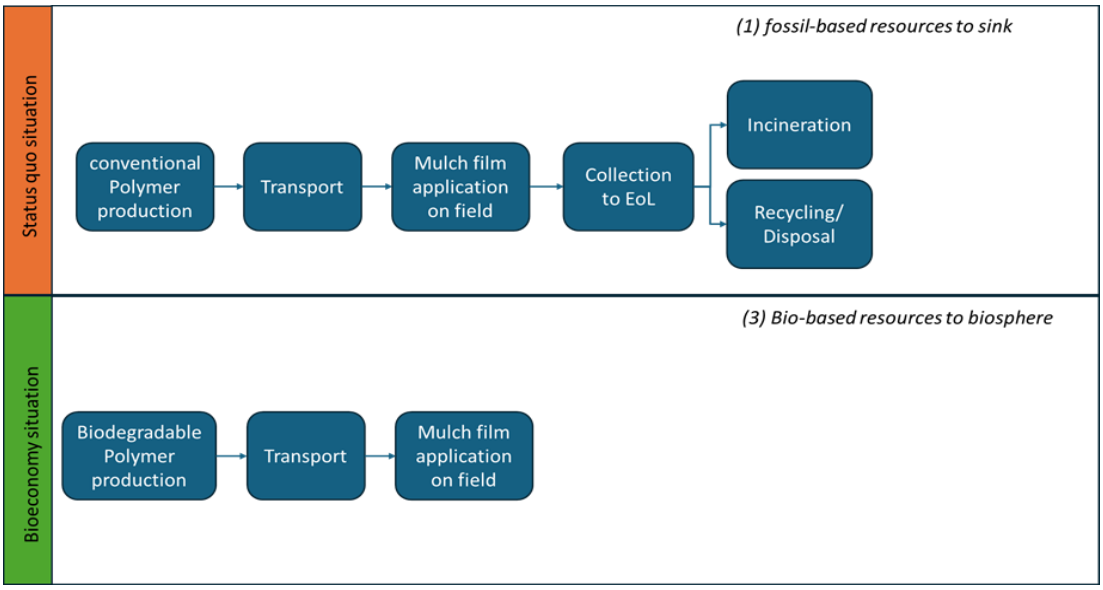
Reasoning for the selection: In contrast to bioplastics made from renewable raw materials, the primary advantage of biodegradable plastics is that they do not remain in nature for decades like conventional plastics, but are broken down. Their use in other areas (e.g. in a recycling system (composting) when disposed of correctly) does not really play a role due to the lack of nutrients. In this respect, one of the main areas of application for biodegradable plastics is agriculture. Plastic mulching materials are used in agriculture as they provide numerous advantages for crop production, e.g. to regulate soil moisture content, temperature, and limit the growth of weeds, thus helping to sustain or increase crop (often fruit and vegetables) yield (Steinmetz et al. 2016; Briassoulis and Giannoulis 2018). However, this once revolutionary material has, in some places, turned into a major problem of plastic pollution as mulches made from conventional plastics present challenges once they have reached their end-of-life as they need to be collected and disposed of after use.

Scenario description: In the scenario option conventional plastic mulching material in agriculture in substituted by biodegradable material. The biodegradable mulch film is assumed to degrade in the soil after use. The time for degradation depends on local conditions as well as type of material used. There is no effect on yield levels, so only the respective material densities are used to produce functional equivalence of the system. (The DATA is derived from de Sadeleer and Woodhouse (2023)

'Status quo situation': Mulch film from LDPE is used for agricultural purposes. It is collected after use, transported and disposed in waste incineration plant (incl. credits)

'Bioeconomy situation': Mulch film from biodegradable material (70% PBAT and 30% starch) is used for agricultural purposes. It is not collected after use, but left in the soil for degradation

System diagram:



:

3.2 Bioenergy and biofuel (ENERG)

3.2.1 ENERG1 "Central and small-scale heating plants (biomethane)"

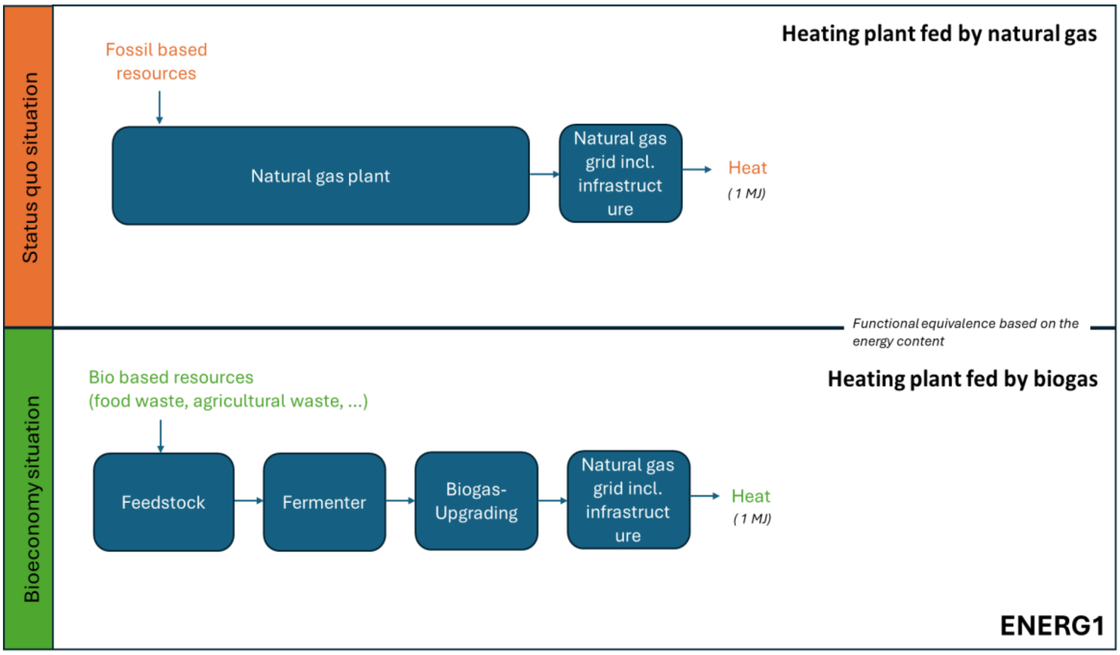
Option ID, short name:	ENERG1 “Central and small-scale heating plants (biomethane)”
Bioeconomy sector:	Bioenergy
Bioeconomy objective:	Replaced fossil based fuels
Scenario name:	Biomethane
Scenario FU:	Heat [MJ]
Up-scaling:	Total heat production per country
Goal:	➢ to enable the production of biomethane for the natural gas grid

Reasoning for the selection: Member states of the European Union have the legal requirement to develop a National Energy and Climate Plan (NECP) to outline climate and energy goals. By 2030, EU MS should reach 35 bcm from biomethane production. The current European biomethane production in EU-27 reached 3.4 bcm in 2022 with 1,124 plants in operation (EBA, 2023). More than 75% of the plants are grid connected. Renewable gases, including biomethane, is key to enable decarbonisation in various field of bioeconomy, such as buildings, industry, mobility, power system. The deployment of biomethane to replace fossil fuels can be achieved by using existing infrastructure and supports the diversification of EU gas supplies. The EU is largely depending on imported gas (40% coming from Russia).
Feedstock to produce biogas and biomethane in Europe: Food waste, Industrial wastewater, Agricultural residues, Animal manure.

Scenario description: The production of biomethane by fermentation of organic substances and up-grading of the biogas produced in the fermentation process for use in the natural gas grid. Reasoning for the selection of the scenario: Natural gas can be replaced by biomethane for the decarbonation of buildings, industry, mobility and power supply.

‘Status quo situation’:	fossil resources that are processed in a natural gas plant and fed in the natural gas grid
‘Bioeconomy situation’:	bio-based resources that are fermented and upgraded (to remove carbon dioxide and other trace gases) to feed in the natural gas grid to use as energy for the heating of buildings, for high-temperature applications at industry, for fuel at mobility and for balancing power supply.

System diagram:



3.2.2 ENERG2 "Biogas plants"

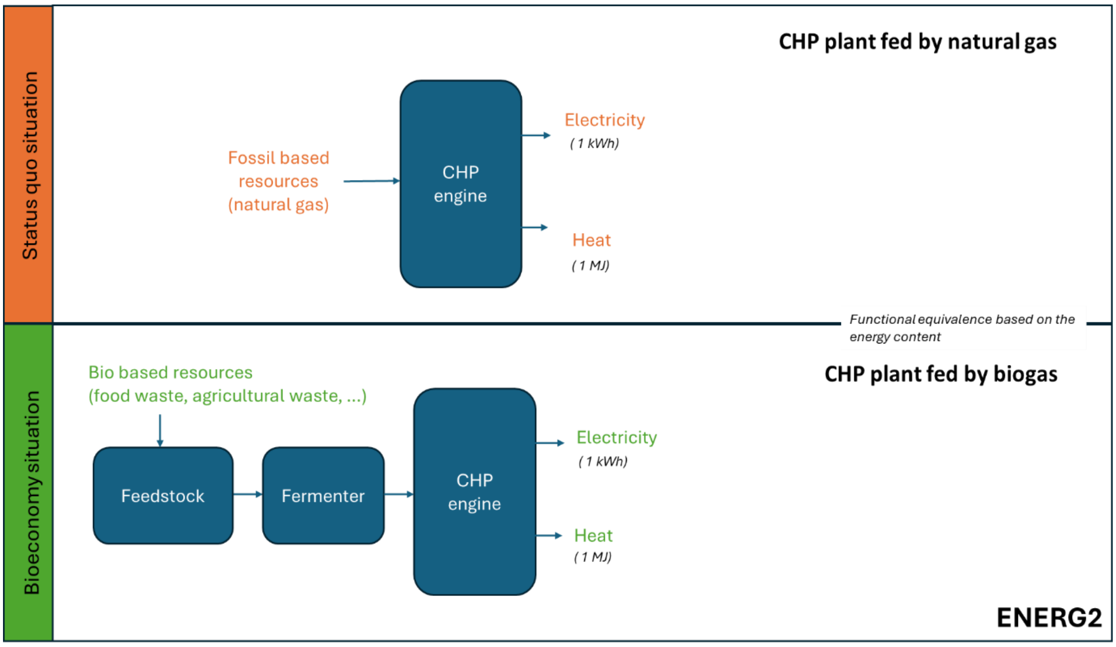
Option ID, short name:	ENERG2 "Biogas plants"
Bioeconomy sector:	Bioenergy
Bioeconomy objective:	Replaced fossil based fuels
Scenario name:	Combined heat and power (CHP) production
Scenario FU:	Electricity and heat [kWh_{electr}/MJ_{heat}]
Up-scaling:	Total electricity and heat production per country
Goal:	➢ to enable the use of biobased resources in CHPs to produce renewable electricity and heat in a biogas plant with a combined heat and power engine

Reasoning for the selection: Biogas is produced from the decomposition of organic materials. These residues are placed in a biogas digester in the absence of oxygen. With the help of a range of bacteria, organic matter breaks down, releasing a blend of gases: 45 – 85 vol% methane (CH4) and 25 – 50 vol% carbon dioxide (CO2). The output is a renewable gas which can be used for multiple applications." (EBA, 2024)
Combined heat and power engines (CHP) are a common valorisation route for biogas in Europe (EBA, 2024). Part of the heat is used for the plant's fermentation proess, but surplus heat can be used in local heating applications. The electricity can be fed into the electricity grid.
The replication potential is very promising. The biogas and biomethane production potential is high in many European countries.

Scenario description: It is assumed that natural gas from fossil resources is replaced by natural gas from bio-based resources by using it in a combined heat and power (CHP) engine to produce electricity and heat

'Status quo situation':	fossil resources that are used to produce heat and electricity. The majority of fossil resources used for electricity production in Europe comes from coal and natural gas (Net electricity generation in the EU by fuel type (2022)).In this scenario natural gas was assumed.
'Bioeconomy situation':	bio-based resources that are fermented and upgraded (to remove carbon dioxide and other trace gases) to feed in the natural gas grid to use as electricity and heat.

System diagram:



3.2.3 ENERG3 "Biofuel"

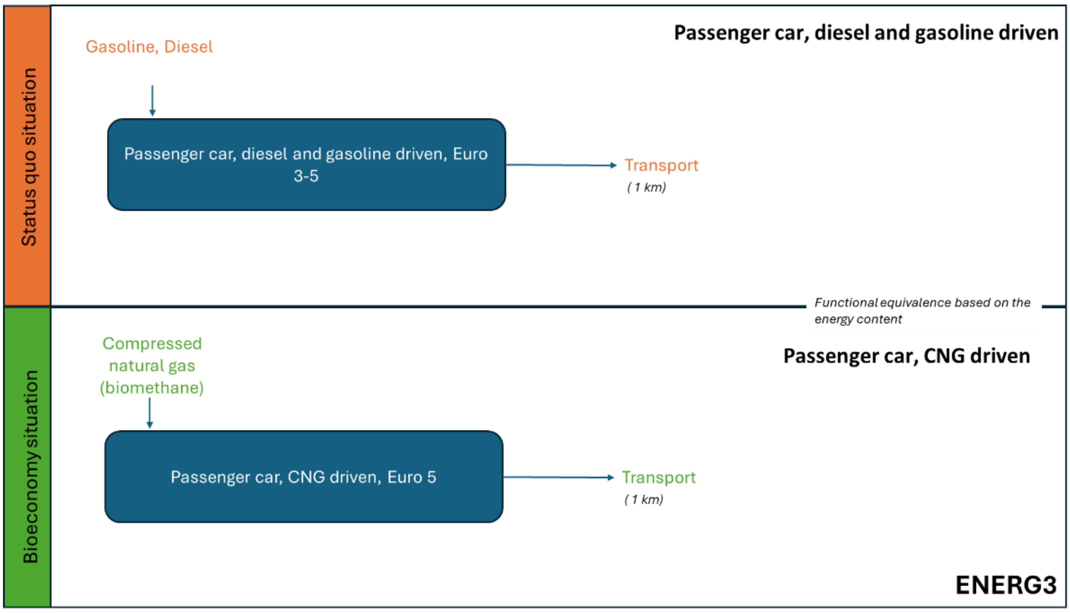
Option ID, short name:	ENERG3 "Biofuel"
Bioeconomy sector:	Biofuel
Bioeconomy objective:	Replaced fossil based fuels
Scenario name:	Biofuel from biomethane in form of compressed natural gas (bio-CNG)
Scenario FU:	Transport (private/passenger car) [person and kilometre]
Up-scaling:	Average distance per country and year
Goal:	➢

Reasoning for the selection: Currently, there is a demand for various types of fuels and propulsion systems to meet the needs of the green transformation. Biogas is an alternative that can decarbonize the heavy-duty vehicle sector while providing a long-term energy solution. The number of liquefied gas refueling stations is currently increasing, especially in Europe, and gas is already a viable alternative to diesel, even for longer routes. At the moment, over 60% of biogas production capacity is located in Europe and North America. Europe is currently the leading region with 20,000 biogas plants. The option aims to assess the potential for increasing the production of bio-CNG or bio-LNG, thereby reducing GHG emissions from transport. _"The latest studies show that biomethane is an effective way to abate GHG emissions from transport, which represent 25% of the total emissions in the EU.[1] Biomethane is used as a biofuel in the form of a CNG (compressed natural gas) or LNG substitute, called bio-CNG or bio-LNG. Biomethane in transport is a high performer in terms of the reduction of GHG emissions, if we consider the full carbon footprint of the vehicles (Well-to-Wheel).

Scenario description: The scenario envisions the development of the biogas and biomethane sector, and then, through the application of innovative solutions, increasing the share of bio-CNG or bio-LNG in the transport sector, thereby reducing the use of fossil fuels.

'Status quo situation':	In the transport sector, fuels are produced and delivered using non-renewable resources, and products are not based on the use of biomass, for example. Fuels are often imported from distant countries, which, considering their production and transportation, generates emissions (high carbon footprint).
'Bioeconomy situation':	We are able to provide access to biofuels, which can partially reduce the use of fossil fuels. By processing bio-waste and by-products from primary sectors of the economy, we produce biofuels such as bio-CNG or bio-LNG, contributing to the increased share of a decentralized energy production network.

System diagram:



3.2.4 ENERG4 “Boiler < 20 kW (solid biomass)”

Option ID, short name:	ENERG4 “Boiler < 20 kW (solid biomass)”
Bioeconomy sector:	Bioenergy
Bioeconomy objective:	Replaced fossil based fuels
Scenario name:	New generation of biomass small scale heating devices
Scenario FU:	Heat production [MJ]
Up-scaling:	Total heat generation from oil per country
Goal:	➢ to enable the adoption of new generation small scale heating technology (<100kW) using biomass to replace outdated equipment and expand biomass as feedstock substitute for fossil fuels

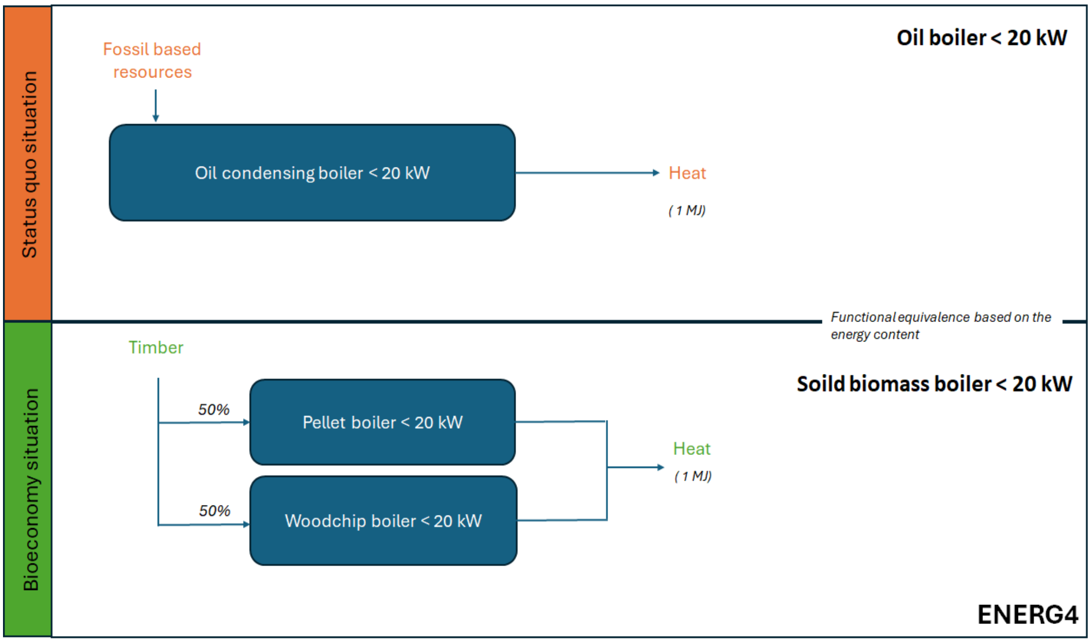
Reasoning for the selection: Energy for heating and cooling makes up around half of the EU’s total gross final energy consumption. In 2022, the share of energy from renewables in heating and cooling continued to rise, with the EU average standing at 24.8% [1]. In the span of 10 years, the average share of energy from renewables for heating and cooling grew from 18.6% to 24.8% (+6.2pp). However, a major push is required to meet the new targets introduced by the EU Directive 2023/2413 of 18 October 2023 on the promotion of the use of energy from renewable sources (RED III). This Directive requires EU countries to increase their annual average share of renewables in heating and cooling by at least 0.8 % from 2021 to 2025 and by at least 1.1 % from 2026 to 2030.

Funded by the European Union

Scenario description: New generation of biomass small scale heating devices: New boilers supply metered air to various combustion areas and employ sophisticated flue gas treatments. Whereas traditional wood boilers may reach an efficiency of 30% to 40%, and produce a lot of smoke and other emissions, modern high-tech boilers reach efficiencies above 90% and result in a tremendous reduction of emissions

'Status quo situation':	Oil condensed boilers (< 20 kW)
'Bioeconomy situation':	Combination of woochip and pellet boilers (20 kW). The energy efficiency of wood chip boiler is 82% and of the pellet boiler 87%.

System diagram:



3.2.5 ENERG5 "Multi-feedstock biorefinery"

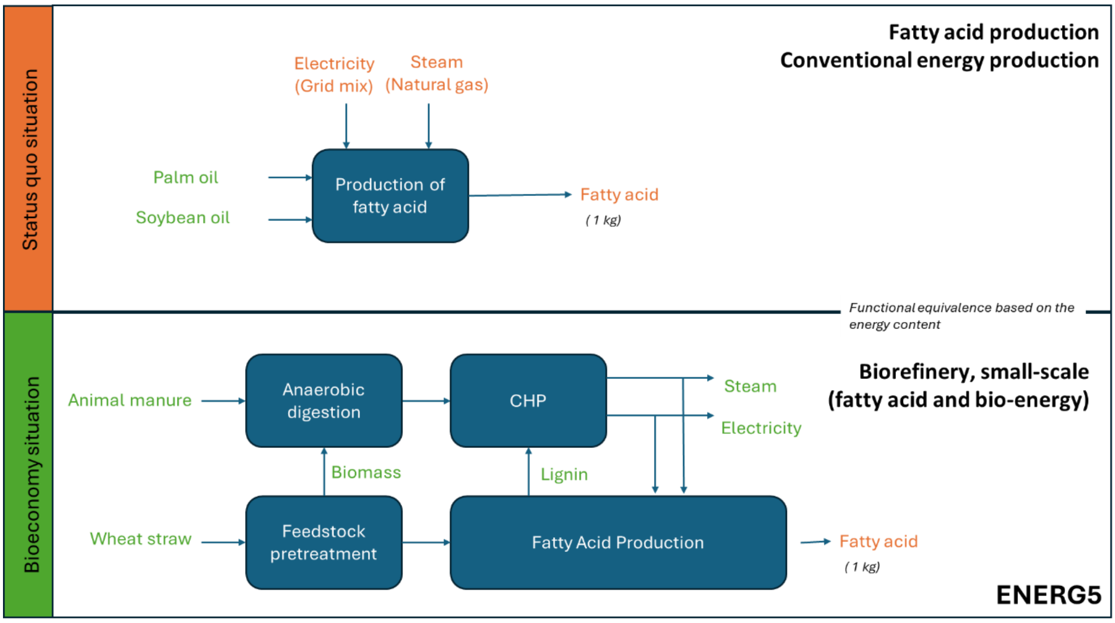
Option ID, short name:	ENERG5 "Multi-feedstock biorefinery"
Bioeconomy sector:	Bioenergy
Bioeconomy objective:	Replaced fossil based fuels
Scenario name:	Fatty acid production
Scenario FU:	Fatty acid [tonnes]
Up-scaling:	Total fatty acid imports and exports
Goal:	➢ to enable sustainable supply for chemicals and fuels

Reasoning for the selection: Biorefineries have been found to provide an efficient solution to find substitutes for fossil resources obtained from biomass. Biorefineries at small scale furthermore tackle the bottlenecks of high capital costs and lack of biomass supply that are necessary for the operation (Suazo, 2023).

Scenario description: The production of butyric acid from low-cost residues and renewable biomass can substitute the commercial production that is dominated by chemical synthesis from fossil resources. Butyric acid a four-carbon fatty acid that is a chemical building block for a variety of chemical compounds with various application in the chemical, textile, plastic, food, beverage, dair and pharmaceutical industries. The utilization of wheat straw and swine manure as a feedstock for the biorefinery was considered as shown in (Suazo, 2023). Wheat straw can be transformed into fermentable sugars and then to butyric acid. Swine manure presents potential for biogas production via anaerobic digestion, offering a renewable energy source to enhance the overall energy efficiency of the biorefinery.

'Status quo situation':	The production of fatty acid from palm oil and soybean oil by using electricity from national electricity grid mix and steam from natural gas
'Bioeconomy situation':	The production of fatty acid from wheat straw in combination of anaerobic digestion of animal manure and biomass to use electricity and steam for production (hydrolysis) and purification of butyric acid (based on Suazo, 2023).

System diagram:



3.3 Feed (FEED)

3.3.1 FEED1 "Insect farming"

Option ID, short name:	FEED1 "Insect farming"
Bioeconomy sector:	Other biomass production/Feed
Bioeconomy objective:	Bio-based products
Scenario name:	Insects protein for feed
Scenario FU:	Feed (fish meal) [1 ton]
Up-scaling:	Total fish meal import per country (70% protein content)
Goal:	to enable secure feed from alternative protein sources other than soya

Reasoning for the selection: The EU import annually around 17 million tonnes of crude proteins for animal feeding, of which 13 million tonnes are soy based and which mainly come from Brazil, Argentian and the USA. Despite increased soya cultivation in countries such as Italy, France and Romania, the EU's self-sufficiency in soya, which continues to be a pivotal plant-based protein source in livestock feed, is only 5% (European Commission, 2018). Food waste would be an alternative source of protein feed, but is currently restructured by law to only some food side-flows (e.g. foodstuffs or food by-products of the food industry) due to disease control (e.g. Agrican swine fever, food-and-mouth disease). Food safety and hygienic issues are, therefore, given priority.

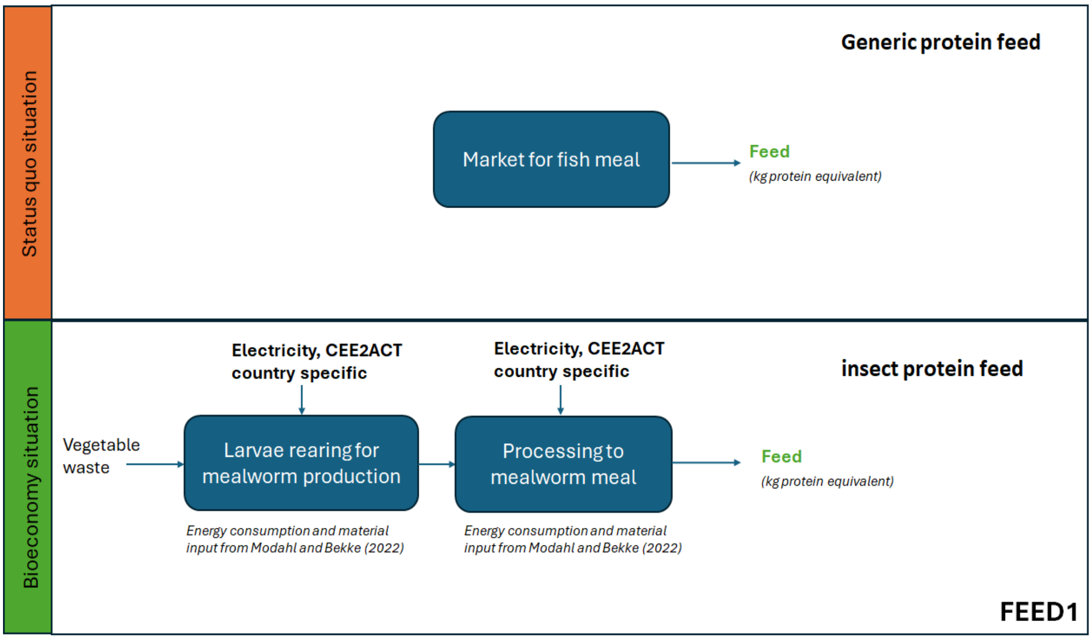
Reasoning for the selection of the option: Insects have high concentrations of complete protein, vitamin B12, riboflavin and vitamin A. Insects offer an economical solution to increasingly pressing food security and environmental issues concerning the production and distribution of protein to feed a growing world population.

According to Regulation (EC) No 1069/20097, insects are considered as 'farmed animals' and thus, for their feeding, the use of certain substrates such as manure, catering waste or former foodstuff containing meat and fish, are not allowed (EFSA, 2015).

Scenario description: Low value food processing by-products (distilled grains) and high-impacting waste streams use for insect growing are confirmed to be among the best strategies for sustainable feed production. The production of insect-based protein powder and meat substitute, based on food by-products, is 2e5 times more environmentally beneficial than that of traditional products (Smetana et al. 2016)

'Status quo situation':	Generic protein feed from fish meal (global market mix)
'Bioeconomy situation':	Insect protein feed from mealworm meal (larvae rearing and processing to mealworm meal included) (Primary data taken from Modahl and Bekke, 2022)

System diagram:



3.3.2 FEED2 "Valorisation of food by-products"

Option ID, short name:	FEED2 "Valorisation of food by-products"
Bioeconomy sector:	Feed
Bioeconomy objective:	Efficient biomass utilization and mobilization
Scenario name:	Animal feed from food by-products
Scenario FU:	Feed [1 ton]
Up-scaling:	Total amount of soybean meal import per country
Goal:	to enable a sustainable source for animal feed (protein-based)

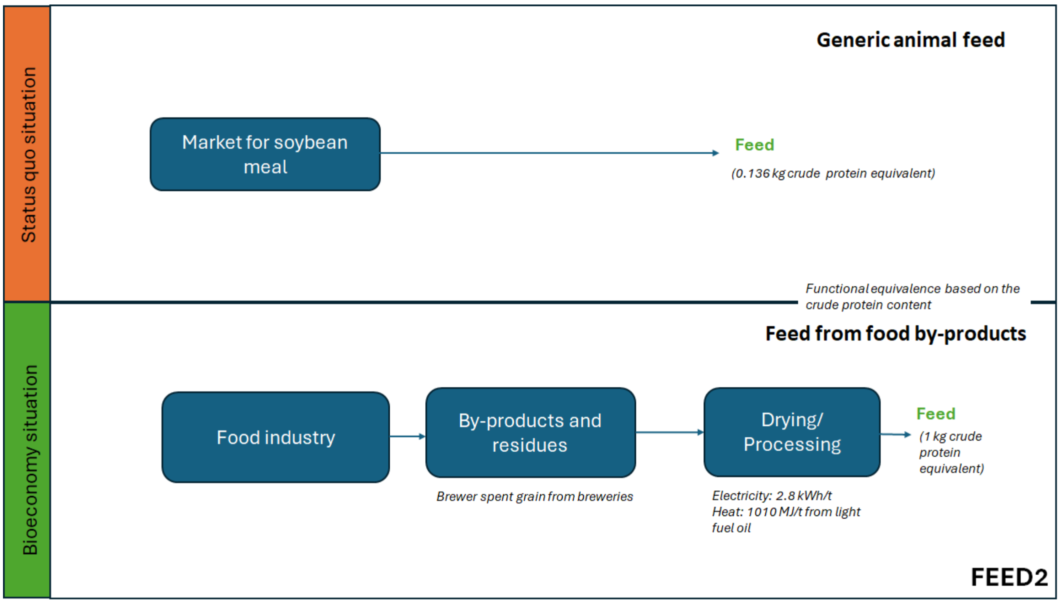
Reasoning for the selection: Foodstuffs, "other than catering reflux, which were manufactured for human consumption in full compliance with the EU food law but which are no longer intended for human consumption because of practical or logistical problems (e.g., manufacturing or packaging defects or other defects)" (European Commission, 2017) are largely reprocessed to animal feed in Europe. Typical former foodstuffs are biscuits, bread, breakfast cereals, chocolate bars, pasta, savory snacks, and sweets. They are authoritative sources for animal feed because of their high energy content in the form of sugars, oils, and starch. Currently, 5 Mt of former foodstuffs, such as bakery and confectionary foods that cannot be sold, are recycled into animal feed (EFFPA, 2019). It is estimated that a further 2 Mt of former foodstuffs could be fed to livestock (Luyckx, 2019). Arguments for using former foodstuffs or food waste as animal feed are reduced costs for livestock farmers, reduced demand for human-edible cereals currently used in livestock feeding, and for unsustainable feed protein such as Amazon soy and fishmeal.

Not only former foodstuffs but also residues of the food industry are likely to feed to animals across Europe. For example, it is estimated that the brewing industry produces 4 Mt of brewer spent grain (BSG) in Europe (Metcalfe, 2019; Metcalfe et al., 2018), which is primarily used as animal feed or in anaerobic digestion. The apple juice manufacturing industry represents another example, producing 0.7 Mt of apple pomace annually in Europe (Metcalfe, 2018). Also, different fruit and vegetable waste from the manufacturing industry are proven to be a potential alternative for animal feeding due to its nutritional value (Mirabella, 2014). Whey permeate is another source as a feed ingredient in Europe. Whey permeate is a by-product of processing whey into whey protein concentrates for the human nutrition and animal feed markets. With much of the protein removed, it consists mainly of the milk sugar lactose in addition to some mineral solids/salts (Metcalfe et al., 2018). Additionally, the main EU-grown oilseed is rapeseed, mainly driven by the demand for biodiesel. Its by-product, rapeseed meal, is a protein-rich source for animal feed (European Commission, 2018b). The actual quantities of food by-products used for animal feed in Europe are hard to estimate (Metcalfe et al., 2018).

Scenario description: Former foodstuffs and residues of the food industry are likely to feed to animals across Europe. Arguments for using former foodstuffs or food waste as animal feed are reduced costs for livestock farmers, reduced demand for human-edible cereals currently used in livestock feeding, and for unsustainable feed protein such as Amazon soy and fishmeal. The feeding of apple pomace is compared with hay from extensive and intensive cultivation. In addition to the direct use of fresh food by-products, the possibility of drying the material (with 2.8 kWh/t electricity and 281 kWh/t heat from light fuel oil) to increase the transport distance was assumed. DATA and assumptions are based on (Scherhaufer, 2020).

'Status quo situation':	Feed from soybean meal (market mix), crude protein content of 44%
'Bioeconomy situation':	Feed from brewer spent grain (fresh and dried) from the food industry (1 kg brewer spent grain can replace 0.136 kg soybean meal based on Flysjö et al. 2008)

System diagram:



3.4 Food (FOOD)

3.4.1 FOOD1 "Agrosilvicultural agroforestry practices"

Option ID, short name:	FOOD1 "Agrosilvicultural agroforestry practices"
Bioeconomy sector:	Agriculture, Forestry
Bioeconomy objective:	Efficient biomass utilization and mobilization
Scenario name:	Wood perennials with crop production
Scenario FU:	Crops (Wheat) [tonnes per hectare]
Up-scaling:	Total land use area for agriculture per country
Goal:	

Reasoning for the selection: Agroforestry is a collective term that describes the integration of woody perennials with livestock and crop production (FAO, 2013). Agroforestry systems, which are sustainable and multifunctional, provide many environmental benefits. They contribute to climate change adaptation and mitigation, protect the soil, enhance biodiversity and improve the overall condition of the landscapes. The positive effects of multispecies crop mixtures like agroforestry system on yield and other ecosystem services stem from ecological complementarity and facilitation among crop species (Faucon et al. 2023). Agroforestry creates opportunity to provide local wood fuel (e.g. poplar, willow) production for low-carbon bioeconomy and contribute significantly to carbon removal in agricultural sector as one of the most promising carbon farming practice (EURAF Policy Briefing 8).

Additionally, this practice contributes to enhanced carbon sequestration on the land (Ferreiro-Dominguez et al. 2022). The last but not least, agroforestry biomass yields could supplement existing uses of biomass for energy. Many farms use biomass boilers for heating farm buildings or providing heat for other farm operations.

Scenario description: Combined production of food/feed/fodder and non-food products (wood/bioenergy, fiber, and bio-based chemistry products) on the same land within cropping system while mitigating land use competition and improved conservation of natural resources. Woody perennials and arable crop production (agrosilvicultural) was chosen as a scenario based on Crous-Duran et al. (2019) was used as data source for the scenario building.

'Status quo situation':	Crop monoculture land use was assumed to be planted on 100% of each hectare; wheat monoculture (Data based on Crous-Duran et al. (2019))
'Bioeconomy situation':	Agroforestry management option assumed a crop area that covered 90% with 10% of agroforestry systems (AFS), combining wheat production with cork oak (Data based on Crous-Duran et al. (2019))

System diagram:

Limitations of the modelling:

- Use of bio-fuels in the bioeconomy situation was omitted (it was assumed that same fuel is uses in status quo and bioeconomy situation)
- Use of wood from maintenance practices was not considered. Could be added, if relevant.
- However, none of the aforementioned methodologies, take into account the potential effect of AFS on water regulating services, retention, and infiltration linked to the soil hydrological properties, as described in Köthke et al. (2022).

3.4.2 FOOD2 "Modernisation of agricultural sector"

Option ID, short name:	FOOD2 "Modernisation of agricultural sector"
Bioeconomy sector:	Agriculture
Bioeconomy objective:	Sustainable production
Scenario name:	Precision/smart farming, predictive modelling
Scenario FU:	Crops (Wheat) [tonnes]
Up-scaling:	Total wheat production mass per country
Goal:	

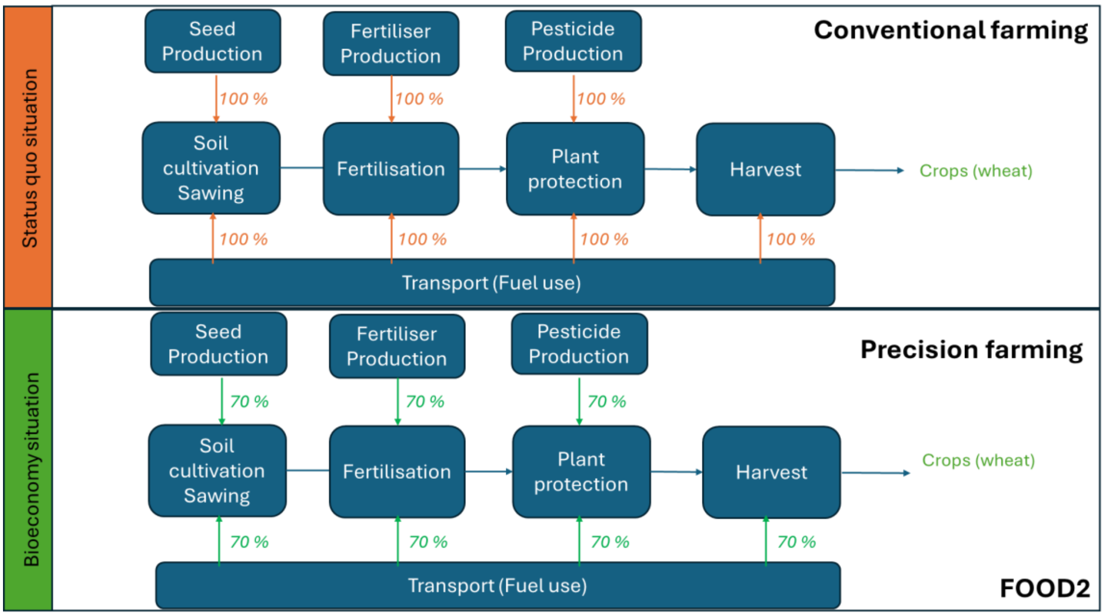
Reasoning for the selection: fusion of technology and regenerative agriculture practices, reduction of in-field operation fuel and as well as fertilizer, seed and pesticide inputs by using PAT (precision agricultural technologies like automatic steering schemes, automatic section control schemes for overlap reduction, Proximal sensors schemes for reduction in fertilizer usage IoT and smart sensors market is maturing already bringing added value to agriculture. Seeding – crop spraying – monitoring – and field analysis drones are available and a combination of technologies like IoT, AI/ML, UAVs, remote sensing, robotics, and big data to automate a range of farming operations are readily implemented.

Introduction of Precision farming employing advanced sensors, drones, and satellite imagery, farmers can now amass detailed data on soil conditions, moisture levels, and crop health. This wealth of information not only guides data-driven decisions but optimises the allocation of resources. Smart farming systems, underpinned by cutting-edge software, enable continuous scrutiny of soil health, biodiversity, and various ecological indicators. Predictive modelling can be implemented by analysing vast amounts of data collected from various sources, such as weather patterns, historical crop performance, and soil composition, farmers can gain valuable insights. This mix of information enables them to make informed decisions on crucial aspects like crop rotation, optimal planting times, and nutrient management.

Scenario description: Precision farming techniques, such as advanced sensors, drones, and satellite imagery, to analyse data on soil conditions, moisture levels, and crop health, can reduce efforts by approx. 30% with the same output (Medel-Jiménez, 2024).

'Status quo situation':	Conventional agriculture
'Bioeconomy situation':	Precision agri techniques can reduce efforts by 30% with the same output (based on Medel-Jiménez et al. (2024) and KARAGKOUNİS A. et al. (2023)

System diagram:



Limitations of the modelling:

- Use of bio-fuels in the bioeconomy situation was omitted (it was assumed that same fuel is uses in status quo and bioeconomy situation)
- Use of wood from maintenance practices was not considered. Could be added, if relevant.
- However, none of the aforementioned methodologies, take into account the potential effect of AFS on water regulating services, retention, and infiltration linked to the soil hydrological properties, as described in Köthke et al. (2022).

3.4.3 FOOD3 “Organic farming”

Option ID, short name:	FOOD3 “Organic farming”
Bioeconomy sector:	Agriculture
Bioeconomy objective:	Sustainable production
Scenario name:	Avoiding the use of synthetic fertilisers
Scenario FU:	Crops (Wheat) [tonnes]
Up-scaling:	Total wheat production mass per country
Goal:	to produce agricultural products in a sustainable agricultural system respecting the environment and animal welfare

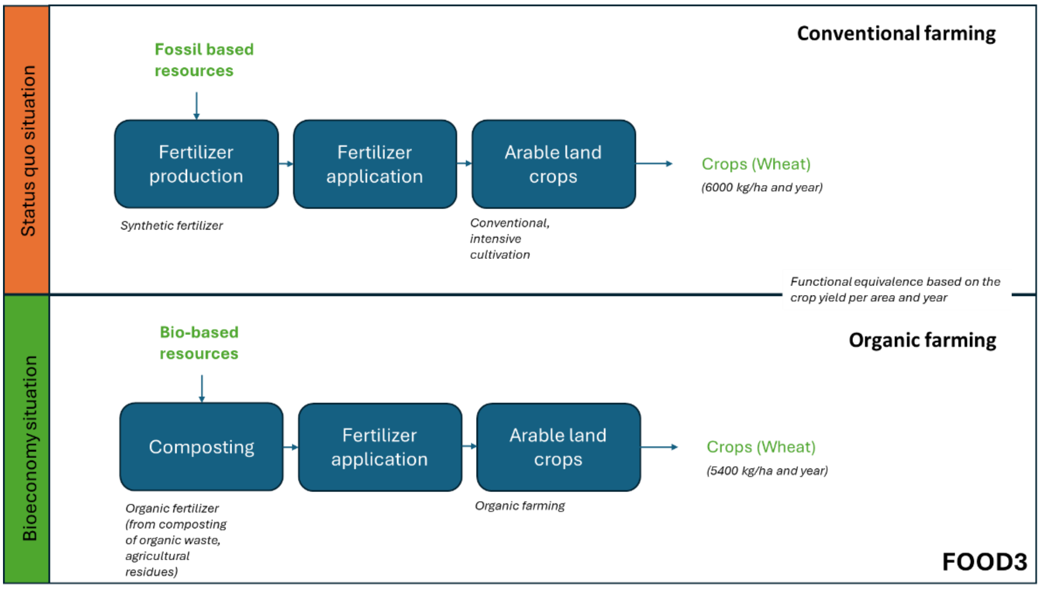
Reasoning for the selection: Under the consideration of the EU’s key principles of organic farming, organic production is an overall system of farm management and food production that combines best environmental practices, a high level of biodiversity, the preservation of natural resources and the application of high animal welfare standards (EUparl, 2018). “A sustainable food system is at the heart of the European Green Deal” (Organic action plan). Under the Green Deal’s Farm to Fork strategy, the European

Commission has set a target of at least 25% of the EU's agricultural land under organic farming and a significant increase in organic aquaculture by 2030.

Scenario description: Organic farming practices in the EU include among others the ban of synthetic fertiliser in the production of arable land crops (mainly cereals, fresh vegetables, green fooder and industrial crops). Other examples are the ban of the use of chemical pesticides, crop rotation for an efficient use of resources and synthetic fertilisers, very strict limits on livestock antibiotics, ban of genetically modified organisms, use of on-site resources for natural fertilisers and animal feed, raising livestock in a free-range, open-air environment and the use of organic fodder, tailored animal husbandry practices, but are not considered in the scenario. A reduced crop yield is assumed by 90%. DATA from Ecoinvent is used.

'Status quo situation':	open-loop (linear) system with the production of synthetic for fertilizing of arable land crops (non-renewable resources to biosphere)
'Bioeconomy situation':	closed-loop (circular) system (bio-based resources to biosphere)

System diagram:



3.4.4 FOOD4 "Small-scale fishing"

Option ID, short name:	FOOD4 "Small-scale fishing"
Bioeconomy sector:	Fisheries
Bioeconomy objective:	Sustainable production
Scenario name:	Sustainable harvesting of fish and seafood within short supply chains

<u>Scenario FU:</u> Fish [tonnes]
<u>Up-scaling:</u> Consumption of fisheries and aquaculture products
<u>Goal:</u> to enable the increase and diversification of products within sustainable food systems, particularly within short value chains, considering the sustainable sourcing of fish

<u>Reasoning for the selection:</u> Fish constitute an essential part of the diet, and consumers cannot imagine their daily lives without fish or seafood. At the same time, small-scale fishing supports numerous jobs and facilitates the implementation of sustainable development principles. Knowledge on aspects of small-scale coastal fisheries (SSCF) in Europe is generally limited, although there has been an improvement in information on the fishing sector and inshore marine resources due to the EU Data Collection Regulations (DCR). SSCF are strongly represented in all EU Member States (81% and 87% of the EU 25 whole fleet is composed of vessels less than 12 and 15 meters respectively) and approximately 100,000 crew are involved in SSCF in Europe. SSCF are present all around the European coast, even in isolated and sensitive areas." (Food and Agriculture Organization of the United Nations)

<u>Scenario description:</u> Sustainable harvesting of fish and seafood within short supply chains. The scenario envisions proper fisheries management and the procurement of an appropriate amount of fish and seafood (t/year), while maintaining biodiversity and ensuring no negative impact on local and global fish stocks. Small-scale fishery is recognized as one of the more sustainable activities when exploiting marine renewable resources (Cavraro et al., 2023). In this scenario, marine fish supply from small-scale fishery on local level is compared with imported marine fish (by air freight) from industrial fishery. Fuel consumption of the vessels is the main issue when discussing sustainability (Cavraro et al., 2023). In Greer et al. (2019) it is reported, that CO2 emission intensity per catch is lower with small-scale compared to industrial fishery (around 10% lower).

'Status quo situation': Fishermen catching fish without adhering to principles of biocycles, sustainable development, and circular economy, leading to negative impacts on the natural environment of aquatic ecosystems Industrial fishery and higher transport efforts of (frozen) fish.

'Bioeconomy situation': Fishermen catching fish while adhering to principles of biocycles, sustainable development, and the circular economy, thereby avoiding negative impacts on the natural environment of aquatic ecosystems. Small-scale fishery and lower transport efforst to generate local fish (50% frozen and 50% fresh assumed)

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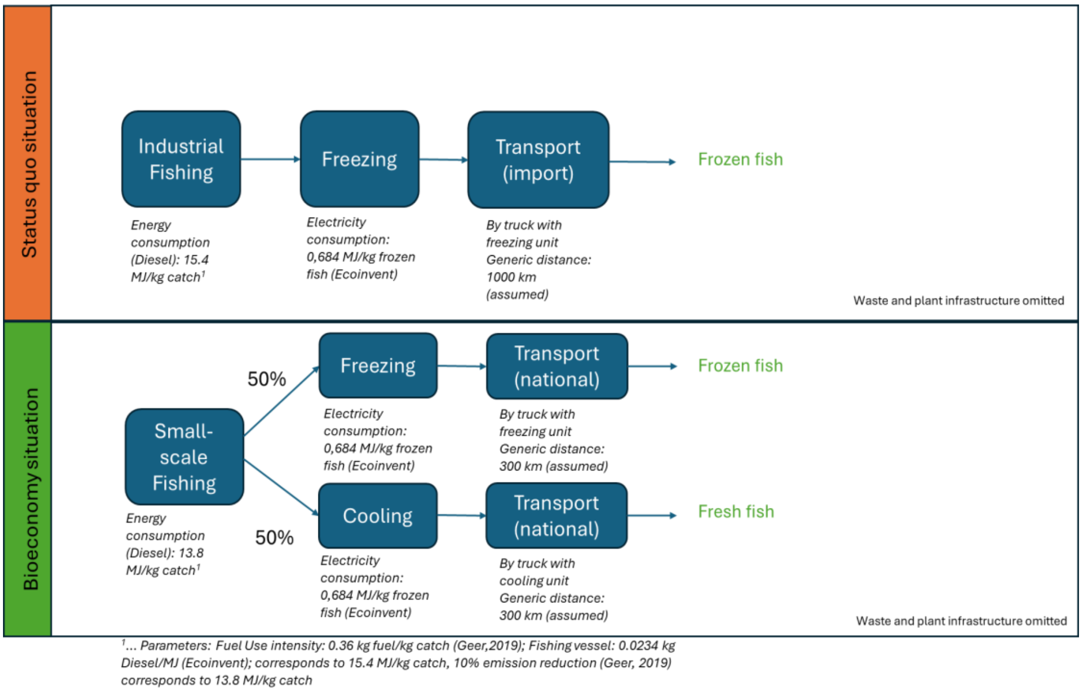
the European Union

System diagram:



Limitations of the modelling:

- Transport distances are only assumptions and the same for all countries
- Electricity mix: CEE2ACT countries for both baseline and bioeconomy, or only bioeconomy? At the moment, it is only for bioeconomy situation.

3.4.5 FOOD5 "Inland aquaculture"

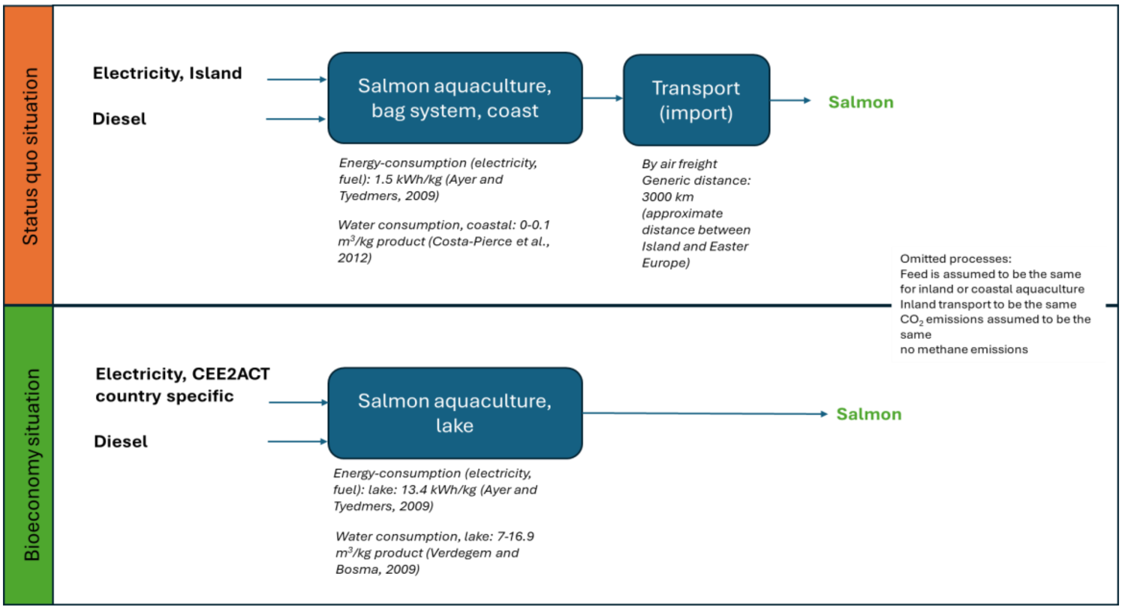
Option ID, short name:	FOOD5 "Inland aquaculture"
Bioeconomy sector:	Aquaculture
Bioeconomy objective:	Sustainable production
Scenario name:	Lake aquaculture
Scenario FU:	Fish [tonnes]
Up-scaling:	Consumption of fisheries and aquaculture products
Goal:	➢ to contribute to food security and promote a source of protein with a lower carbon footprint (promoted by the European Green Deal)

Reasoning for the selection: In 2020, EU aquaculture accounted for less than 1 % of global aquaculture production and imported products represented more than 60 % of the EU's seafood supply. The sustainable development of aquaculture is one of the main objectives of the common fisheries policy and an important component of the Blue Economy strategy. The global demand for seafood is currently higher than ever before. Almost the half were farmed in aquacultures. (FAO, 2018, P. 4). At the same time as wild stocks are declining, demand for aquaculture products is increasing and the growth trend in this production sector is steadily rising. In 2019, global aquaculture production of fish increased by five percent, while wild catches shrank by four percent. For Europe as a whole, fish production from aquaculture accounts for around 22% (European Commission, 2021). The input of feed and fertilizers into aquaculture increases the concentrations of phosphorus and nitrogen and influences biological production (Hubold & Klepper, 2013) . Intensively managed aquacultures accumulate correspondingly large quantities of feed and fertilizer residues as well as metabolic products.

Scenario description: In this scenario it is assumed that salmon is produced in inland lakes instead of in coastal areas in Island and imported to Eastern European Countries.

'Status quo situation':	Salmon production in bag system coastal area, less energy consumption but higher transport (imported good)
'Bioeconomy situation':	Salmon production in lake, more energy consumption but less transport (inland production) based on (Hubold & Klepper, 2013)

System diagram:



Limitations of the modelling:

- Feed mix: could be different in status quo and bioeconomy, but no background data for feed mix (there is although fish meal)

3.4.6 FOOD6 "Food loss and waste prevention and reduction"

Option ID, short name:	FOOD6 "Food loss and waste reduction along the supply chain"
Bioeconomy sector:	Food
Bioeconomy objective:	Efficient biomass utilization and mobilization
Scenario name:	Low-waste food supply chain
Scenario FU:	Food [tonnes]

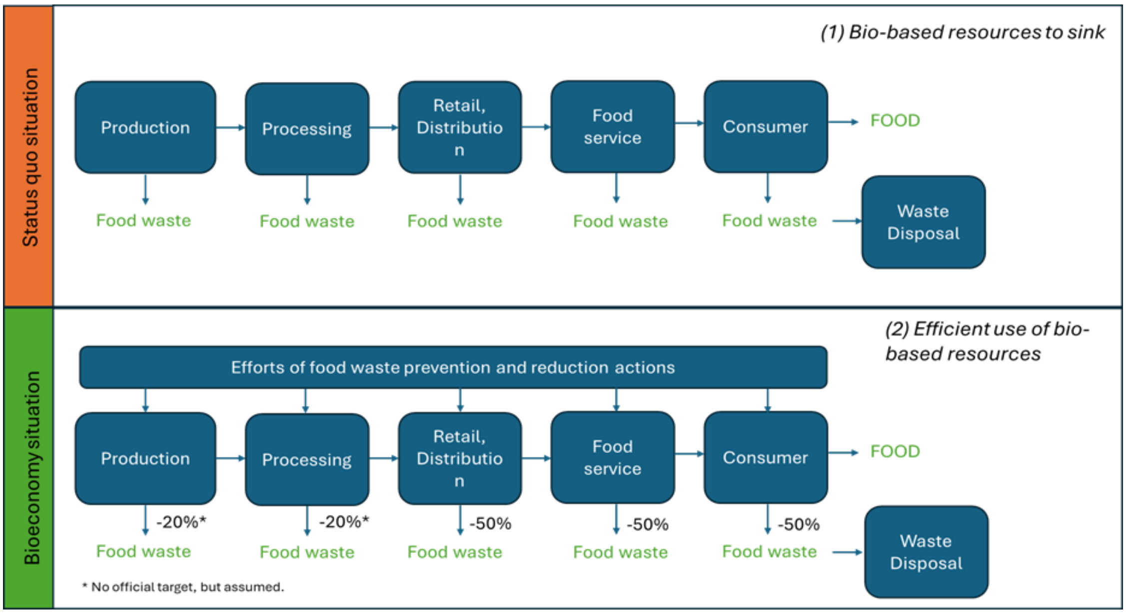
Up-scaling:	Food consumption (animal and vegetal products)
Goal:	to enable an efficient food sector by establishing a low-waste food supply chain

Reasoning for the selection: In the EU, over 58 million tonnes of food waste (131 kg/inhabitant) were estimated to be generated in 2021 (Eurostat, 2024). The total food waste reported in CEE2ACT targeting countries (incl. Baltic states, excl. Serbia) amounted to around 11 million tonnes in 2021 (Eurostat, 2024). Most food waste was produced at households, restaurants, and food service (62% EU-wide and 64% in CEE2ACT targeting counties incl. Baltic states excl. Serbia). The reduction of food waste along the supply chain is on the global (UNEP's SDGs) and also the EU's agenda. By 2030, the EU member states are committed to reduce food waste from retail and consumers by 50% and to reduce food waste also up-stream.

Scenario description: The reduction of food waste can be achieved by food waste prevention measures., like: Food waste reduction at primary production through the elimination of unfair trading practices (e.g. elimination of prompt ordering cancellations); Food waste reduction at processing through valorisation (e.g. food residues are used as food ingredients); Food waste reduction at retail through redistribution (e.g. food donation to food banks); Food waste reduction at consumer level through digitalisation (e.g. forecasting software at food services, mobile applications for a better food management at home). For the calculation of the impact categories the food waste composition for each step of the supply chain was considered. Food waste compositions were taken from studies of Austria: production (Schneider et al., 2014), processing (Hietler, 2018), wholesale (Hietler & Pladerer, 2019), retail (Lebersorger & Schneider, 2014), food service (Hrad et al., 2016), households (Schneider et al., 2012). The emission factors for the food products were taken from Agribalyse database v3.1.1 (ADEME, 2023).

'Status quo situation':	Conventional food supply chain with food waste levels reported for each country in 2021
'Bioeconomy situation':	Low-waste food supply chain with reduced food waste levels for each country in the same magnitude (20% waste reduction at production and processing; 50% waste reduction at retail, food service and consumer);

System diagram:



3.4.7 FOOD7 "Sustainable healthy diet"

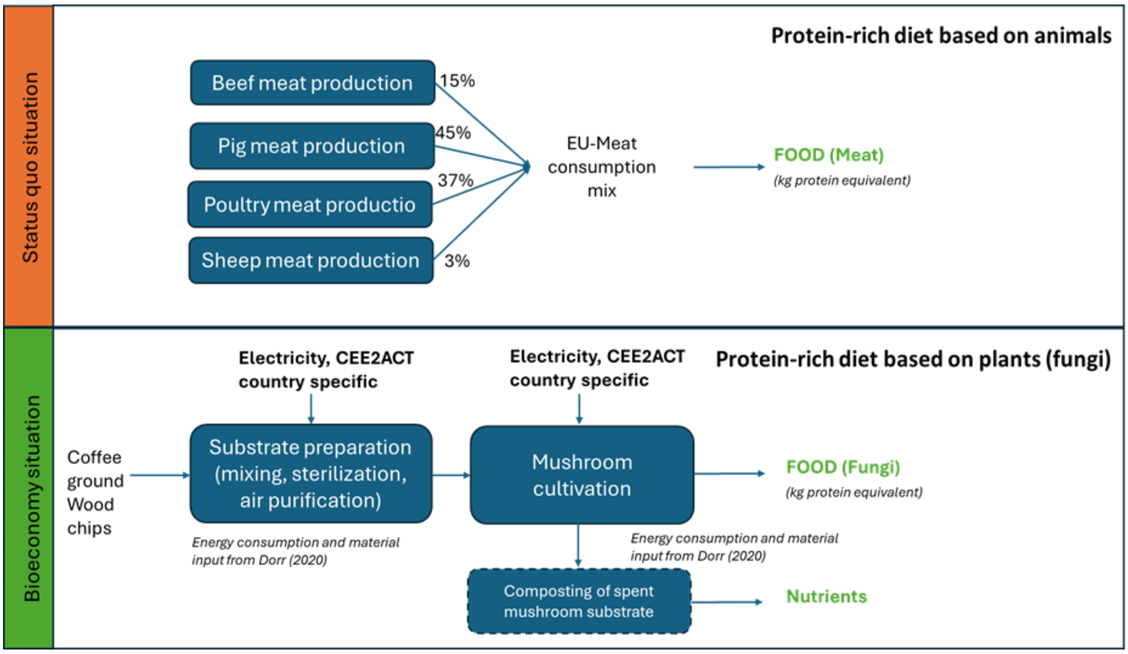
Option ID, short name:	FOOD7 "Sustainable healthy diet"
Bioeconomy sector:	Society
Bioeconomy objective:	Bio-based products
Scenario name:	Non animal protein sources from fungi
Scenario FU:	Food [tonnes]
Up-scaling:	Food consumption (only animal products)
Goal:	➢ to support a food diet that is less harmful for the environment (e.g. by reducing meat consumption or by replacing meat with other protein sources)

Reasoning for the selection: Protein-rich diets are common especially in industrialized countries, where individuals are consuming more protein than needed in the daily nutritional requirements and most of it comes from animals. It has been estimated that 50% of protein intake in the EU in 2007 was of animal origin. Half of that intake was from meat and around 35% from dairy. The same assessment also found that, on average, people in the EU consumed 70% more protein than required and 40% more saturated fat. Overall, red meat consumption was found to be twice as high than the recommended levels (Pushkarev, 2021). Meat and dairy products are sources of high-quality protein and essential nutrients, but their intensive production comes together with environmental problems. Almost a third of greenhouse gas emissions can be attributed to the food system. Livestock production is one of the main drivers of environmental damage (FAO, 2019). The FAO defines sustainable diets as those that promote human health and well-being while ensuring environmental sustainability and cultural acceptability. These diets must be nutrient-rich and free from harmful substances, providing food that is accessible and affordable for all, while minimizing negative environmental impacts such as greenhouse gas emissions, land degradation, and water use. In essence, sustainable diets aim to balance health, environmental, and socio-economic goals, ensuring that they are culturally appropriate and resilient to the challenges posed by urbanization and climate change.

Scenario description: Integration of protein sources other than from animals in the diets, such as soy and legumes as well as more intriguing options like plant-based meat substitutes (meat analogues), insects, algae and lab-grown meat. In this scenario we chose the production of mushroom as an alternative protein source (protein content of mushrooms: 23.80 g/100 g dry weight) in an urban mushroom farm.

'Status quo situation':	Protein-rich diet based on animals, mixture of beef, pig, poultry and sheep meat based on European Commission, DG Agriculture and Rural Development. EU agricultural outlook for markets and income,2019-2030. Brussels, 2019) (DATA from Agribalyse)
'Bioeconomy situation':	Protein-rich diet based on plants, in this case mushroom production, substrate: coffee grounds and wood chips (Life Cycle Inventory from Dorr et al. (2021)

System diagram:



Limitations of the modelling:

- emissions of sterilization with sour gas? Is it burnt? In Ecoinvent there is only a process, where sour gas is burned in gas turbine (emissions from burning are included)
- consumer travel was not included, although is mentioned in DATA of Dorr, 2020
- no emissions from coffee grounds as input material

- Allocation for wood chips as by-product (economic allocation) not included, yet. To be included?
- Composting of mushroom substrate was omitted due to lack of data.

3.5 Sustainable activities (SUST)

3.5.1 SUST1 "Nature Tourism"

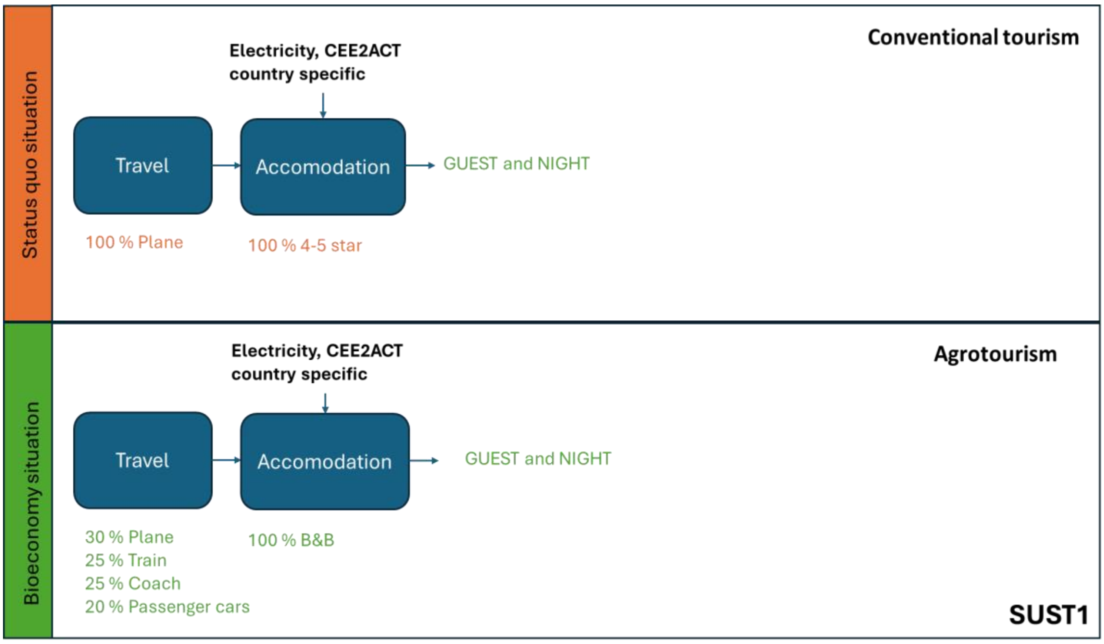
Option ID, short name:	SUST1 "Nature Tourism"
Bioeconomy sector:	Ecosystem services
Bioeconomy objective:	Sustainable production
Scenario name:	Agritourism
Scenario FU:	Holiday [1 guest * overnight stay]
Up-scaling:	Total overnight stays per country
Goal:	to enable sustainable tourism

Reasoning for the selection: International tourism is one of the largest and fastest growing economic sectors worldwide . Tourism's contribution to the worldwide gross domestic product (GDP) is estimated at some 5% (UNWTO, 2010).). Tourism is globally responsible for 5% of all carbon dioxide emissions, the most important greenhouse gas causing climate change (UNWTO UNEP WMO, 2008).

Scenario description: Agritourism (community based tourism) is considered a subset of rural tourism based on the use of the resources present in the countryside and finds its basis in the new models of consumption and enjoyment of rural areas (Phillip et al., 2010). Reasoning for the selection of the scenario: The global agritourism market is expected to grow about 10% annually to reach in 2028 80 billion USD (Global Agritourism Market Report 2024). Agritourism offer is often associated with a specific system of farming (e.g. organic) (Piwowar, 2017).

'Status quo situation':	conventional tourism; assumed 1000 km to travel by plane to holiday accommodation for a 3-day stay in a 4 to 5 star hotel
'Bioeconomy situation':	agrotourism; assumed 1000 km to travel by plane (30%), by train (25%), by coach (25%) and by passenger car (20%) to holiday accommodation for a 3-day stay in a B & B (DATA from Candia and Pirlone (2021).

System diagram:



Limitations of the modelling:

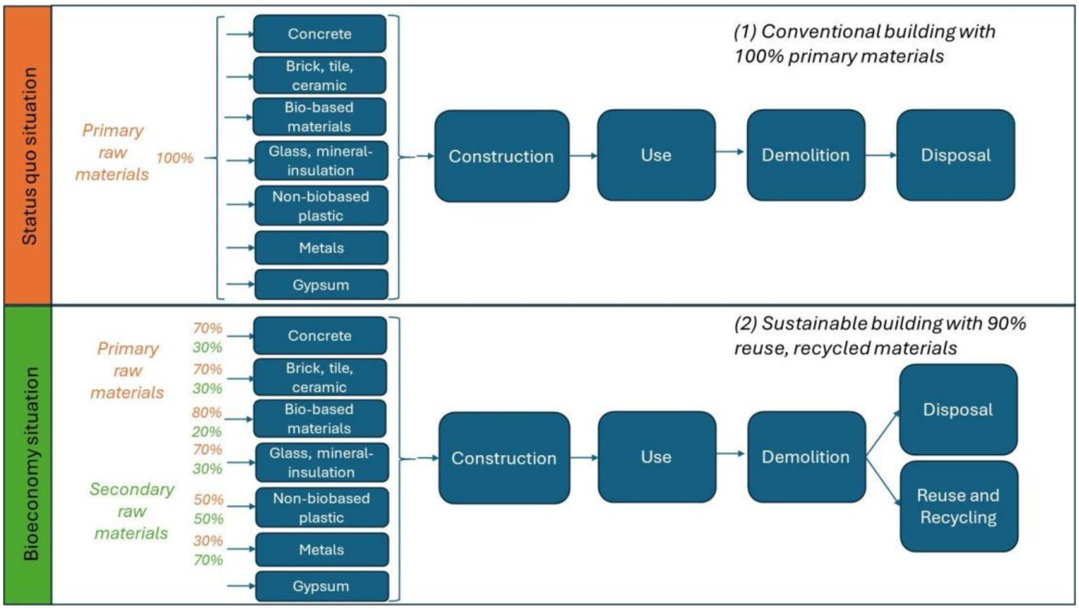
- One transportation mode per direction was assumed for simplification reasons.
- No tourist activities (food consumption, boat tours etc.) considered, due to lack of data
- Baseline 100% 4 to 5 star assumed, mix of other hotels (3 star, 1 to 2 star) possible
- Equivalent between accommodation in 4-5 star hotel and B&B? default: 1:1.2 (assumed)

3.5.2 SUST2 "Sustainable buildings"

Option ID, short name:	SUST2 "Sustainable buildings"
Bioeconomy sector:	Construction
Bioeconomy objective:	Sustainable production
Scenario name:	Use of secondary raw materials in construction
Scenario FU:	Living area in new buildings [1 square metre]
Up-scaling:	Total residential area newly constructed per country
Goal:	to enable sustainable activities in the construction sector; buildings shall support circular economy

Reasoning for the selection: The EU Taxonomy Regulation includes obligations that shall support environmentally sustainable activities. For activities in the construction sector aspects shall be considered to contribute to climate mitigation, climate adaptation and circular economy. Among other the following criteria are listed in the EU Taxonomy compass: Reduction of the energy demand, Reduction of water demand

, Reuse, recycling and material recovery of 90% (new buildings) and of 70% (renovation of existing buildings), Reduction of pollution prevention, reduction of land use.
Scenario description: The use of primary raw material in the construction of the building is minimised through the use of secondary raw materials. Construction designs and techniques support circularity via the incorporation of concepts for design for adaptability and deconstruction. Realistic exchange rates are assumed.
'Status quo situation':
'Bioeconomy situation':
System diagram:



3.5.3 SUST3 "Consumer behaviour change to more sustainability"

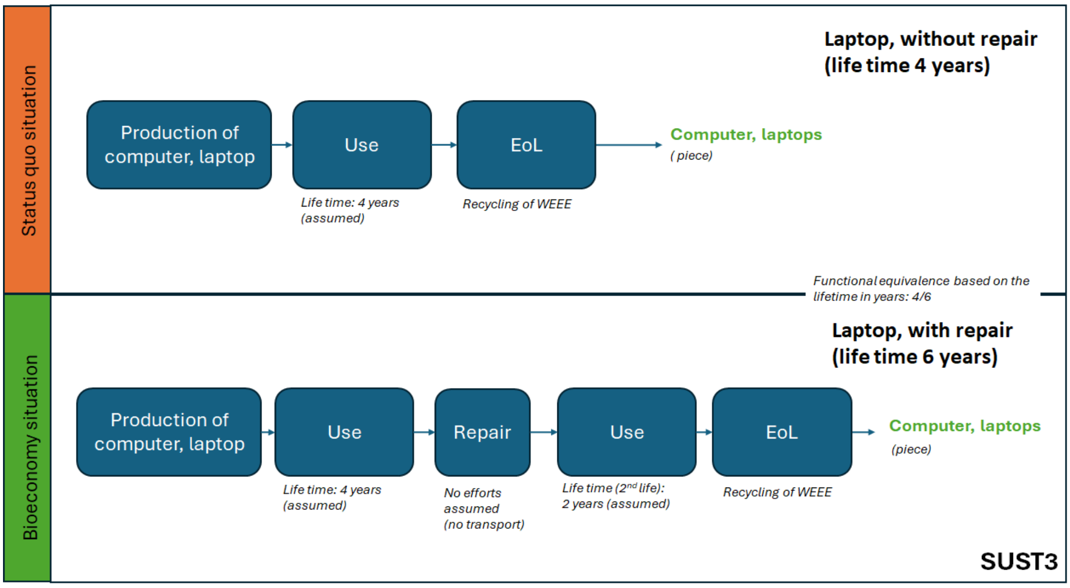
Option ID, short name:	SUST3 "Consumer behaviour change to more sustainability"
Bioeconomy sector:	Society
Bioeconomy objective:	Sustainable activities
Scenario name:	Repair bonus for electronic equipment (laptop)
Scenario FU:	Computer laptop [1 ton]
Up-scaling:	Total computer laptops in use per country
Goal:	to enable more sustainable consumption by prolonging the lifetime of electronic equipment

Reasoning for the selection: A repair bonus is a financial incentive introduced by cities, states or countries to encourage citizens to have defective or damaged items repaired instead of throwing them away and replacing them with new ones. Typically, a repair bonus scheme involves financial support or discounts for repair services. This can take the form of direct subsidies, rebates or vouchers. The introduction of a repair bonus system aims to raise citizens' awareness of sustainable consumption, promote the longer use of products and thus contribute to resource and climate protection.

Repairs have the potential to extend the service life of products and thus save energy, resources and climate-damaging emissions (Poppe et al., 2024).
Scenario description: In the scenario the repair of laptops was considered. A general avoidance effect of 50% is assumed in the base scenario in relation to the generic environmental data determined for the respective product group as applied in Poppe et al. (2024). This assumption is based on the results of various studies that have identified potential savings of between 24 and 91% through reuse and repair.

'Status quo situation':	Laptop production and use for a life time of 4 years
'Bioeconomy situation':	Laptop production and use, then repair for re-use and a prolonged life time of in total 6 years

System diagram:



3.5.4 SUST4 "Recycling of organic waste"

Option ID, short name:	SUST4 "Recycling of organic waste"
Bioeconomy sector:	Organic residues and waste management
Bioeconomy objective:	Sustainable production
Scenario name:	Commercial and municipal composting
Scenario FU:	Organic waste [1 ton]
Up-scaling:	Total municipal solid organic waste per country
Goal:	to enable circular bioeconomy by using compost as natural fertiliser by increasing high-quality recycling of organic waste from households and food service

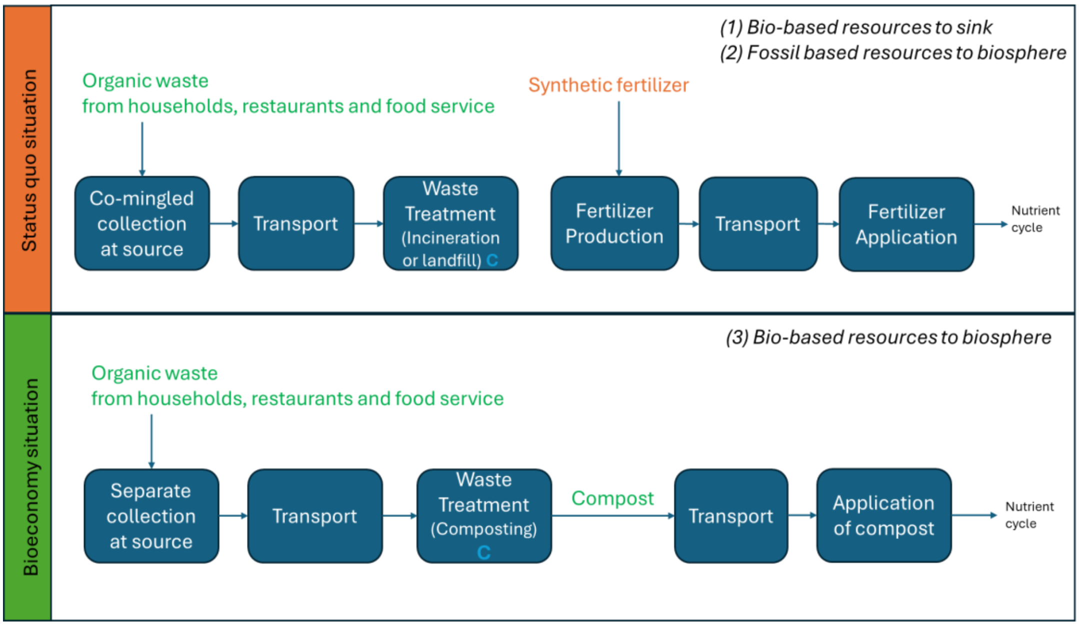
Reasoning for the selection: The total food waste reported in CEE2ACT targeting countries (incl. Baltic states, excl. Serbia) amount to around 11 million tonnes, of which 64% are produced at households, restaurants and food service (Eurostat, 2023). CEE2ACT targeting countries report a lack of recycling of organic waste. Data from

Eurostat show that the majority of household and similar waste is landfilled in CEE2ACT targeting countries, despite EU framework directive to cut waste to landfill down to 10% or less by 2035 (EU Directive 2018/850). It was furthermore proposed by stakeholders (CEE2ACT HUBs) as an option for fostering bioeconomy.

Scenario description: separate collection of organic waste from households and food service, transport and composting of this fraction and application of compost in agriculture (bio-based resources to biosphere). Separate waste collection at source is the most feasible option, if the goal is to use compost as fertilizer.

'Status quo situation':	Open-loop (linear) system with a sink of organic waste at incineration or landfill and production of synthetic fertilizer to cover the needs of fertilizing in agriculture (non-renewable resources to biosphere)
'Bioeconomy situation':	Closed-loop (circular) system (bio-based resources to biosphere)

System diagram:



3.6 Wood and wood products (WOOD)

3.6.1 WOOD1 "Sustainable wood supply"

Option ID, short name:	WOOD1 "Sustainable wood supply"
Bioeconomy sector:	Forestry
Bioeconomy objective:	Efficient biomass utilization and mobilisation
Scenario name:	Harvesting via chainsaw and a long-distance transport by train
Scenario FU:	Timber [1 solid cubic metre]

Up-scaling: Total roundwood (wood in the rough); under bark production volume per country

Goal: to enable a sustainable supply of wood

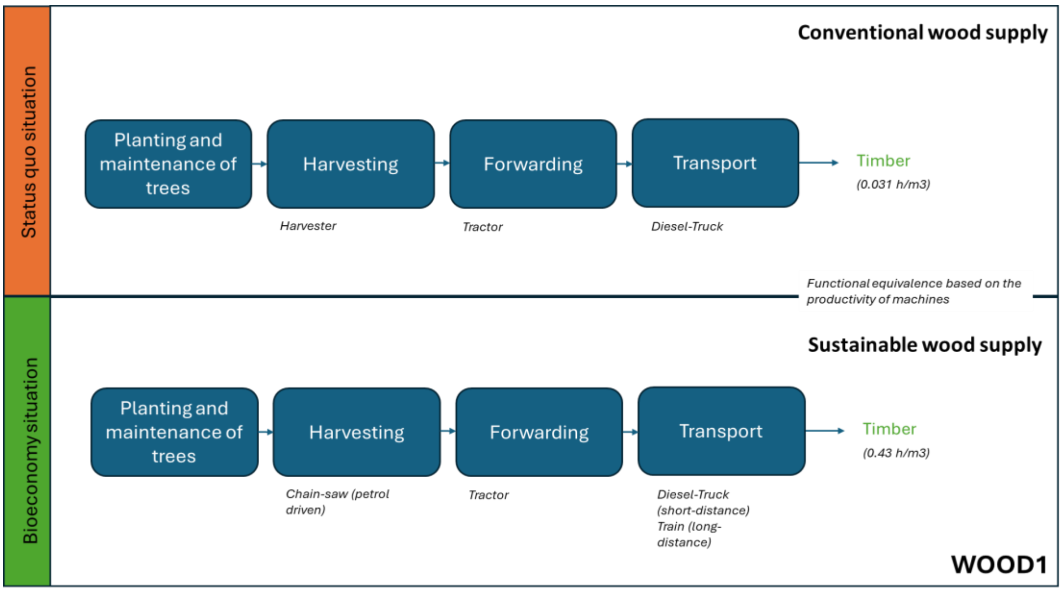
Reasoning for the selection: The transport of timber by lorry has proven to be the largest emitter of greenhouse gases within the supply chain (Kühmaier, 2019). Accordingly, the greatest potential for savings would also arise here. New technologies for harvesters or forwarders based on electric or hybrid technology are only just beginning to emerge and still require further development before they can be used extensively in timber harvesting and transport. Only for brush cutters, chainsaws and travelling carts market-ready models are in use in large numbers.

Scenario description: A sustainable supply of wood in forests include the harvesting via chainsaw and a short-distance transport by Diesel-truck and long-distance transport by rail or by hydrogen fuelled trucks. As most models for sustainable harvesters or forwarders are only on the cusp of market maturity, it is considered in this scenario to use electric chain saw for forest maintenance and diesel chain saw for harvesting. For the transport, hydrogen fuelled trucks are already on the road and suitable for long-distance transports. For short distances, still diesel-driven transport is assumed.

'Status quo situation': conventional wood supply; harvester and transport with diesel driven truck

'Bioeconomy situation': sustainable wood supply: harvesting with chain-saw (combination of electric and diesel fuelled chain saw) as well as transport with diesel fuelled truck for short distances and hydrogen fuelled truck for long distances

System diagram:



3.6.2 WOOD2 “Sustainable forest management”

Option ID, short name:	WOOD2 “Sustainable forest management”
Bioeconomy sector:	02_Forestry
Bioeconomy objective:	Sustainable production
Scenario name:	Preventing clear cuts
Scenario FU:	Timber [solid cubic metres per hectare]
Up-scaling:	Total forest area per country
Goal:	to enable transition to a sustainable and circular bioeconomy by utilizing forest resources in a suitable way that promotes economic growth, environmental and social sustainability.

Reasoning for the selection: For centuries, Europe's forests were severely damaged by deforestation and forest degradation. Over the last 200 years, however, forests have been regenerating and now cover almost 40% of the European Union (EU). European forests and the forest-based sector play a key role in the development of a bioeconomy. They supply various materials such as wood and non-wood products, as well as bioenergy, a variety of regulating and cultural ecosystem services. Forests in the EU are crucial ecosystems, providing natural resources, supporting biodiversity, and storing carbon. They're also a source of income. As the EU's bioeconomy grows, so does the demand for wood and biomass, and that's both an opportunity and a challenge. Balancing the production of wood and biomass with the conservation of forests and biodiversity is a classic dilemma we're likely to face.

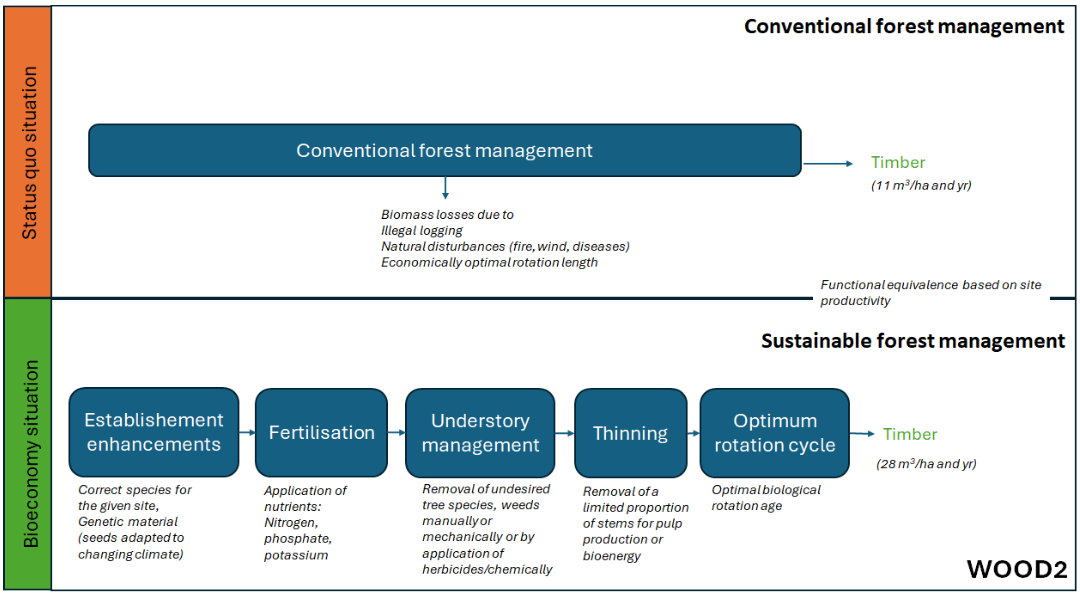
Sustainable Forest management (SFM) is defined in sources such as FSC, PEFC, European Commission and FAO. There is no common definition but social, environmental and economic impacts are addressed throughout the definitions.

Scenario description: For this scenario sustainable forest management (SFM) includes practices improving growth and carbon storage in forests. These are using fertilizers to supplement soil nutrients (nitrogen, phosphate, potassium), understory management and thinning forest stands to reduce competition and increase nutrient and light availability for growing trees as well as improved genetic material or species that are suitable for the sites. These measures also diminish the risk of fire damage, wind damage as well as pests and diseases. The maximum mean annual increment (= the mean volume accumulated per year over all years of growth) is reached at the optimal biological rotation age. So, if trees are grown with a rotation equal to this age, biological volume production is maximised over its lifetime. This is not always aligned to economically optimal rotation length. An example of biomass increment for Sitka spruce stand in the UK show an increase in site productivity from approximately 11 m3 to 28 m3 mean annual increment per hectare and year as maximum.

‘Status quo situation’:	Forest management without sustainable practices can lead to loss of biodiversity, carbon emissions and overexploitation of forests due to illegal logging practices, rotation length orientated on economic benefits and higher risk for natural disturbances such as fire, wind, and pests.
‘Bioeconomy situation’:	Sustainable forest management practices such as establishment enhancements, fertilisation, understory

	management, thinning and optimum rotation cycle to increase growth and carbon storage.

System diagram:



Limitations of the modelling:
Only the difference in site productivity is modelled
Application of nutrients in forest soil and herbicides are not considered due to lack of data

3.6.3 WOOD3 "Cascade utilization of wood"

Option ID, short name:	WOOD3 "Cascade utilization of wood"
Bioeconomy sector:	07_Wood products
Bioeconomy objective:	Sustainable production
Scenario name:	Virgin wood to glue laminated timber to particleboard to refined lignin oil & bioethanol
Scenario FU:	Sawn wood [1 solid cubic metre]
Up-scaling:	Total roundwood (wood in the rough); under bark production volume per country
Goal:	to enable a more sustainable and efficient wood utilization system that maximizes economic, environmental, and social benefits while minimizing waste and negative impacts.

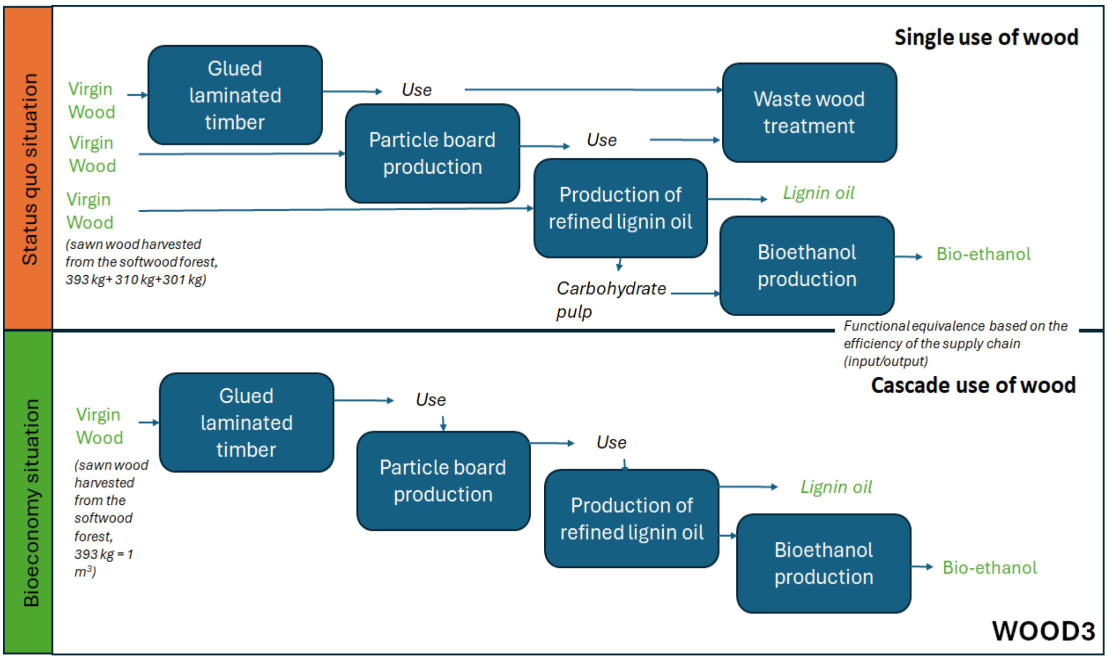
Reasoning for the selection: 25% of the EU's round wood production in 2022 was used as fuelwood; the rest was used for sawn wood and veneers, pulp and paper production (Eurostat, 2024). Cascade wood usage typically refers to a concept in sustainable forestry and resource management where wood products are utilized in a cascading manner to maximize their value and minimize waste. By utilizing wood in a cascading manner, waste is minimized and resource efficiency optimized (Sikkema et al, 2017).

Additionally, cascade usage promotes sustainable forestry practices by reducing the demand for new wood resources and minimizing the environmental impact associated with harvesting and processing wood. Wood products continue to store carbon throughout their lifecycle. By extending the lifecycle of wood through cascade usage, more carbon is retained in wood products rather than being released back into the atmosphere, contributing in a lot of cases to climate change mitigation efforts

Scenario description: Transition from single use of virgin wood to a cascading use in the form of Virgin wood to glue laminated timber to particleboard to refined lignin oil & bioethanol. DATA is taken from (Navare, 2022).

'Status quo situation':	Three separate pathways for virgin wood: 1) Glued laminated timber production, 2) particle board production, 3) Biorefinery (lignin oil and bio-ethanol production)
'Bioeconomy situation':	Cascade use of virgin wood: 1) Glued laminated timber is produced from virgin wood, 2) Particle board is produced from waste wood, 3) biorefinery is fed by waste wood.

System diagram:



Limitations of the modelling:

Waste wood treatment in status quo scenario is not modelled as assumed to be neglectable.

4 Results

The outcomes of the analysis are presented for each targeting country of CEE2ACT in the following sub-chapters.

4.1 Bulgaria

Figure 7 shows the results in an interval scale across all indicators (equal weighting for indicators). For Bulgaria the best score is achieved for the option *Sustainable healthy diet* (FOOD7) because of the high extent of impact and despite the relatively low rate of realisation (0.34) in the country. The scenario concerns the nutrition of the entire population, so that even a low degree of realization will have a corresponding influence. The next best options are *Nature tourism* (SUST1) and *Biogas plants with combined heat and power (CHP)* (ENERG2). The lowest score is reached for the option *Insects protein for feed* (FEED1), *Food by-product for feed* (FEED2) and *Multi-feedstock biorefinery* (ENERG5).

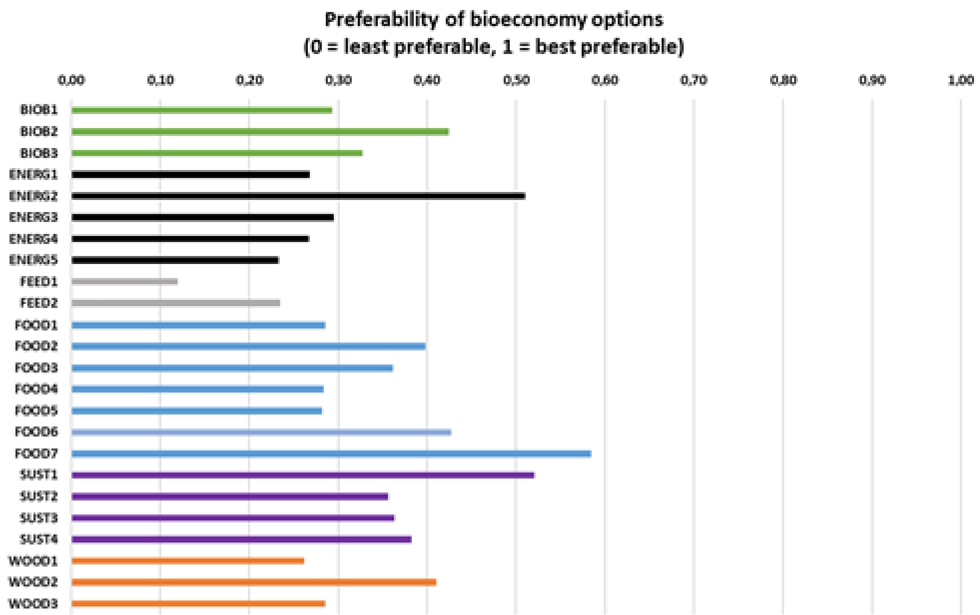


Figure 7: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Bulgaria

Figure 8 illustrates the results in an interval scale per indicator and per option grouped in four categories ('bio-based products & sustainability activities', 'bioenergy & biofuel', 'food & feed', 'wood & wood products').

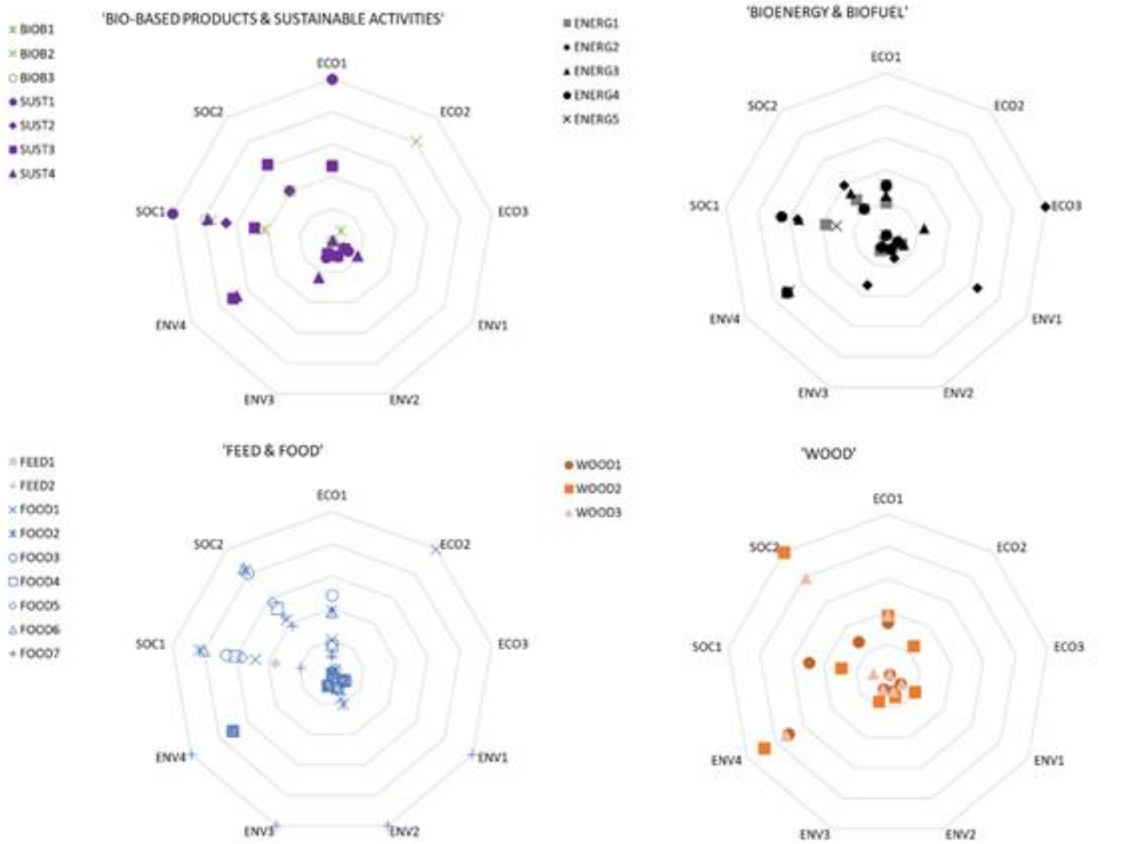


Figure 8: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Bulgaria

Table 6: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Bulgaria

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,47	0,09		0,08	0,09	0,08	0,71	0,42	0,41
BIOB2	0,47	0,81		0,09	0,10	0,08	0,71	0,75	0,41
BIOB3	0,47	0,00		0,08	0,09	0,08	0,71	0,79	0,41
ENERG1	0,20			0,11	0,09	0,10	0,71	0,38	0,28
ENERG2	0,29		1,00	0,65	0,15	0,33	0,71	0,55	0,40
ENERG3	0,24		0,24	0,13	0,08	0,08	0,71	0,55	0,34
ENERG4	0,31		0,00	0,08	0,09	0,08	0,71	0,65	0,21
ENERG5	0,31			0,06	0,00	0,04	0,69	0,31	0,21
FEED1	0,00	0,00		0,08	0,09	0,08	0,71	0,00	0,00
FEED2	0,11	0,00		0,08	0,09	0,08	0,71	0,35	0,45
FOOD1	0,20	1,00		0,00	0,16	0,00	0,00	0,48	0,43
FOOD2	0,39	0,03		0,10	0,20	0,10	0,71	0,83	0,83
FOOD3	0,48	0,03		0,10	0,02	0,08	0,71	0,66	0,81
FOOD4	0,17	0,00		0,08	0,09	0,08	0,71	0,61	0,53
FOOD5	0,17	0,00		0,08	0,09	0,08	0,71	0,56	0,57
FOOD6	0,38			0,08	0,09	0,08	0,71	0,80	0,85
FOOD7	0,10	0,00		1,00	1,00	1,00	1,00	0,19	0,38
SUST1	1,00			0,12	0,10	0,11	0,71	1,00	0,62
SUST2	0,47			0,08	0,09	0,08	0,71	0,66	0,41
SUST3	0,47			0,09	0,10	0,08	0,71	0,48	0,62
SUST4	0,47	0,01		0,18	0,10	0,24	0,67	0,78	0,62
WOOD1	0,33	0,02		0,09	0,09	0,08	0,71	0,49	0,28
WOOD2	0,38	0,25		0,19	0,13	0,16	0,88	0,29	1,00
WOOD3	0,38	0,02		0,10	0,10	0,09	0,73	0,09	0,79

Key Findings on Sustainability Options

1. **Job Creation Potential (ECO1)**: Among the options considered, *Nature tourism* (SUST1) demonstrates the strongest potential for creating jobs.
2. **Domestic biomass production (ECO2)**: The most effective approach for ensuring biomass availability is implementing *Agrosilvicultural Agroforestry Practices* (FOOD1).
3. **Renewable Energy Production (ECO3)**: *Biogas plants with combined heat and power (CHP)* (ENERG2) are the top-performing option for renewable energy generation.
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:
   - For overall environmental impact, the best option is a *Sustainable Healthy Diet* (FOOD7), which outperforms others on multiple fronts.
   - When specifically considering *fossil resource savings*, *Biogas plants with CHP* (ENERG2) are highly effective.

- For efficient *land use*, *Sustainable Forest Management* (WOOD2) stands out.

5. **Social Indicators (SOC1, SOC2)**:
    - *Nature tourism* (SUST1) receives the highest ratings for *consumer acceptance*, indicating strong public support.
    - For *willingness to pay*, *Sustainable Forest Management* (WOOD2) emerges as the preferred choice.

4.2 Croatia

Figure 9 shows the results in an interval scale across all indicators (equal weighting for indicators). For Croatia the best score is reached for *Sustainable healthy diet* (FOOD7) followed by *Nature tourism* (SUST1) and *PLA food packaging* (BIOB2). The least preferable options are *Insect protein for feed* (FEED1), *Mycelium for packaging* (BIOB1), *Sustainable wood supply* (WOOD1) and *Cascade utilisation of wood* (WOOD3).

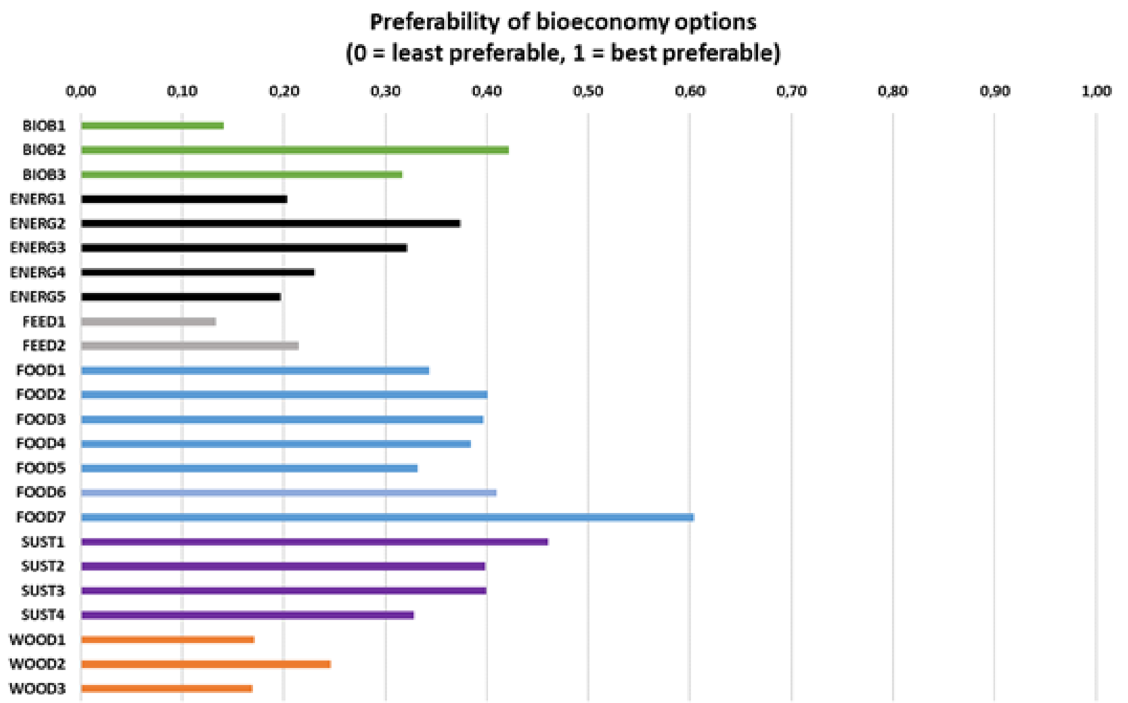


Figure 9: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Croatia

Figure 10 illustrates the results in an interval scale per indicator and per option grouped in four categories (‘bio-based products & sustainability activities’, ‘bioenergy & biofuel’, ‘food & feed’, ‘wood & wood products’).

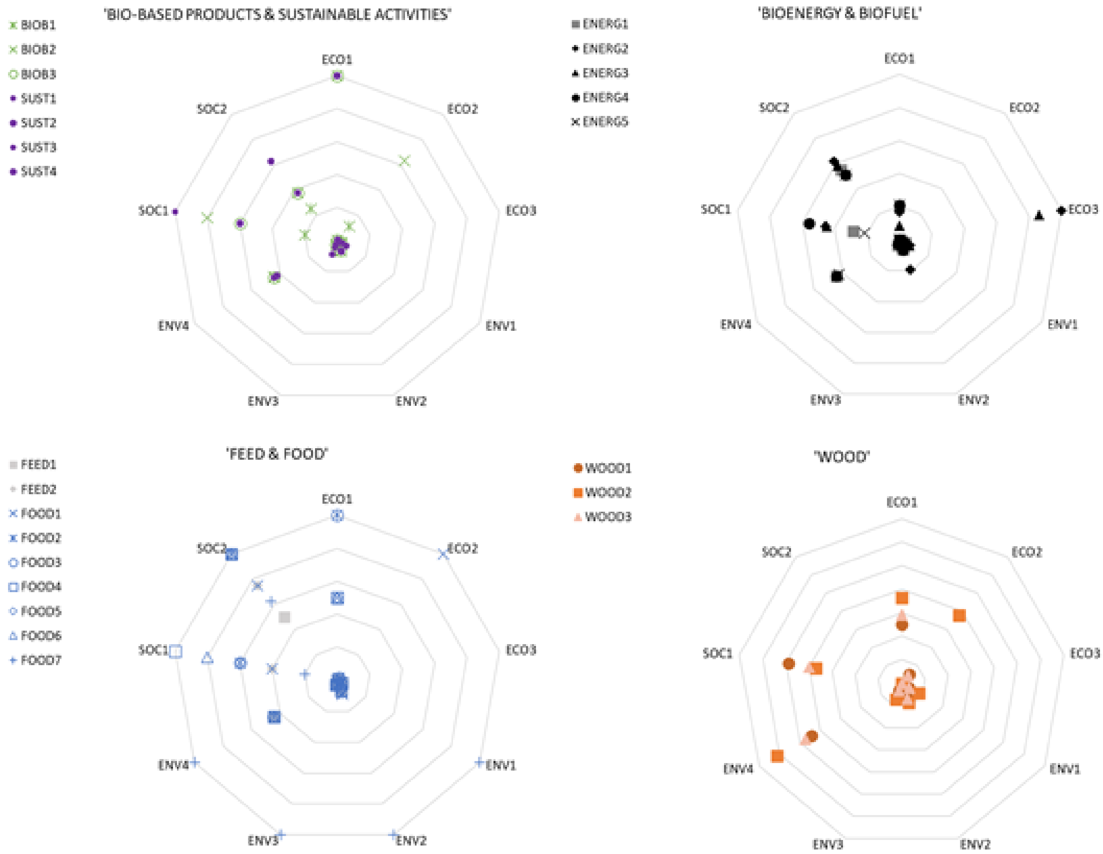


Figure 10: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Croatia

Table 7: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Croatia

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,00	0,11		0,03	0,07	0,03	0,44	0,20	0,25
BIOB2	1,00	0,63		0,03	0,07	0,03	0,44	0,80	0,38
BIOB3	1,00	0,00		0,03	0,07	0,03	0,44	0,60	0,38
ENERG1	0,00			0,04	0,07	0,04	0,44	0,28	0,55
ENERG2	0,17		1,00	0,07	0,19	0,04	0,44	0,46	0,62
ENERG3	0,08		0,86	0,07	0,05	0,03	0,44	0,45	0,58
ENERG4	0,21		0,00	0,03	0,07	0,03	0,44	0,56	0,51
ENERG5	0,21			0,02	0,00	0,00	0,42	0,22	0,51
FEED1	0,00	0,00		0,03	0,07	0,03	0,44	0,00	0,50
FEED2	0,00	0,00		0,03	0,07	0,03	0,44	0,40	0,75
FOOD1	0,50	1,00		0,00	0,09	0,00	0,00	0,40	0,75
FOOD2	1,00	0,02		0,03	0,09	0,03	0,45	0,60	1,00
FOOD3	1,00	0,02		0,03	0,05	0,03	0,45	0,60	1,00
FOOD4	0,50	0,00		0,03	0,07	0,03	0,44	1,00	1,00
FOOD5	0,50	0,00		0,03	0,06	0,03	0,44	0,60	1,00
FOOD6	0,50			0,03	0,07	0,03	0,44	0,80	1,00
FOOD7	0,00	0,01		1,00	1,00	1,00	1,00	0,20	0,63
SUST1	1,00			0,04	0,07	0,04	0,44	1,00	0,63
SUST2	1,00			0,03	0,07	0,03	0,44	0,60	0,63
SUST3	1,00			0,03	0,07	0,03	0,44	0,60	0,63
SUST4	1,00	0,01		0,06	0,07	0,09	0,42	0,60	0,38
WOOD1	0,25	0,05		0,03	0,07	0,03	0,44	0,49	0,00
WOOD2	0,36	0,38		0,08	0,09	0,07	0,61	0,37	0,00
WOOD3	0,29	0,04		0,04	0,07	0,03	0,47	0,40	0,00

Key Findings on Sustainability Options

1. **Job Creation Potential (ECO1)**: The most promising options for generating jobs include:
    - *PLA Food Packaging (BIOB2)*
    - *Biodegradable Mulch Film (BIOB3)*
    - *Precision/Smart Farming (FOOD2)*
    - *Organic Farming (FOOD3)*
    - *Nature tourism (SUST1)*
    - *Sustainable Buildings (SUST2)*
    - *Repair Bonus for Electronic Equipment (Computers) (SUST3)*
    - *Recycling of Organic Waste (Composting) (SUST4)*
2. **Domestic biomass production (ECO2)**: *Agrosilvicultural Agroforestry Practices* (FOOD1) are identified as the most effective approach.

3. **Renewable Energy Production (ECO3)**: *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2) achieve the highest scores for renewable energy generation.
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:A *Sustainable Healthy Diet* (FOOD7) performs best overall, particularly in reducing environmental impact.
    - For *land use efficiency*, *Sustainable Forest Management* (WOOD2) is the leading option.
5. **Social Indicators (SOC1, SOC2)**:
    - For *SOC* (Social Organic Carbon), *Small-Scale Fishing* (FOOD4) and *Nature tourism* (SUST1) show the highest potential.
    - In terms of *willingness to pay*, the top options are:
        - *Precision/Smart Farming (FOOD2)*
        - *Organic Farming (FOOD3)*
        - *Small-Scale Fishing (FOOD4)*
        - *Inland Aquaculture (FOOD5)*
        - *Food Waste Prevention and Reduction (FOOD6)*

4.3 Czech Republic

Figure 11 shows the results in an interval scale across all indicators (equal weighting for indicators). For the Czech Republic the best score is attained for *Food waste prevention and reduction* (FOOD6), followed by *Biogas plants with combined heat and power (CHP)* (ENERG2) and *Central and small-scale heating plants from biomethane* (ENERG2), ‘MULTI-FEEDSTOCK BIOREFINERY’ as well as ‘REPAIR BONUS FOR ELECTRONIC EQUIPMENT (COMPUTERS)’. The least preferable options resulted in ‘INLAND AQUACULTURE’, *Insect protein for feed* (FEED1) and *Mycelium for packaging* (BIOB1).

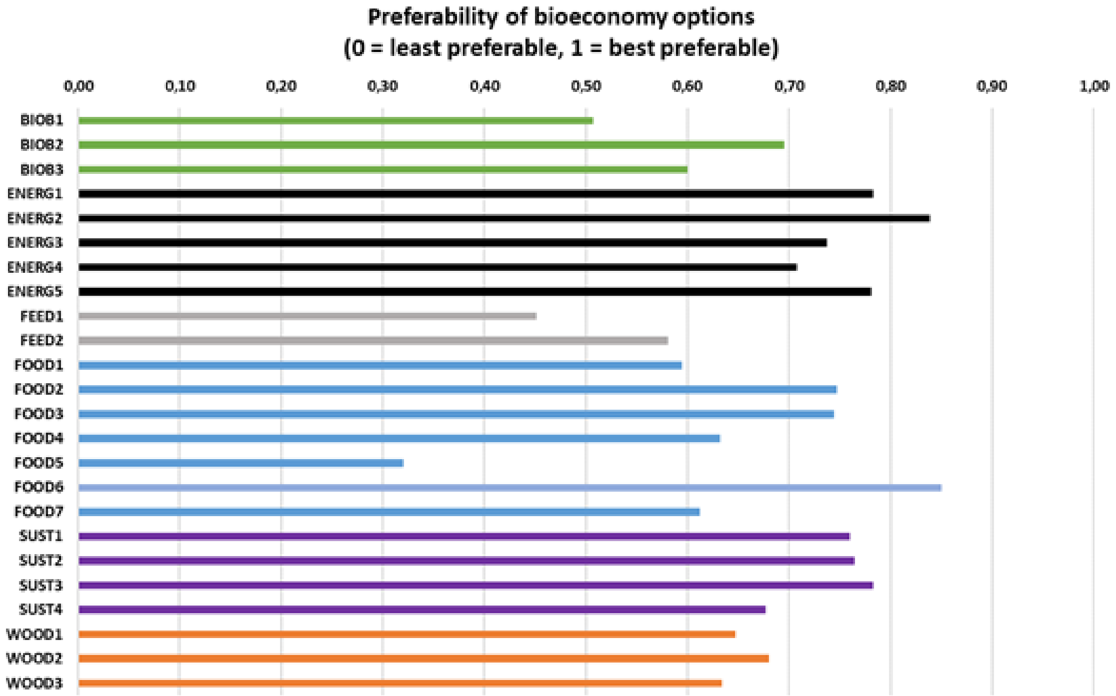


Figure 11: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Czech Republic

Figure 12 illustrates the results in an interval scale per indicator and per option grouped in four categories ('bio-base products & sustainability activities', 'bioenergy & biofuel', 'food & feed', 'wood & wood products').

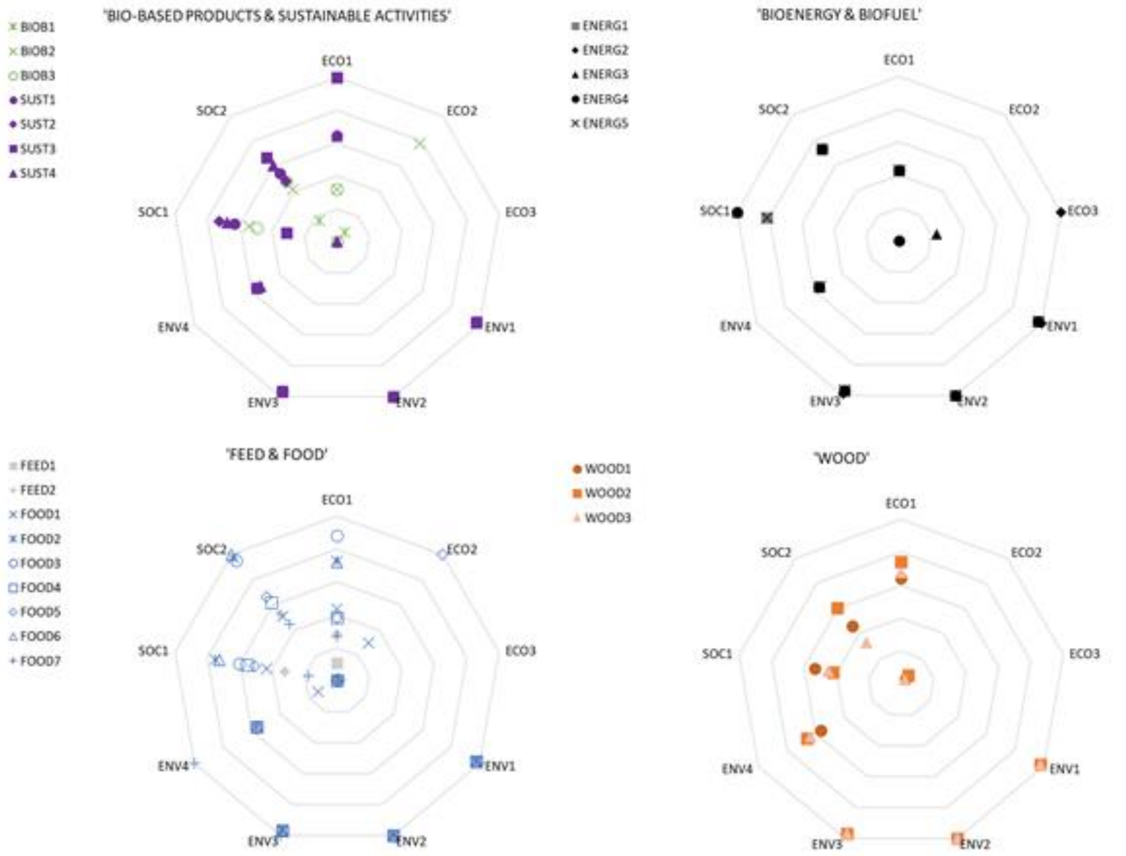


Figure 12: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Czech Republic

Table 8: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Czech Republic

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,00	0,08		0,98	1,00	0,97	0,56	0,31	0,17
BIOB2	0,32	0,78		0,98	1,00	0,97	0,56	0,54	0,42
BIOB3	0,32	0,00		0,98	1,00	0,97	0,56	0,50	0,48
ENERG1	0,43			0,98	1,00	0,97	0,56	0,82	0,73
ENERG2	0,43		1,00	1,00	1,00	0,99	0,56	1,00	0,73
ENERG3	0,43		0,23	0,98	1,00	0,97	0,56	1,00	0,73
ENERG4	0,43		0,00	0,98	1,00	0,97	0,56	1,00	0,73
ENERG5	0,43			0,98	1,00	0,97	0,55	0,82	0,73
FEED1	0,11	0,00		0,98	1,00	0,97	0,56	0,00	0,00
FEED2	0,29	0,00		0,98	1,00	0,97	0,56	0,32	0,53
FOOD1	0,44	0,30		0,98	1,00	0,97	0,13	0,44	0,51
FOOD2	0,73	0,01		0,98	1,00	0,97	0,56	0,75	0,98
FOOD3	0,88	0,01		0,98	1,00	0,97	0,56	0,60	0,95
FOOD4	0,38	0,00		0,98	1,00	0,97	0,56	0,55	0,62
FOOD5	0,38	1,00		0,00	0,00	0,00	0,00	0,51	0,67
FOOD6	0,72			0,98	1,00	0,97	0,56	0,73	1,00
FOOD7	0,27	0,00		1,00	1,00	1,00	1,00	0,18	0,45
SUST1	0,64			0,98	1,00	0,97	0,56	0,63	0,54
SUST2	0,64			0,98	1,00	0,97	0,56	0,72	0,48
SUST3	1,00			0,98	1,00	0,97	0,56	0,31	0,67
SUST4	0,64	0,00		0,98	1,00	0,97	0,54	0,68	0,60
WOOD1	0,64	0,04		0,98	1,00	0,97	0,56	0,53	0,46
WOOD2	0,74	0,07		0,98	1,00	0,97	0,66	0,42	0,60
WOOD3	0,68	0,03		0,98	1,00	0,97	0,64	0,45	0,33

Key Insights on Sustainability Options

1. **Job Creation Potential (ECO1)**:
   - The best option is the *Repair Bonus for Electronic Equipment (Computers)* (SUST3).
   - *Organic Farming* (FOOD3) is also a strong performer in this category.
2. **Domestic biomass production (ECO2)**:
   - *Inland Aquaculture* (FOOD5) ranks as the top option, followed closely by *PLA Food Packaging* (BIOB2).
3. **Renewable Energy Production (ECO3)**:
   - *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2) achieve the highest score for renewable energy production.
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:
   - Across all environmental metrics, a *Sustainable Healthy Diet* (FOOD7) emerges as the leading option.

- Additionally, *Biogas Plants with CHP* (ENERG2) perform exceptionally well in saving *fossil resources*, *water resources*, and reducing *greenhouse gas emissions*.

5. **Social Indicators (SOC1, SOC2)**:
    - For *Consumer Acceptance*, the best-performing options are:
        - *Biogas Plants with CHP (ENERG2)*
        - *Biofuel in the Form of Compressed Natural Gas (Bio-CNG) (ENERG3)*
        - *Biomass Heating Plants (ENERG1)*
    - Regarding *Willingness to Pay*, *Food Waste Prevention and Reduction* (FOOD6) scores the highest.

4.4 Greece

Figure 13 shows the results in an interval scale across all indicators (equal weighting for indicators). For Greece the best score is performed for *Sustainable buildings* (SUST2), followed by *Nature tourism* (SUST1) and *Food waste prevention and reduction* (FOOD6). The least preferable option is identified as *Inland aquaculture* (FOOD5), followed by *Mycelium for packaging* (BIOB1) and *Insect protein for feed* (FEED1).

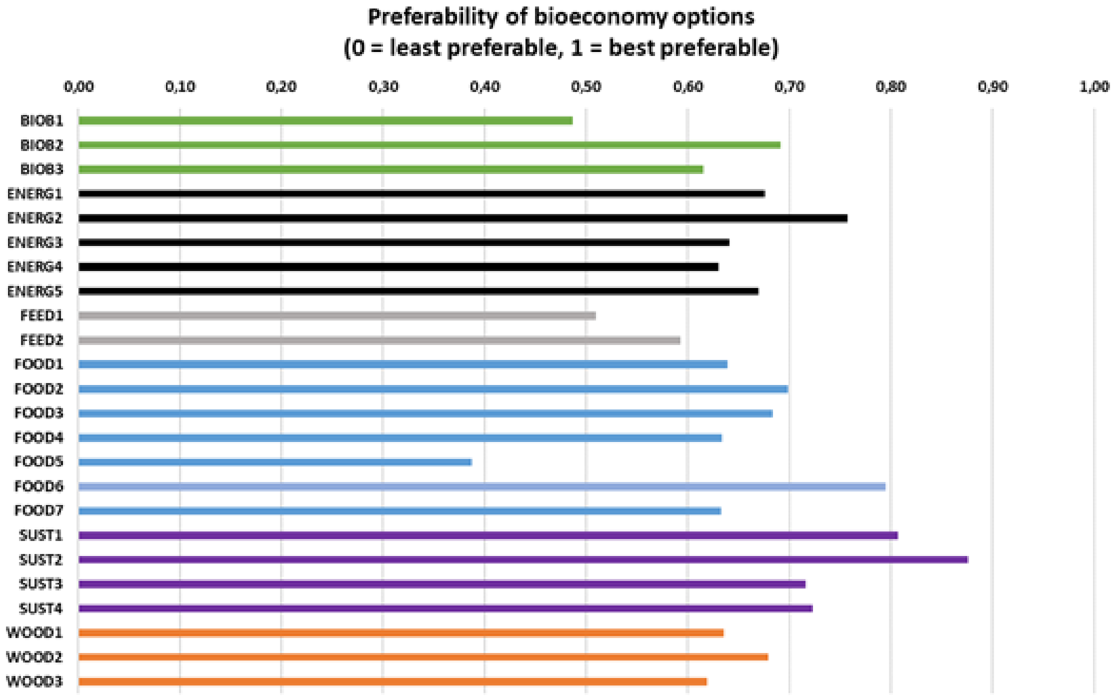


Figure 13: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Greece

Figure 14 illustrates the results in an interval scale per indicator and per option grouped in four categories (‘bio-base products & sustainability activities’, ‘bioenergy & biofuel’, ‘food & feed’, ‘wood & wood products’).

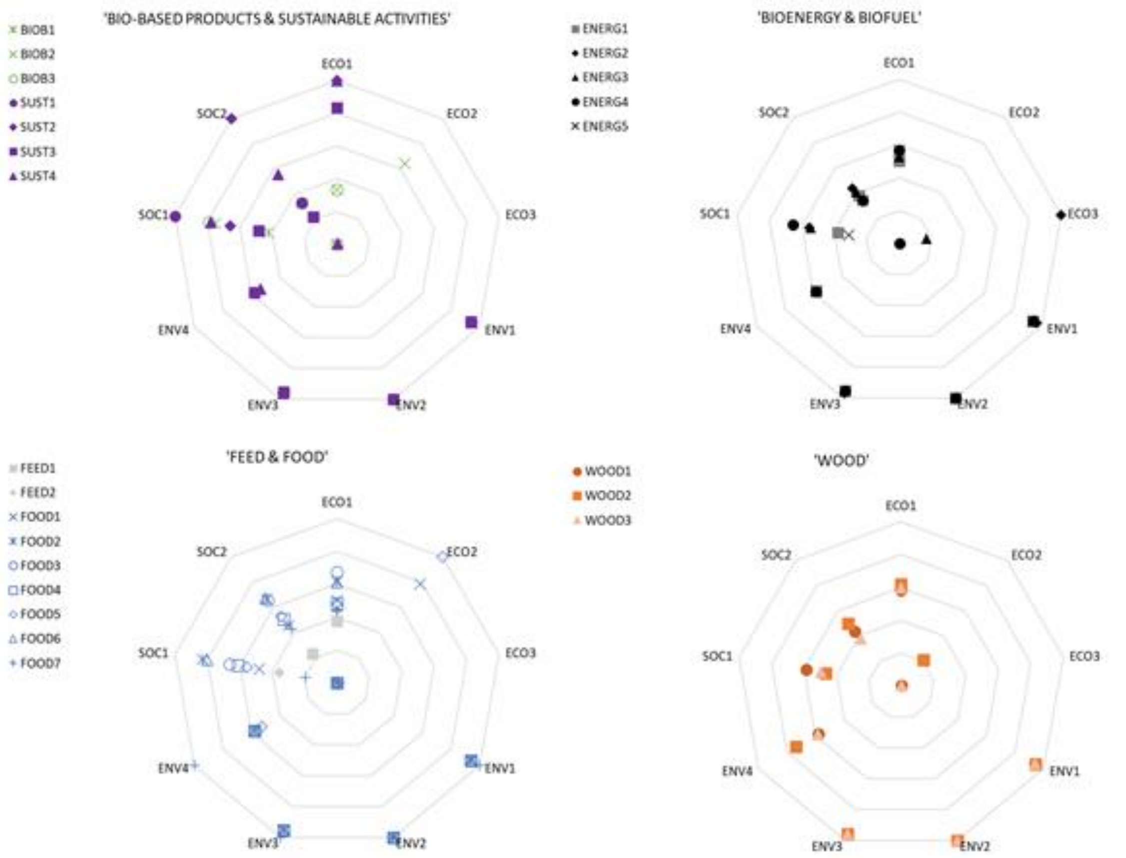


Figure 14: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: ‘bio-based products & sustainable activities’, ‘bioenergy & biofuel’, ‘feed & food’, ‘wood & wooden products’) for Greece

Table 9: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Greece

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,00	0,00		0,94	1,00	0,95	0,58	0,42	0,00
BIOB2	0,33	0,64		0,94	1,00	0,95	0,58	0,75	0,33
BIOB3	0,33	0,00		0,94	1,00	0,95	0,58	0,79	0,33
ENERG1	0,50			0,94	1,00	0,95	0,58	0,38	0,38
ENERG2	0,56		1,00	0,97	1,00	0,97	0,58	0,55	0,44
ENERG3	0,53		0,17	0,94	1,00	0,95	0,58	0,55	0,41
ENERG4	0,57		0,01	0,94	1,00	0,95	0,58	0,65	0,34
ENERG5	0,57			0,94	1,00	0,95	0,58	0,31	0,34
FEED1	0,38	0,00		0,94	1,00	0,95	0,58	0,00	0,23
FEED2	0,44	0,00		0,94	1,00	0,95	0,58	0,35	0,47
FOOD1	0,50	0,78		0,94	1,00	0,95	0,00	0,48	0,46
FOOD2	0,62	0,00		0,94	1,00	0,95	0,58	0,83	0,67
FOOD3	0,68	0,00		0,94	1,00	0,95	0,58	0,66	0,66
FOOD4	0,48	0,00		0,94	1,00	0,95	0,58	0,61	0,51
FOOD5	0,48	1,00		0,00	0,00	0,00	0,53	0,56	0,53
FOOD6	0,61			0,94	1,00	0,95	0,58	0,80	0,68
FOOD7	0,44	0,00		1,00	1,00	1,00	1,00	0,19	0,43
SUST1	0,83			0,94	1,00	0,96	0,58	1,00	0,33
SUST2	1,00			0,94	1,00	0,95	0,58	0,66	1,00
SUST3	0,83			0,94	1,00	0,95	0,58	0,48	0,22
SUST4	1,00	0,01		0,95	1,00	0,96	0,54	0,78	0,56
WOOD1	0,58	0,01		0,94	1,00	0,95	0,58	0,59	0,44
WOOD2	0,62	0,21		0,94	1,00	0,96	0,74	0,46	0,50
WOOD3	0,60	0,01		0,94	1,00	0,95	0,59	0,49	0,38

Key Findings on Sustainability Options

1. **Economic Impact (ECO 1)**:
   - The best options are *Sustainable Buildings* (SUST2) and *Recycling of Organic Waste (Composting)* (SUST4)
2. **Domestic biomass production (ECO2)**:
   - *Inland Aquaculture* (FOOD5) leads, followed by *Agrosilvicultural Agroforestry Practices* (FOOD1) and *PLA Food Packaging* (BIOB2)
3. **Renewable Energy Production (ECO3)**:
   - *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2) are the top-performing solution.
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:
   - Most options perform well in terms of *fossil resource savings*, *water resource savings*, and *greenhouse gas savings*, with the exception of *Inland Aquaculture* (FOOD5)

- For *land use efficiency*, a *Sustainable Healthy Diet* (FOOD7) is the best option.

5. **Social Indicators (SOC1 SOC2)**:
    - For *Consumer Acceptance*, *Nature tourism* (SUST1) scores the highest.
    - Regarding *Willingness to Pay*, *Sustainable Buildings* (SUST2) achieve the best results.

4.5 Hungary

Figure 15 shows the results in an interval scale across all indicators (equal weighting for indicators). For Hungary the best score is arrived for *Sustainable healthy diet* (FOOD7), followed by *Nature tourism* (SUST1) and *Biogas plants with combined heat and power (CHP)* (ENERG2). The least preferable option is *Insect protein for feed* (FEED1), followed by *Mycelium for packaging* (BIOB1) and *Food by-product for feed* (FEED2).

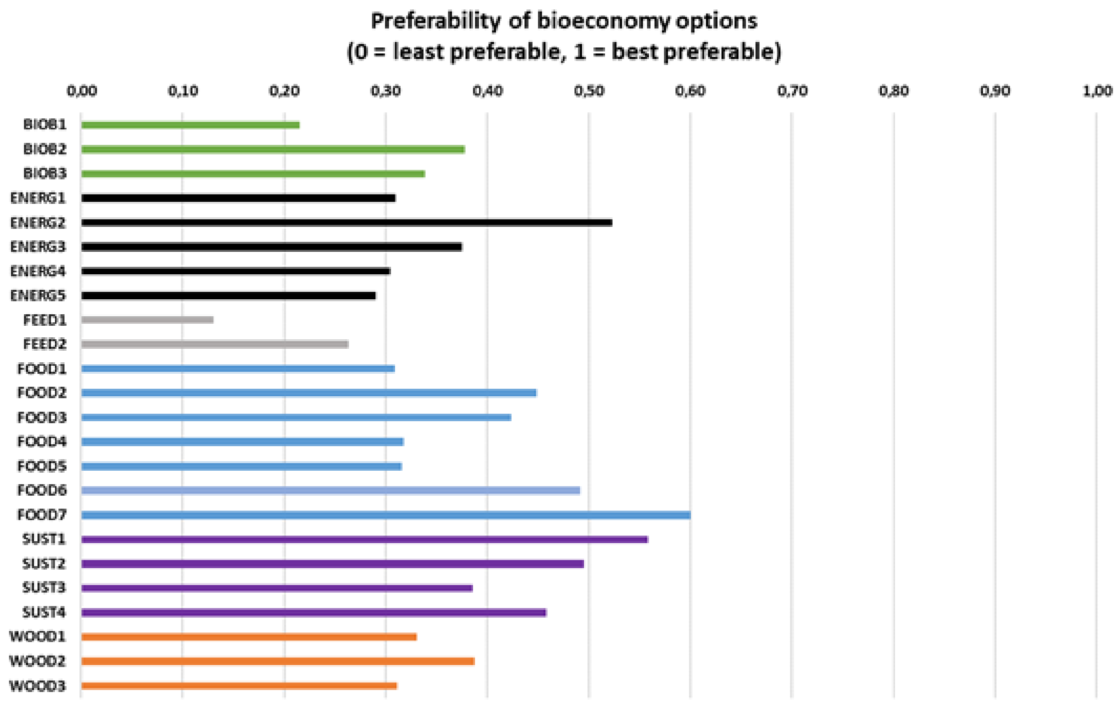


Figure 15: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Hungary

Figure 16 illustrates the results in an interval scale per indicator and per option grouped in four categories ('bio-base products & sustainability activities', 'bioenergy & biofuel', 'food & feed', 'wood & wood products').

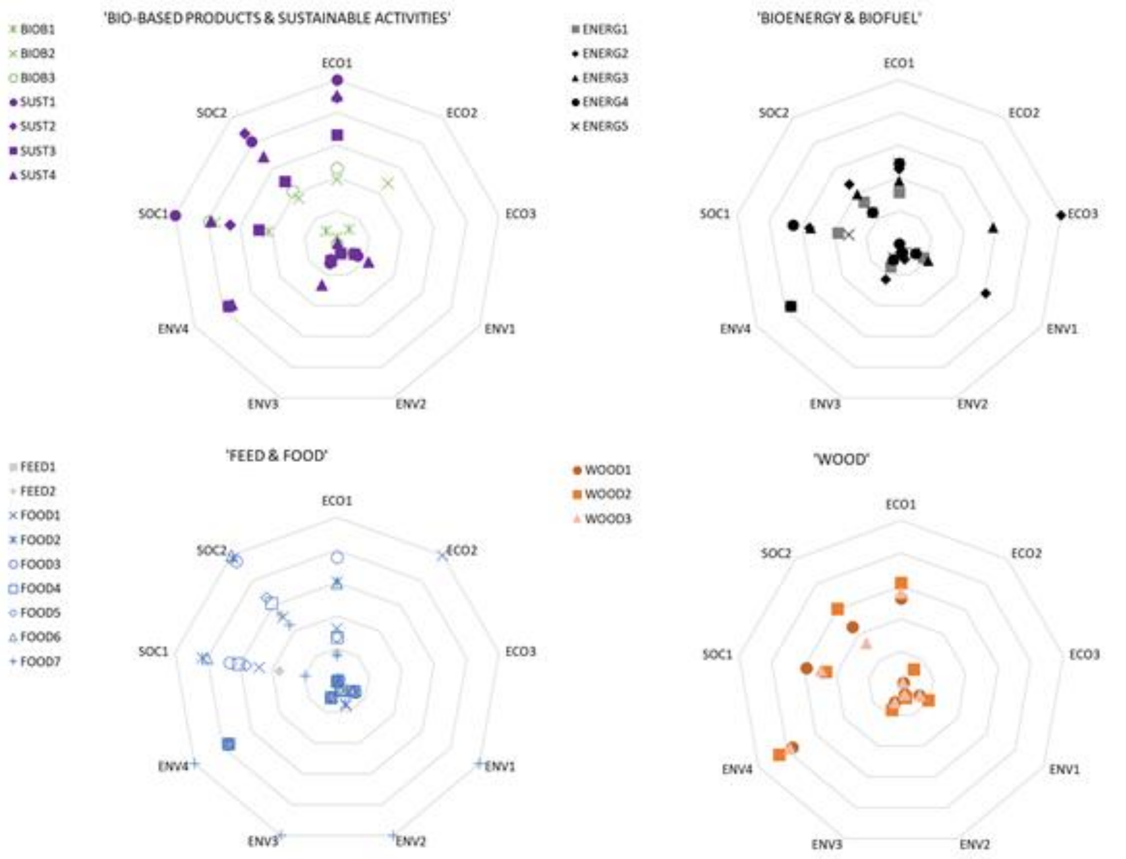


Figure 16: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Hungary

Table 10: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Hungary

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,04	0,11		0,12	0,06	0,10	0,76	0,42	0,10
BIOB2	0,39	0,48		0,12	0,06	0,10	0,76	0,75	0,36
BIOB3	0,46	0,00		0,12	0,06	0,10	0,76	0,79	0,42
ENERG1	0,31			0,17	0,06	0,15	0,76	0,38	0,33
ENERG2	0,45		1,00	0,61	0,10	0,23	0,76	0,55	0,47
ENERG3	0,38		0,58	0,20	0,03	0,10	0,76	0,55	0,40
ENERG4	0,49		0,00	0,12	0,06	0,10	0,76	0,65	0,25
ENERG5	0,49			0,11	0,03	0,09	0,76	0,31	0,25
FEED1	0,00	0,00		0,12	0,06	0,10	0,76	0,00	0,00
FEED2	0,17	0,00		0,12	0,06	0,10	0,76	0,35	0,53
FOOD1	0,32	1,00		0,00	0,16	0,00	0,00	0,48	0,51
FOOD2	0,61	0,02		0,13	0,15	0,12	0,77	0,83	0,98
FOOD3	0,76	0,02		0,13	0,00	0,10	0,77	0,66	0,95
FOOD4	0,27	0,00		0,12	0,06	0,10	0,76	0,61	0,62
FOOD5	0,27	0,00		0,12	0,05	0,10	0,76	0,56	0,67
FOOD6	0,60			0,12	0,06	0,10	0,76	0,80	1,00
FOOD7	0,16	0,00		1,00	1,00	1,00	1,00	0,19	0,45
SUST1	1,00			0,15	0,06	0,13	0,76	1,00	0,81
SUST2	0,89			0,12	0,06	0,10	0,76	0,66	0,87
SUST3	0,66			0,12	0,06	0,11	0,76	0,48	0,49
SUST4	0,90	0,00		0,22	0,06	0,27	0,74	0,78	0,69
WOOD1	0,52	0,02		0,13	0,06	0,11	0,76	0,59	0,46
WOOD2	0,62	0,12		0,19	0,09	0,16	0,86	0,46	0,60
WOOD3	0,56	0,02		0,13	0,06	0,12	0,78	0,49	0,33

Key Findings on Sustainability Options

1. **Economic Impact (ECO1)**:
   - The top-performing option is *Nature tourism (SUST1)* , followed by *Recycling of Organic Waste (Composting)* (SUST4) and *Sustainable Buildings* (SUST2)
2. **Domestic biomass production (ECO2)**:
   - The best option is *Agrosilvicultural Agroforestry Practices* (FOOD1).
3. **Renewable Energy Production (ECO3)**:
   - *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2) achieve the highest score.
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:
   - Across all metrics, a *Sustainable Healthy Diet* (FOOD7) stands out as the best option.
   - *Sustainable Forest Management* (WOOD2) excels in *land use efficiency*, while *Biogas Plants with CHP* (ENERG2) lead in *fossil resource savings*.

5. **Social Indicators (SOC1, SOC2)**:
    - For *Consumer Acceptance*, *Nature tourism* (SUST1) scores the highest.
    - Regarding *Willingness to Pay*, the top options are:
        - *Food Waste Prevention and Reduction (FOOD6)*
        - *Organic Farming (FOOD3)*
        - *Precision/Smart Farming (FOOD2)*

4.6 Poland

Figure 17 shows the results in an interval scale across all indicators (equal weighting for indicators). For Poland the best score is achieved for *Nature tourism* (SUST1), followed by *Food waste prevention and reduction* (FOOD6) and *Biofuel in form of compressed natural gas (bio-CNG)* (ENERG3). The least preferable options are *Inland aquaculture* (FOOD5), followed by *Insect protein for feed* (FEED1).

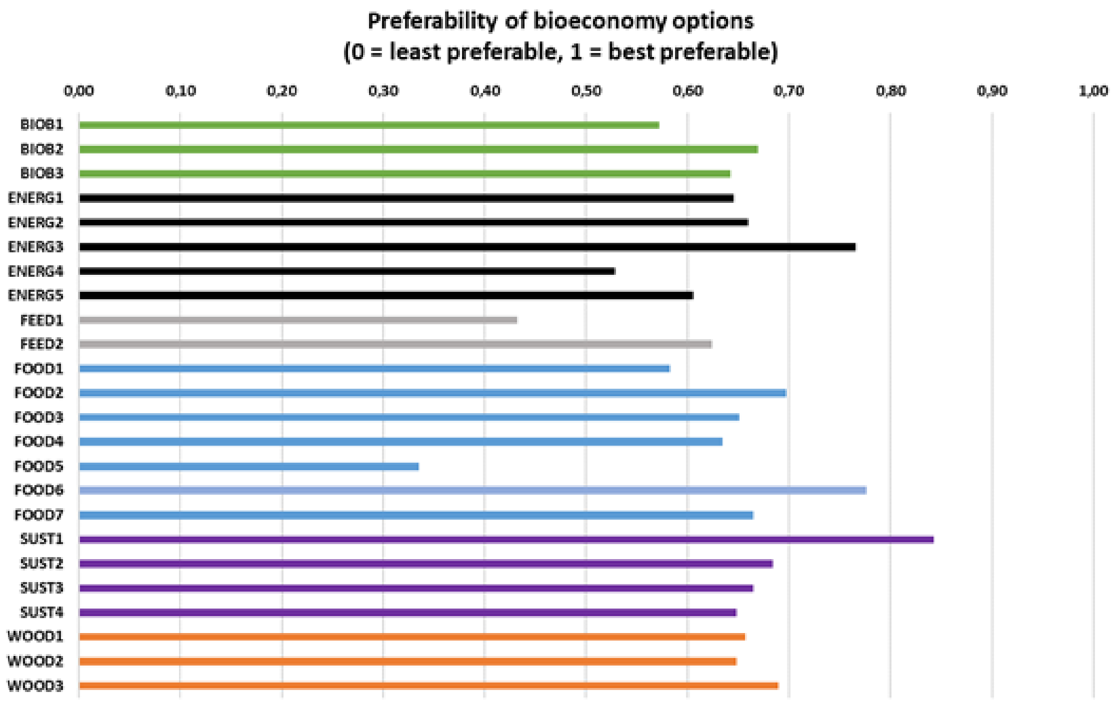


Figure 17: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Poland

Figure 18 illustrates the results in an interval scale per indicator and per option grouped in four categories (‘bio-base products & sustainability activities’, ‘bioenergy & biofuel’, ‘food & feed’, ‘wood & wood products’).

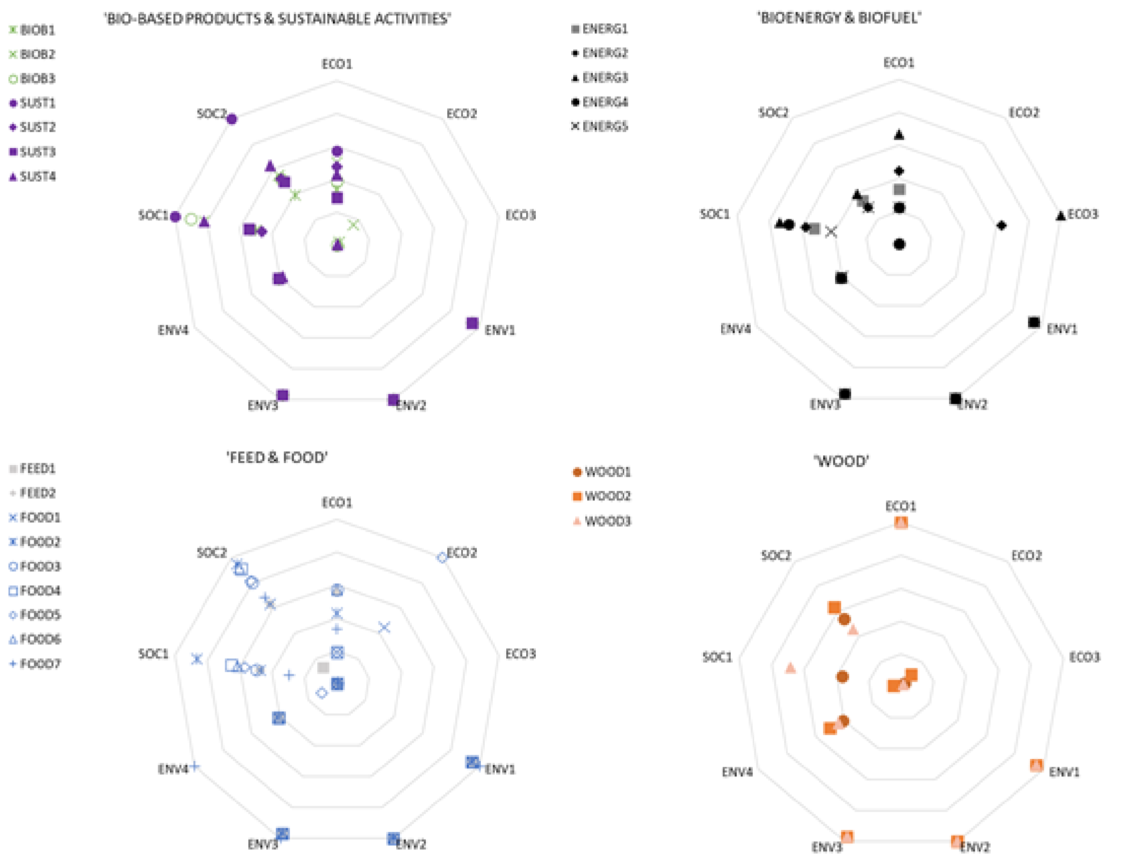


Figure 18: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Poland

Table 11: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Poland

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,33	0,02		0,95	1,00	0,97	0,41	0,50	0,39
BIOB2	0,50	0,16		0,95	1,00	0,97	0,41	0,82	0,55
BIOB3	0,39	0,00		0,95	1,00	0,97	0,41	0,90	0,53
ENERG1	0,33			0,95	1,00	0,97	0,41	0,52	0,34
ENERG2	0,44		0,63	0,95	1,00	0,97	0,41	0,58	0,29
ENERG3	0,67		1,00	0,95	1,00	0,97	0,41	0,73	0,39
ENERG4	0,22		0,00	0,95	1,00	0,97	0,41	0,68	0,00
ENERG5	0,22			0,95	1,00	0,97	0,40	0,42	0,29
FEED1	0,00	0,00		0,95	1,00	0,97	0,41	0,00	0,13
FEED2	0,56	0,00		0,95	1,00	0,97	0,41	0,48	0,63
FOOD1	0,19	0,45		0,95	1,00	0,97	0,00	0,48	0,63
FOOD2	0,43	0,01		0,95	1,00	0,97	0,41	0,86	0,95
FOOD3	0,57	0,01		0,95	1,00	0,97	0,41	0,50	0,81
FOOD4	0,19	0,00		0,95	1,00	0,97	0,41	0,65	0,91
FOOD5	0,19	1,00		0,00	0,00	0,00	0,11	0,57	0,82
FOOD6	0,57			0,95	1,00	0,97	0,41	0,61	0,92
FOOD7	0,33	0,00		1,00	1,00	1,00	1,00	0,30	0,68
SUST1	0,57			0,95	1,00	0,97	0,41	1,00	1,00
SUST2	0,48			0,95	1,00	0,97	0,41	0,46	0,53
SUST3	0,29			0,95	1,00	0,97	0,41	0,54	0,50
SUST4	0,43	0,00		0,95	1,00	0,97	0,38	0,82	0,63
WOOD1	1,00	0,03		0,95	1,00	0,97	0,41	0,36	0,54
WOOD2	1,00	0,10		0,95	1,00	0,97	0,50	0,05	0,63
WOOD3	1,00	0,02		0,95	1,00	0,97	0,44	0,68	0,46

Key Findings on Sustainability Options

1. **Economic Impact (ECO1)**:
   - The best-performing options are:
     - *Sustainable Wood Supply (WOOD1)*
     - *Sustainable Forest Management (WOOD2)*
     - *Cascade Utilization of Wood (WOOD3)*
2. **Domestic biomass production (ECO2)**:
   - The top option is *Inland Aquaculture* (FOOD5)
3. **Renewable Energy Production (ECO3)**:
   - *Biofuel in the Form of Compressed Natural Gas (Bio-CNG)* (ENERG3) ranks highest for renewable energy generation.
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:
   - Most options perform well across environmental metrics.

- Exceptions include *Inland Aquaculture* (FOOD5) and *Agrosilvicultural Agroforestry Practices* (FOOD1), which are less favorable in terms of *land use*.

5. **Social Indicator (SOC1, SOC2)**:
   - For both *Consumer Acceptance* and *Willingness to Pay*, the top-performing option is *Nature tourism* (SUST1)

4.7 Romania

Figure 19 shows the results in an interval scale across all indicators (equal weighting for indicators). For Romania the best score is attained for *Nature tourism* (SUST1), followed by *Sustainable buildings* (SUST2) and *Recycling of organic waste* (SUST4). The least preferable options are *Inland aquaculture* (FOOD5), followed by *Insect protein for feed* (FEED1) and *Biofuel in form of compressed natural gas (bio-CNG)* (ENERG3).

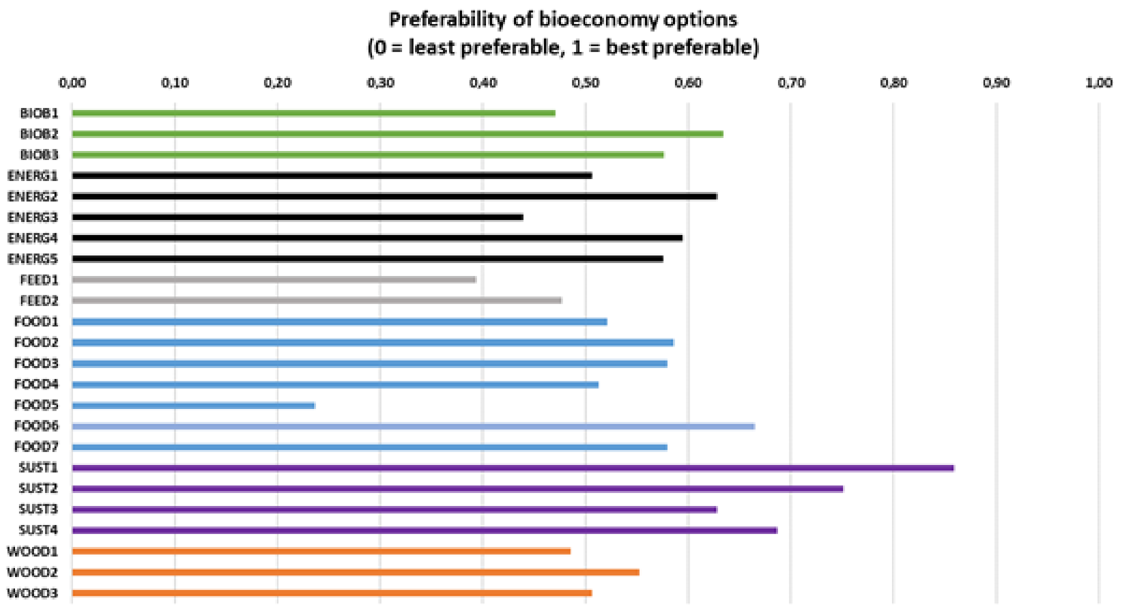


Figure 19: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Romania

Figure 20 illustrates the results in an interval scale per indicator and per option grouped in four categories ('bio-base products & sustainability activities', 'bioenergy & biofuel', 'food & feed', 'wood & wood products').

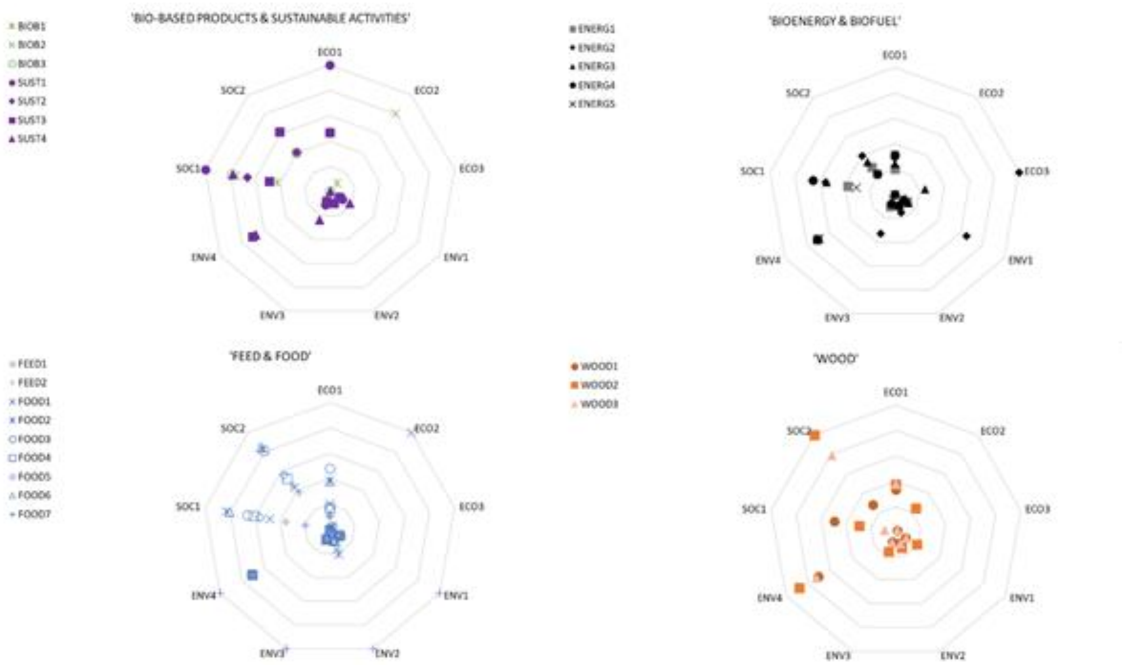


Figure 20: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Romania

Table 12: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Romania

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,00	0,05		0,74	1,00	0,63	0,64	0,43	0,28
BIOB2	0,00	1,00		0,74	1,00	0,63	0,64	0,64	0,42
BIOB3	0,25	0,00		0,74	1,00	0,63	0,64	0,79	0,57
ENERG1	0,25			0,75	1,00	0,63	0,64	0,00	0,28
ENERG2	0,25		1,00	0,87	1,00	0,70	0,64	0,07	0,49
ENERG3	0,00		0,21	0,76	1,00	0,63	0,64	0,00	0,28
ENERG4	0,75		0,00	0,74	1,00	0,63	0,64	0,50	0,49
ENERG5	0,75			0,74	1,00	0,63	0,64	0,00	0,28
FEED1	0,06	0,00		0,74	1,00	0,63	0,64	0,08	0,00
FEED2	0,17	0,00		0,74	1,00	0,63	0,64	0,33	0,31
FOOD1	0,25	0,88		0,72	1,00	0,60	0,00	0,42	0,30
FOOD2	0,42	0,01		0,74	1,00	0,63	0,64	0,67	0,57
FOOD3	0,51	0,01		0,74	1,00	0,63	0,64	0,55	0,55
FOOD4	0,22	0,00		0,74	1,00	0,63	0,64	0,51	0,36
FOOD5	0,22	0,17		0,00	0,00	0,00	0,64	0,47	0,39
FOOD6	0,42			0,74	1,00	0,63	0,64	0,65	0,58
FOOD7	0,16	0,00		1,00	1,00	1,00	1,00	0,22	0,26
SUST1	1,00			0,74	1,00	0,63	0,64	1,00	1,00
SUST2	0,75			0,74	1,00	0,63	0,64	0,64	0,86
SUST3	0,25			0,74	1,00	0,63	0,64	0,50	0,64
SUST4	0,75	0,00		0,75	1,00	0,65	0,63	0,93	0,78
WOOD1	0,00	0,02		0,74	1,00	0,63	0,64	0,57	0,28
WOOD2	0,25	0,16		0,76	1,00	0,65	0,76	0,57	0,28
WOOD3	0,00	0,02		0,75	1,00	0,63	0,66	0,71	0,28

Key Findings on Sustainability Options

1. **Job Creation Potential (ECO1)**:
    - The best option is *Nature Tourism (SUST1)*, followed by:
        - *Sustainable Buildings (SUST2)*
        - *Recycling of Organic Waste (SUST4)*
        - *Biomass Heating Plants (ENERG1)*
        - *Multi-feedstock biorefinery processes (ENERG5)*
2. **Domestic biomass production (ECO2)**:
    - *PLA Food Packaging (BIOB2)* ranks highest in this category.
3. **Renewable Energy Production (ECO3)**:
    - The leading option is *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2)
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:
    - Most options perform well across environmental metrics.

- However, *Lake Aquaculture* (FOOD5) and *Agrosilvicultural Agroforestry Practices* (FOOD1) are less favourable for *land use*.

5. **Social Indicators (SOC1, SOC2)**:
    - For *Consumer Acceptance*, *Nature Tourism* (SUST1) scores highest, closely followed by *Recycling of Organic Waste* (SUST4)
    - Regarding *Willingness to Pay*, the top option is *Nature Tourism (SUST1)* , with strong performance also by:
        - *Sustainable Buildings (SUST2)*
        - *Recycling of Organic Waste (SUST4)*
        - *Consumer behaviour change to more sustainability (SUST3)*

4.8 Serbia

Figure 21 shows the results in an interval scale across all indicators (equal weighting for indicators). For Slovakia the best score is attained for *Biogas plants with combined heat and power (CHP)* (ENERG2), closely followed by *Nature tourism* (SUST1). The least preferable options are *Biomass heating plants* (ENERG4) and *Multi-feedstock biorefinery* (ENERG5).

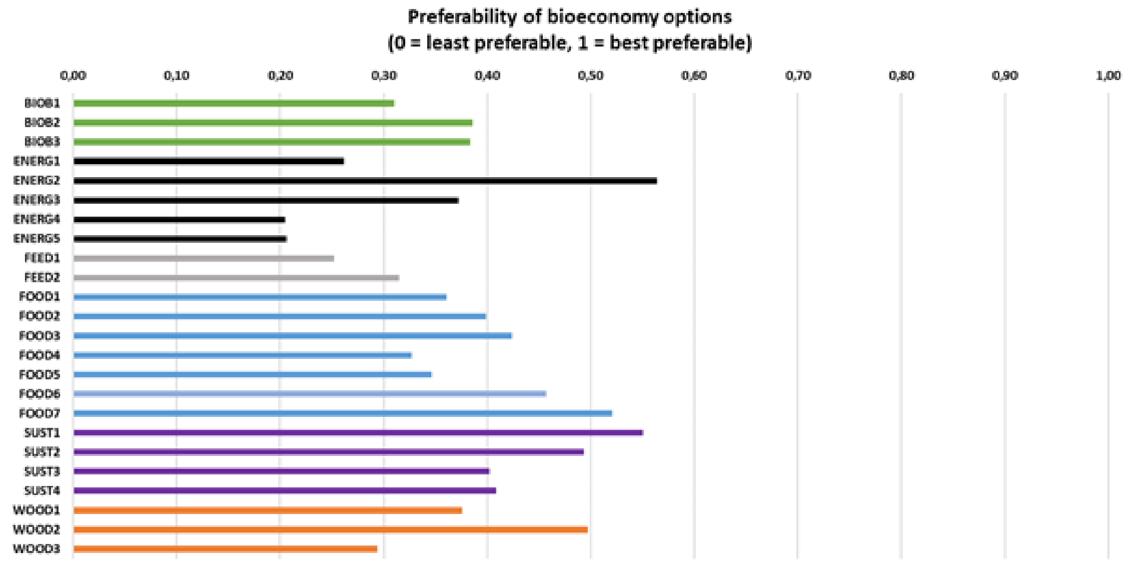


Figure 21: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Serbia

Figure 22 illustrates the results in an interval scale per indicator and per option grouped in four categories (‘bio-base products & sustainability activities’, ‘bioenergy & biofuel’, ‘food & feed’, ‘wood & wood products’).

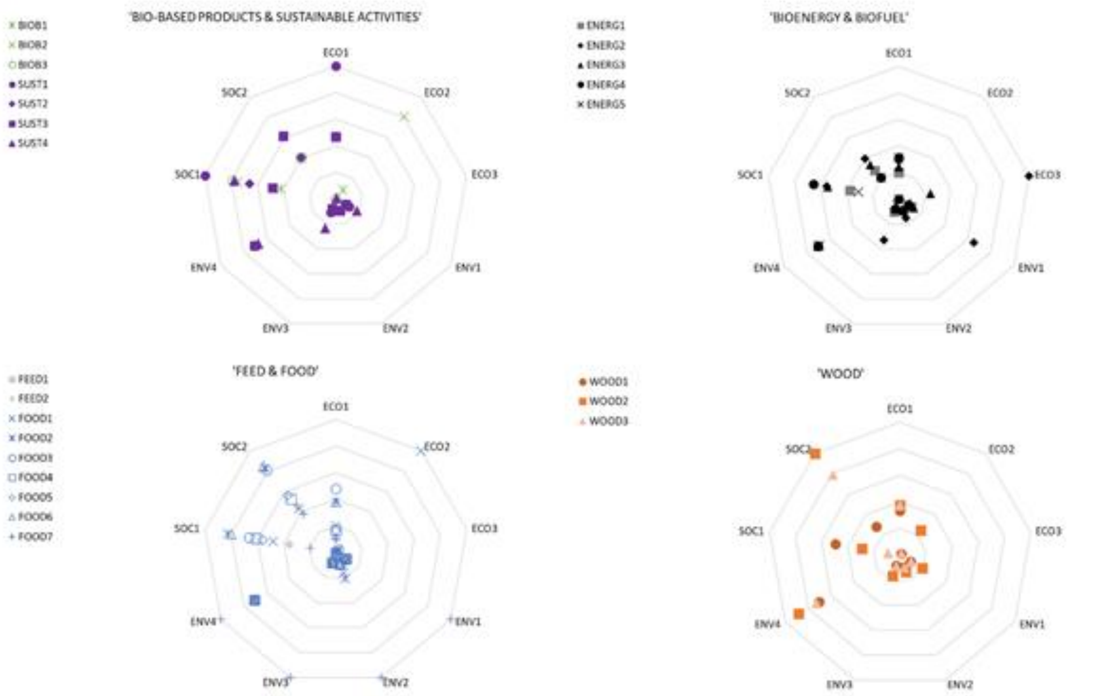


Figure 22: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Serbia

Table 13: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Serbia

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,34	0,03		0,10	0,04	0,10	0,73	0,64	0,49
BIOB2	0,46	0,38		0,11	0,04	0,10	0,73	0,72	0,55
BIOB3	0,67	0,00		0,10	0,04	0,10	0,73	0,78	0,64
ENERG1	0,21			0,12	0,04	0,11	0,73	0,37	0,25
ENERG2	0,64		1,00	0,44	0,16	0,40	0,73	0,65	0,49
ENERG3	0,50		0,52	0,16	0,02	0,10	0,73	0,54	0,41
ENERG4	0,21		0,00	0,11	0,04	0,10	0,73	0,37	0,08
ENERG5	0,21			0,10	0,04	0,10	0,73	0,25	0,00
FEED1	0,21	0,00		0,10	0,04	0,10	0,73	0,34	0,49
FEED2	0,21	0,00		0,10	0,04	0,10	0,73	0,51	0,82
FOOD1	0,43	1,00		0,00	0,13	0,00	0,00	0,59	0,74
FOOD2	0,43	0,01		0,11	0,09	0,11	0,74	0,85	0,86
FOOD3	0,85	0,01		0,11	0,00	0,10	0,74	0,85	0,74
FOOD4	0,64	0,00		0,11	0,04	0,10	0,73	0,51	0,49
FOOD5	0,64	0,00		0,10	0,03	0,10	0,73	0,59	0,57
FOOD6	0,64			0,10	0,04	0,10	0,73	0,85	0,74
FOOD7	0,00	0,00		1,00	1,00	1,00	1,00	0,00	0,16
SUST1	0,93			0,11	0,04	0,10	0,73	0,93	1,00
SUST2	1,00			0,10	0,04	0,10	0,73	0,69	0,79
SUST3	0,57			0,11	0,04	0,10	0,73	0,56	0,70
SUST4	0,93	0,00		0,21	0,04	0,26	0,71	0,56	0,55
WOOD1	0,43	0,00		0,11	0,04	0,10	0,73	0,90	0,69
WOOD2	0,32	0,24		0,24	0,09	0,20	0,91	1,00	0,98
WOOD3	0,50	0,00		0,11	0,04	0,10	0,74	0,42	0,44

Key Findings on Sustainability Options

(1) **Job Creation Potential (ECO1)**:
   a. The best option is *Sustainable Buildings (SUST2)* , followed closely by:
      i. *Nature Tourism (SUST1)*
      ii. *Recycling of Organic Waste (SUST4)*

(2) **Domestic biomass production (ECO2)**:
   a. The top-performing option is *Agrosilvicultural Agroforestry (FOOD1) Practices*.

(3) **Renewable Energy Production (ECO3)**:
   a. *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2) achieve the highest score.

(4) **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:
   a. A *Sustainable Healthy Diet* (FOOD7) is the leading option across all environmental metrics.

(5) **Social Indicators (SOC1, SOC2)**:

a. For *Consumer Acceptance*, the best option is *Sustainable Forest Management (WOOD2)*, with strong performance also from:
    i. *Nature Tourism (SUST1)*
    ii. *Sustainable Wood Supply (WOOD1)*
b. In terms of *Willingness to Pay*, *Nature Tourism* (SUST1) ranks highest, closely followed by *Sustainable Forest Management (WOOD2)*.

4.9 Slovakia

Figure 23 shows the results in an interval scale across all indicators (equal weighting for indicators). For Slovakia the best score is attained for *Food waste prevention and reduction* (FOOD6), followed by *Sustainable healthy diet* (FOOD7) and *Biofuel in form of compressed natural gas (bio-CNG)* (ENERG3). The least preferable options are Inland Aquaculture (FOOD5), followed by *Insect protein for feed* (FEED1) and *Food by-product for feed* (FEED2).

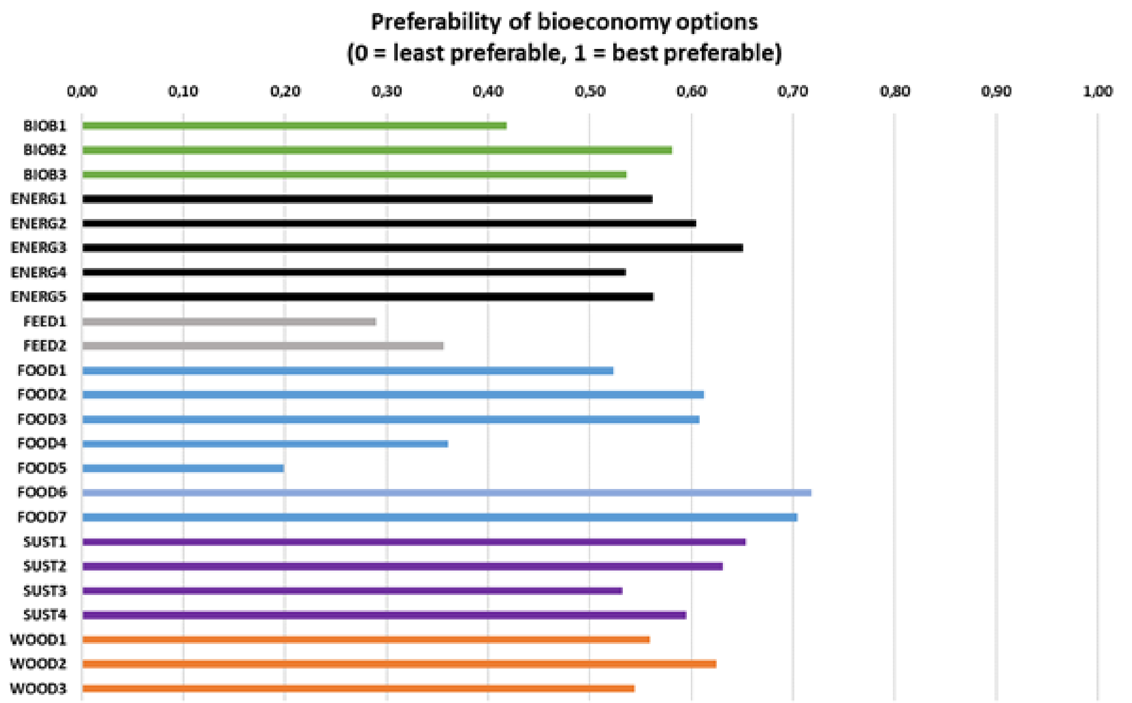


Figure 23: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Slovakia

Figure 24 illustrates the results in an interval scale per indicator and per option grouped in four categories ('bio-base products & sustainability activities', 'bioenergy & biofuel', 'food & feed', 'wood & wood products').

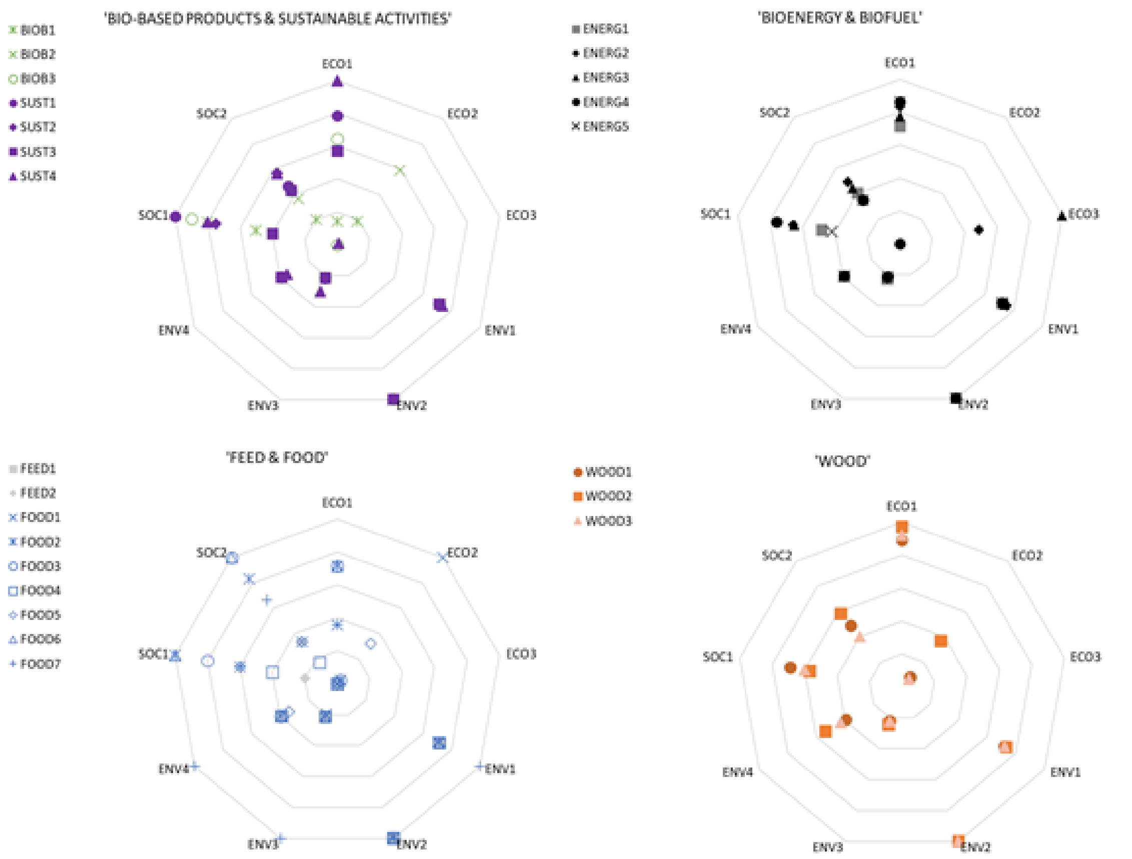


Figure 24: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Slovakia

Table 14: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Slovakia

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,14	0,19		0,71	1,00	0,21	0,39	0,50	0,20
BIOB2	0,57	0,59		0,72	1,00	0,21	0,39	0,80	0,37
BIOB3	0,64	0,00		0,71	1,00	0,21	0,39	0,90	0,43
ENERG1	0,71			0,72	1,00	0,23	0,39	0,48	0,40
ENERG2	0,83		0,49	0,75	1,00	0,22	0,39	0,66	0,49
ENERG3	0,77		1,00	0,74	1,00	0,21	0,39	0,65	0,44
ENERG4	0,86		0,00	0,71	1,00	0,21	0,39	0,76	0,35
ENERG5	0,86			0,71	1,00	0,21	0,39	0,42	0,35
FEED1	0,00	0,00		0,71	1,00	0,21	0,39	0,00	0,00
FEED2	0,00	0,00		0,71	1,00	0,21	0,39	0,20	0,33
FOOD1	0,36	1,00		0,71	1,00	0,19	0,00	0,60	0,33
FOOD2	0,71	0,03		0,72	1,00	0,22	0,40	1,00	0,83
FOOD3	0,71	0,03		0,72	1,00	0,21	0,40	0,80	1,00
FOOD4	0,00	0,00		0,71	1,00	0,21	0,39	0,40	0,17
FOOD5	0,00	0,32		0,00	0,00	0,00	0,34	0,60	0,33
FOOD6	0,71			0,71	1,00	0,21	0,39	1,00	1,00
FOOD7	0,36	0,01		1,00	1,00	1,00	1,00	0,60	0,67
SUST1	0,79			0,72	1,00	0,22	0,39	1,00	0,47
SUST2	0,79			0,71	1,00	0,21	0,39	0,75	0,57
SUST3	0,57			0,72	1,00	0,21	0,39	0,40	0,43
SUST4	1,00	0,01		0,74	1,00	0,30	0,35	0,80	0,57
WOOD1	0,89	0,08		0,72	1,00	0,22	0,39	0,69	0,49
WOOD2	0,97	0,37		0,73	1,00	0,24	0,54	0,57	0,58
WOOD3	0,92	0,06		0,72	1,00	0,22	0,43	0,60	0,40

Key Findings on Sustainability Options

1. **Economic Impact (ECO1)**:
    - The best-performing options is *Recycling of organic waste (Composting)* (SUST4) closely followed by
        - *Sustainable forest management* (WOOD 2)
        - *Cascade utilisation of wood* (WOOD3) and
        - *Sustainable wood supply* (WOOD1)
2. **Domestic biomass production (ECO2)**:
    - The top-performing option is *Agrosilvicultural Agroforestry (FOOD1) Practices*.
3. **Renewable Energy Production (ECO3)**:
    - *Biofuel in form of compressed natural gas (bio-CNG)* (ENERG3) achieve the highest score.
4. **Environmental Indicators (ENV1, ENV2, ENV3, ENV4)**:

   - All options are favourable looking at the indicators ‘fossil resources savings’ and ‘water resources savings’ except for *Inland aquaculture* (FOOD5)
   - For ‘greenhouse gas savings’ and ‘land use’’ the best option is *Sustainable Healthy Diet* (FOOD7).
5. **Social Indicators (SOC1, SOC2)**:
   - For *Consumer Acceptance*, the best options are
     - *Agritourism* (SUST1),
     - *Food waste prevention and reduction* (FOOD6) and
     - *Precision/smart farming* (FOOD2) closely followed by
     - *Biodegradable mulch film* (BIOB3) and
     - PLA food packaging (BIOB2).
   - Looking at ‘willingness to pay’ the best options are
     - *Organic farming* (FOOD3) and
     - *Food waste prevention and reduction* (FOOD6),
     - closely followed by *Precision/smart farming* (FOOD2)

4.10 Slovenia

Figure 25 shows the results in an interval scale across all indicators (equal weighting for indicators). For Slovenia the best score is accomplished for *Sustainable healthy diet* (FOOD7), followed by *Biogas plants with combined heat and power (CHP)* (ENERG2) and *Nature tourism* (SUST1). The least preferable option is *Insect protein for feed* (FEED1) and *Mycelium for packaging* (BIOB1).

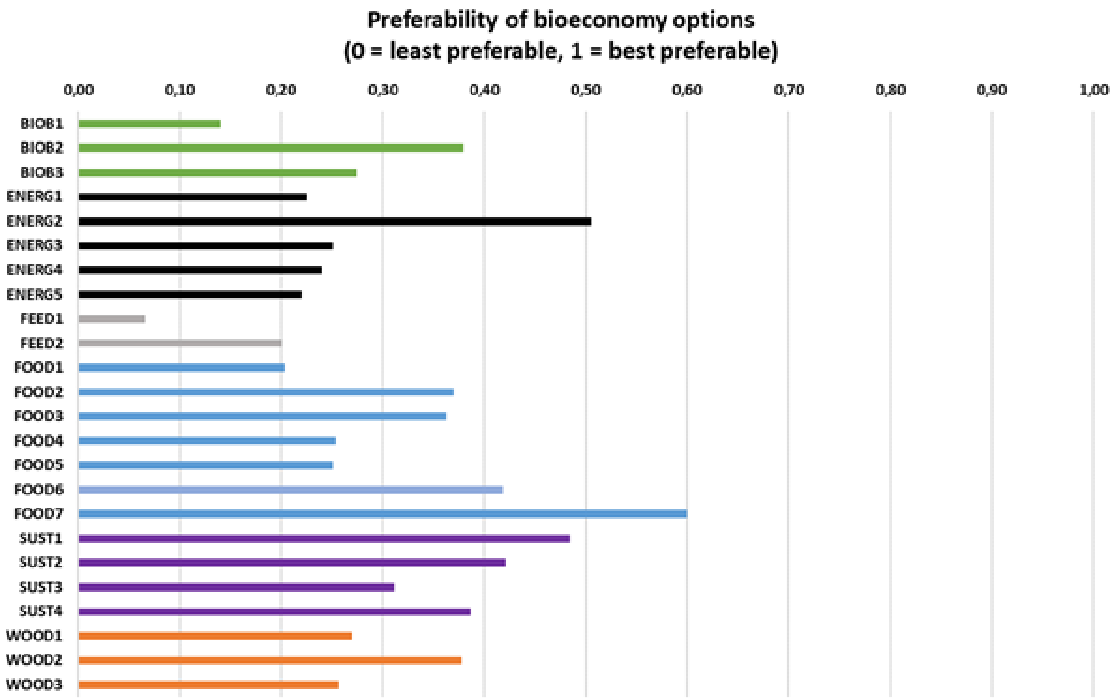


Figure 25: Results per option across all nine indicators in an interval scale between 0 and 1 representing the least and best preferable options for Slovenia

Figure 26 illustrates the results in an interval scale per indicator and per option grouped in four categories ('bio-base products & sustainability activities', 'bioenergy & biofuel', 'food & feed', 'wood & wood products').

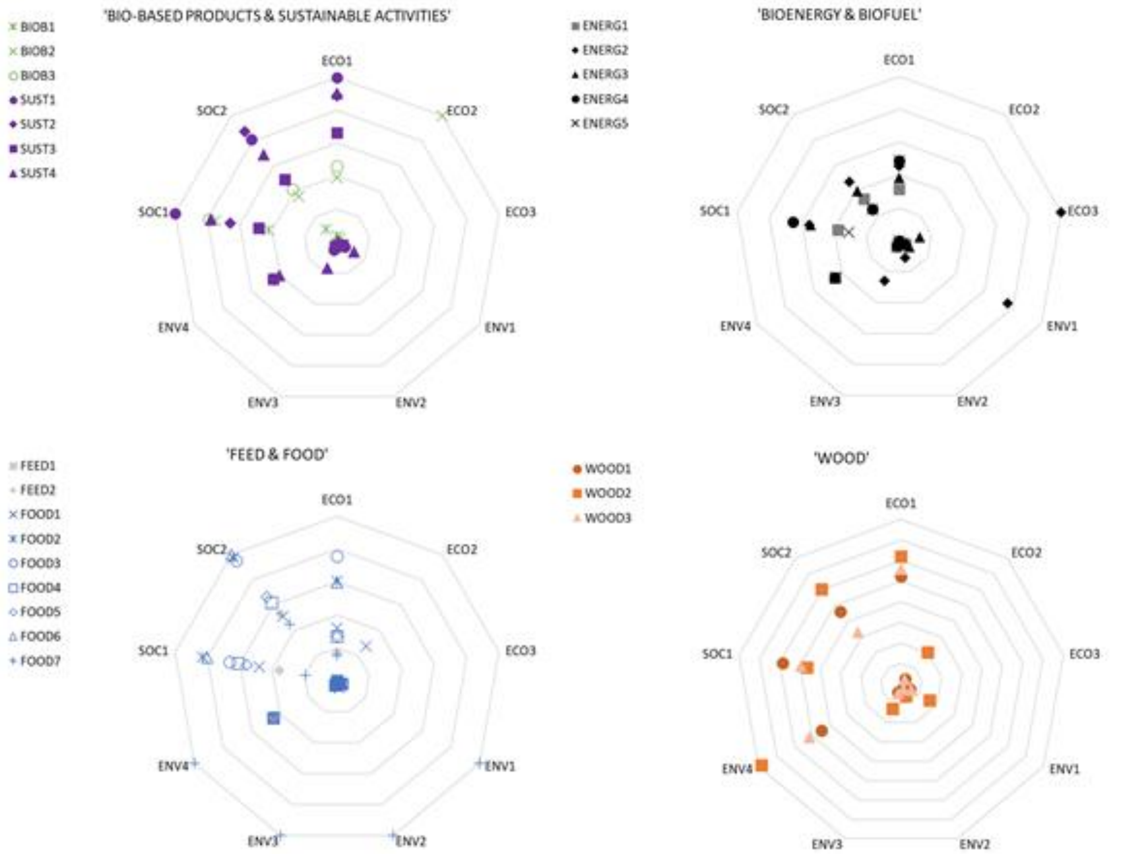


Figure 26: Results per option and per indicator in an interval scale between 0 and 1 representing the least and best preferable options respectively (grouped into four types of options from above left to below right: 'bio-based products & sustainable activities', 'bioenergy & biofuel', 'feed & food', 'wood & wooden products') for Slovenia

Table 15: Results per option and per indicator in an interval scale between 0 (red colour) and 1 (green colour) representing the least and best preferable options respectively for Slovenia

Options	ECO1	ECO2	ECO3	ENV1	ENV2	ENV3	ENV4	SOC1	SOC2
BIOB1	0,04	0,03		0,03	0,02	0,03	0,45	0,42	0,10
BIOB2	0,39	1,00		0,03	0,02	0,03	0,45	0,75	0,36
BIOB3	0,46	0,00		0,03	0,02	0,03	0,45	0,79	0,42
ENERG1	0,31			0,05	0,02	0,04	0,45	0,38	0,33
ENERG2	0,45		1,00	0,76	0,11	0,26	0,45	0,55	0,47
ENERG3	0,38		0,13	0,07	0,01	0,03	0,45	0,55	0,40
ENERG4	0,49		0,00	0,03	0,02	0,03	0,45	0,65	0,25
ENERG5	0,49			0,03	0,00	0,02	0,44	0,31	0,25
FEED1	0,00	0,00		0,03	0,02	0,03	0,45	0,00	0,00
FEED2	0,17	0,01		0,03	0,02	0,04	0,45	0,35	0,53
FOOD1	0,32	0,27		0,00	0,05	0,00	0,00	0,48	0,51
FOOD2	0,61	0,00		0,03	0,03	0,03	0,45	0,83	0,98
FOOD3	0,76	0,00		0,03	0,02	0,03	0,45	0,66	0,95
FOOD4	0,27	0,00		0,03	0,02	0,03	0,45	0,61	0,62
FOOD5	0,27	0,00		0,03	0,00	0,03	0,45	0,56	0,67
FOOD6	0,60			0,03	0,02	0,03	0,45	0,80	1,00
FOOD7	0,16	0,00		1,00	1,00	1,00	1,00	0,19	0,45
SUST1	1,00			0,06	0,02	0,05	0,45	1,00	0,81
SUST2	0,89			0,03	0,02	0,03	0,45	0,66	0,87
SUST3	0,66			0,04	0,02	0,03	0,45	0,48	0,49
SUST4	0,90	0,00		0,12	0,02	0,17	0,40	0,78	0,69
WOOD1	0,52	0,03		0,05	0,02	0,04	0,45	0,59	0,46
WOOD2	0,62	0,20		0,16	0,06	0,13	0,79	0,46	0,60
WOOD3	0,56	0,03		0,06	0,03	0,05	0,52	0,49	0,33

Key Findings on Sustainability Options

(1) Economic Impact (ECO1):

- The best option is *Nature tourism (SUST1)*, followed closely by:
  - *Recycling of organic waste (Composting) (SUST4),*
  - *Sustainable buildings (SUST2)*

(2) Domestic biomass production (ECO2):

- The top option is *PLA Food Packaging* (BIOB2).

(3) Renewable Energy Production (ECO3):

- *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2) achieve the highest score.

(4) Environmental Indicators (ENV1, ENV2, ENV3, ENV4):

- *Sustainable Healthy Diet (FOOD7)* is the best option in all environmental indicators, followed by
  - *Biogas Plants with Combined Heat and Power (CHP)* (ENERG2) in case of 'fossil resources savings' and

        - Sustainable forest management (WOOD2) in case of 'land use'
        - All options perform well for *fossil resource savings* and *water resource savings*, except for *Inland Aquaculture* (FOOD5)

(5) Social Indicators (SOC1, SOC2):

- For *Consumer Acceptance*, the top-performing option is
    - *Nature tourism (SUST1)*
- Regarding *Willingness to Pay*, the best option is
    - *Food Waste Prevention and Reduction (FOOD6)*

4.11 Comparative Analysis of Bioeconomy Opportunities in the CEE Region

(1) Economic Potential (ECO 1)

Across the region, *Nature tourism*, *Sustainable Buildings*, and *Recycling of Organic Waste (Composting)* consistently emerge as top options for driving economic growth and job creation. *Cascade Utilization of Wood* and *Sustainable Forest Management* are also frequently identified as strong contributors to economic potential, particularly in forestry-dominant areas. This reflects a broad opportunity to leverage local natural resources and labor markets to boost rural development and green economic activity.

(2) Domestic biomass production (ECO2)

Agrosilvicultural Agroforestry Practices (FOOD1) and *PLA Food Packaging* are prominent options for improving biomass availability, reflecting a shared emphasis on sustainable land use and bioplastic production. However, certain practices, such as *Inland Aquaculture*, show mixed results, with limitations in land-use efficiency highlighted in some contexts. This indicates a need to tailor biomass strategies to local ecological and spatial conditions.

(3) Renewable Energy Production (ECO3)

Biogas Plants with Combined Heat and Power (CHP) stand out as the leading option for renewable energy generation across all countries, supported by their dual role in energy production and waste management. Additionally, *Biofuel in the Form of Compressed Natural Gas (Bio-CNG)* shows regional potential, although its impact appears more localized. These findings suggest that integrating biogas plants into national energy strategies could provide a unifying opportunity to enhance energy security while reducing greenhouse gas emissions.

(4) Environmental Indicators (ENV1, ENV2, ENV3, ENV4)

A *Sustainable Healthy Diet* consistently outperforms other options in terms of environmental benefits, excelling in metrics such as fossil resource savings, water resource efficiency, and greenhouse gas reduction. However, forestry-related practices, including *Sustainable Forest Management*, are especially effective in land use optimization, reinforcing the role of sustainable forestry as a cornerstone of regional bioeconomy strategies. The relatively consistent environmental advantages of these options underline the importance of policy frameworks that support sustainable dietary transitions and responsible forestry practices.

(5) Social Indicators (SOC1, SOC2)

In terms of *Consumer Acceptance*, *Nature tourism* is a dominant choice, reflecting strong public interest in initiatives that combine economic, cultural, and environmental benefits. Similarly, *Food Waste Prevention and Reduction*, *Precision/Smart Farming*, and *Organic Farming* frequently rank high in *Willingness to Pay*, indicating that these practices resonate well with consumer priorities. This highlights an opportunity for policymakers to align bioeconomy efforts with public preferences, ensuring societal buy-in and long-term success.

Overarching Insights for the CEE Region

- **Cross-Sector Opportunities**: The region demonstrates strong potential in cross-sector initiatives, particularly in Nature tourism, sustainable forestry, and renewable energy generation. These areas offer synergistic opportunities to address economic, environmental, and social goals simultaneously.
- **Localized Approaches within a Regional Framework**: While certain options, such as biogas plants and sustainable healthy diets, show universal applicability, variations in biomass strategies and land-use efficiency underscore the need for tailored approaches at the national and local levels.
- **Strategic Integration**: Policymakers are encouraged to integrate bioeconomy options into broader policy agendas, focusing on workforce development, public engagement, and infrastructure investment. Emphasis on consumer-driven initiatives, such as agritourism and food waste reduction, could bolster regional economic resilience while addressing global sustainability challenges.
- **Policy Coherence and Collaboration**: To maximize the region's bioeconomy potential, fostering cross-border collaboration on knowledge sharing, capacity building, and financing mechanisms is crucial. Coordinated efforts can ensure that best practices, such as those in renewable energy or sustainable forestry, are effectively scaled and adapted to local contexts.

By leveraging these insights, the CEE region is well-positioned to become a leader in sustainable bioeconomy practices, contributing to both regional prosperity and global sustainability goals.

5 Discussion

The aim of the analysis was to identify the best preferable option for a country. This is depending on the framework condition of each country, meaning the forest and agricultural area, wood generation, food production, tourism, livestock and population as well as the different electricity and heat production and consumption mix.

The rational decision making applied in this analysis considers all those different framework conditions in addition to stakeholder preferences with respect to considered indicators. Unfortunately, not all indicators that were identified are important and

measurable could be evaluated in this context, as detailed data on scenario level was missing or not identifiable in this period of time. To balance the cost/benefit ratio (pareto principle) only a selection of indicators and options was possible to include in this analysis.
Interpretation of the results is limited to the scope of the selected options. Options cannot be interpreted independently from other options, as the results were scaled by intervals between the least preferable (option with the lowest score in each specific indicator) and best preferable option (option with the highest score in each specific indicator). This ranking is a limitation of the study. If one option would be added, it would mix up the ranking and thus the results.
The results are influenced by the upscaling values on the one hand (representing the country's framework conditions) and the realisation potential on the other hand (representing the extent/implementation size of the option in a country). Due to the dependence of these two factors, the choice of the upscaling unit as well as the expert judgement for the realisation potential need to be analysed in more detail. It is recommended to look at the sensitivity of these two factors and the impacts on the overall results in the course of a scientific publication.
Moreover, the LCA results for indicators Fossil resources savings, Water resources Greenhouse gas savings and Land use are based on very specific scenarios. Although, recent studies (not older than 2020) were used to build the scenarios and the respective life cycle inventory, the selected scenarios might not be representative for the entire option (e.g. Multi-feedstock biorefinery, it was assumed that fatty acid is the end-product of the biorefinery; the nature of a biorefinery is to use multiple feedstock and creating multiple outputs, this is hardly possible to generalize). Additionally, the choice of scenarios was based on expert consultation (e.g. Biomass heating plants, it was assumed that oil is replaced with pellet and woodchip boilers, as oil is priority for replacement).

Please note that measures or actions that stipulate the implementation of bioeconomy options such as funding or other incentives, awareness raising or other public relations, education and research are not considered in this study. Authors want to acknowledge that those measures are not least important but need to be evaluated by a different methodological framework.

Other limitations of the analysis include the following aspects:

- Scenario selection is subject to data availability (for both foreground and background data)
- Limitations of the modelling: Focus is only on the differences between status quo and bioeconomy scenario. Only the differences are considered and modelled. So, absolute results are not evident, only the change is measured!
- Limitations of the decision analysis: Expectations about exogeneous influences (uncontrollable factors) are not considered. So are consequences of a decision not considered.

The understanding and definitions of the concept of bioeconomy differ among countries, and so do the pathways chosen to promote the bioeconomy strategies according to prerequisites of the individual countries (Navratilova et al, 2020, Staffas et al. 2013). The EU Bioeconomy Strategy Progress Report (2022) revealed that the implementation of bioeconomy depends on the local environmental, social and economic potentials and challenges. Hence, we may expect variations in citizens' understanding of bioeconomy in their countries and to some extent, consumers' general acceptance of bio-based products available in their countries.

6 Summary and conclusion

Bioeconomy is expected to contribute to all 17 Sustainable Development Goals (SDGs) and in particular to SDGs 1 and 2 (Zero Hunger & Good Health and Well-Being), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). CEE2Act has set itself the goal of supporting the countries in the CEE region on their path towards a circular bioeconomy. The aim is to achieve sustainable utilisation of the various types of biomass by converting them into corresponding value-added products. There are different solutions that can contribute to the implementation of the bioeconomy from a bottom-up perspective in different EU Member States (MS). Therefore, it is necessary to give advice on which specific bioeconomy solutions should be implemented in a specific target country based on sustainability criteria.

To realize the full potential of bioeconomy and facilitate transition towards bioeconomy, it is necessary to go beyond the previous general approaches and to close up the focus on the national circumstances, from the general potential of biomass in the various areas to the acceptance of the population as early as in the planning phase. All bioeconomy sectors as defined at the beginning of the project (Agriculture, Forestry, Fisheries, Aquaculture, Food and Feed, Biobased industries, Wood, Biotechnology, Ecosystem services Bioenergy, Society and organic residues and waste) should be given equal consideration along with the various products (food, feed, wood, energy, sustainable activities and biobased products) that are possible in each of them.

To ensure sustainable bioeconomy strategies the evaluation of options must be carried out against the respective national framework conditions. This applies to both national circumstances and political preferences. Different stakeholders have most often divergent preferences that need to be considered as well.

For this purpose, an interactive, collaborative approach was pursued in the evaluation, which took into account both the national conditions and the various interest groups from the countries to eventually shape relevant options and indicators. Based on the outcomes of a baseline assessment for each of the 10 target countries, challenges and potentials could be identified which could be taken as starting points for the stakeholder process. Subsequently, the selected options and indicators were primarily evaluated based on their feasibility. In a similar participative approach relevant indicators have been defined together with partners from all countries. Criteria have been defined which are applicable for all countries and bioeconomy sectors focusing on importance and measurability. At the end of the process, 24 concrete scenarios developed in a stakeholder-inclusive and bottom-up approach process were evaluated on behalf of the respective options using nine indicators that take into account the three dimensions of sustainability for the 10 target countries of CEE2ACT. Environmental indicators have been assessed using Life Cycle Assessment, additionally quantitative assessment was applied based on desktop research including the renewable energy production as energy-based indicator and the domestic biomass production as mass-based criteria. Social indicators like consumer acceptance as well as economic indicators like willingness to pay were measured by a qualitative survey to stakeholders.

The aim of the analysis was to identify the best preferable option for a country. This is depending on the framework condition of each country, meaning the forest and agricultural area, wood generation, food production, tourism, livestock and population as well as the different electricity and heat production and consumption mix.

The results proved the importance of the chosen approach. Depending on the local conditions, different options perform better or worse in the individual countries. On average across all countries, the options central and small-scale heating plants (ENERG1), food waste prevention and reduction (FOOD6), Sustainable and healthy diets (FOOD7) and Nature Tourism (SUST1) options stand out as particularly sustainable. Little potential can be seen for the options Insect farming (FEED1) mainly due to very little acceptance in all countries and sustainable inland aquaculture (FOOD5) as the mass of fish produced is generally low compared to the biomass converted in other areas.

Based on the analyses, the following options can be recommended as a priority for implementation in the individual countries:

- Bulgaria:
    - FOOD7 “Sustainable healthy diet”
    - SUST1 “Nature Tourism”
    - ENERG2 “Biogas plants”
- Croatia
    - FOOD7 “Sustainable healthy diet”
    - SUST1 “Nature Tourism”
    - BIOB2 “Bio-plastic”
- Czech Republic
    - FOOD6 “Food loss and waste prevention and reduction”
    - ENERG2 “Biogas plants”
    - ENERG1 “Central and small-scale heating plants (biomethane)”, ENERG5 “Multi-feedstock biorefinery”, SUST3 “Consumer behaviour change to more sustainability”
- Greece
    - SUST2 “Sustainable buildings”
    - SUST1 “Nature Tourism”
    - FOOD6 “Food loss and waste prevention and reduction”
- Hungary
    - FOOD7 “Sustainable healthy diet”
    - SUST1 “Nature Tourism”
    - ENERG2 “Biogas plants”

- Poland
    - SUST1 “Nature Tourism”
    - ENERG3 “Biofuel”
    - FOOD6 “Food loss and waste prevention and reduction”
- Romania
    - SUST1 “Nature Tourism”
    - SUST2 “Sustainable buildings”
    - SUST4 “Recycling of organic waste”
- Serbia
    - ENERG2 “Biogas plants”
    - SUST1 “Nature Tourism”
    - FOOD7 “Sustainable healthy diet”
- Slovakia
    - FOOD6 “Food loss and waste prevention and reduction”
    - FOOD7 “Sustainable healthy diet”
    - ENERG3“ Biofuel” and SUST1 “Nature Tourism”
- Slovenia
    - FOOD7 “Sustainable healthy diet”
    - ENERG2 “Biogas plants”
    - SUST1 “Nature Tourism”

CEE2ACT will enable the target counties to shift to a more diversified economic base and a smarter green growth (T 6.3), while safeguarding social cohesion. Based on the baseline assessment and outputs of WP2, guidelines will be drafted for the regional actors on transition for bioeconomy strategies for research and innovation (common protocols and methods for the preparation of the bioeconomy strategies T 6.1 and guidelines for new collaboration and organizations T6.2, SWOT analysis for implementation of strategies T 6.4), social challenges and re-skilling needs, and finance and investment. National-level roadmaps for the bioeconomy strategies in CEE2ACT target countries will be created in T6.3.

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8 Annex I – Evaluation indicators

Acronyms

SOC	Soil Organic Carbon
LULUC	Land Use and Land Use Change
LUC	Land Use Change
LMC	Land Management Change
IPCC	Intergovernmental Panel of Climate Change
GHG	GreenHouse Gas emissions
C	Carbon

ENV1 Fossil resources savings

Fossil resources saved by the production of bio-material replacing non-renewable resources; e.g. wood-based constructions, bio-based textiles, bio-based furniture, bio-based plastics and bio-energy replacing non-renewable energy

Indicator name	Unit	Quantification method	Time	Preference direction
Resource use, fossils (Abiotic resource depletion, fossil fuels, ADP-fossil)	**MJ**	van Oers et al., 2002 as in CML 2002 method, v.4.8 as of the Environmental Footprint method of the European Union (EU Commission Recommendation 2021/2279)	Time independent	Fossil resource use should **decrease** from status quo to bioeconomy situation or Fossil resource savings should **increase** from status quo to bioeconomy situation

ENV2 Water resources savings

Water resources saved by the production of bio-material replacing non-renewable resources; e.g. Wood-based constructions, bio-based textiles, bio-based furniture, bio-based plastics and bio-energy replacing non-renewable energy
AWARE is to be used as a water use midpoint indicator representing the relative Available WAter REmaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met.

Indicator name	Unit	Quantification method	Time	Preference direction
Water use (User deprivation potential; deprivation-	m^3 world water eq of deprived water	Available WAter REmaining (AWARE) model (Boulay et al., 2018; UNEP 2016) as of	Time independent	Water use should **decrease** from status quo to bioeconomy situation or

weighted water consumption)		the Environmental Footprint method of the European Union (EU Commission Recommendation 2021/2279)		water resource savings should **increase** from status quo to bioeconomy situation

ENV3 Greenhouse gas savings

Greenhouse gas emissions saved by the production of bio-material replacing non-renewable resources; e.g. Wood-based constructions, bio-based textiles, bio-based furniture, bio-based plastics and bio-energy replacing non-renewable energy

Indicator name	Unit	Quantification method	Time	Preference direction
Climate change fossil (Global Warming Potential, GWP 100)	Kg CO_2 eq.	Bern model - Global warming potentials (GWP) over a 100-year time horizon (based on IPCC 2013) as of the Environmental Footprint method of the European Union (EU Commission Recommendation 2021/2279)	Time independent	Greenhouse gas emissions should **decrease** from status quo to bioeconomy situation or Greenhouse gas savings should **increase** from status quo to bioeconomy situation

ENV4 Soil condition

Soil condition refers to the ability of a particular soil to operate effectively within the confines of land use and ecosystem limitations. This involves supporting biological productivity, preserving environmental well-being, and fostering the health of plants, animals, and humans.

Indicator name	Unit	Quantification method	Time	Preference direction
Soil quality index	Dimensionless (pt)	Soil quality index based on LANCA model (De Laurentiis et al. 2019) and on the LANCA CF version 2.5 (Horn and Maier, 2018) as of the Environmental Footprint method	Time independent	Indicator should **increase** from status quo to bioeconomy situation

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		of the European Union (EU Commission Recommendation 2021/2279)		

SOC1 Consumer acceptance

Consumer acceptance of bio-based products. Consumers seem to have positive associations with bio-based products, but their lack of knowledge on bioeconomy and limited access to robust product information could pose a threat to an increased market uptake of the bio-based products. In recent years, several EU-funded projects have implemented a number of consumer surveys that addressed the public acceptance and perception of bio-based products, such as the OpenBio project, the BIOWAYS project and the STAR-ProBio project. Even though these surveys had slightly different focal points, some similarities in the results related to consumers' perception of bio-based products can be observed. Consumers expressed a willingness to buy bio-based products but were unfamiliar with what they constituted. Moreover, consumers consistently confirmed the usefulness of a (multi-criteria) labelling scheme to stimulate the market uptake of bio-based products (BIOBRIDGES D5.4 report, 2020).

Indicator name	Unit	Quantification method	Time	Preference direction
Consumer acceptance	Qualitative (Ordinal 1-10) 1 = consumers will not accept it at all/won't use it/won't buy it 10 = consumers will fully accept it/use it in their daily routine/buy it as usual purchase	**Survey**	2024	Indicator should **increase** from status quo to bioeconomy situation

SOC2 Willingness to pay

Description: How much the consumers are willing to pay for certain quantity of the biobased product.

Indicator name	Unit	Quantification method	Time	Preference direction
Willingness to pay	Qualitative (Ordinal 1-10) 1 = consumers will not want to pay more than the price for conventional products 10 = consumers will pay more than actual average market price	**Survey**	2024	Indicator should **increase** from status quo to bioeconomy situation

ECO1 Job creation potential

Description: Job creation potential refers to the capacity of a specific policy, project, industry, technology, or investment to generate employment opportunities, either directly or indirectly, within a defined timeframe and geographic scope. It is often used in economic planning, policy analysis, and impact assessments to evaluate how different initiatives can stimulate labor market growth and contribute to socioeconomic development.

Indicator name	Unit	Quantification method	Time	Preference direction
Job creation potential	Qualitative (Ordinal categories: 0, 1-20, 21-100, 101-1'000, >1'000, >5'000, >10'000)	**Survey**	2024	Indicator should **increase** from status quo to bioeconomy situation

ECO2 Domestic biomass production

Description: Domestic biomass production refers to the generation of biomass materials within a specific country or region for various purposes, including energy production, industrial processes, or agricultural use. Biomass is organic material derived from plants, animals, or microbial sources that can be used as a renewable resource. Domestic production emphasizes local or national generation rather than imports, making it a key indicator in assessing a region's self-sufficiency and sustainability in bioresource utilization.

Indicator name	Unit	Quantification method	Time	Preference direction
Production amount of Bio-based packaging Bio-based food production Bio-based mulch film Feed Food Roundwood Organic waste	**kg**	Eurostat, FAOstat, EU trade statistics,	not later than 2018	Indicator should **increase** from status quo to bioeconomy situation

ECO3 Renewable energy production

Description: Renewable energy production refers to the generation of energy from natural resources that are replenished naturally and sustainably over time. Unlike fossil fuels, which are finite and emit greenhouse gases, renewable energy sources harness resources such as sunlight, wind, water, and biological materials to produce electricity, heat, and fuels. Renewable energy is a cornerstone of global efforts to mitigate climate change and transition toward more sustainable energy systems.

Indicator name	Unit	Quantification method	Time	Preference direction
Energy production from Heat Electricity Fuel	**MJ**	Eurostat, International Energy Agency (IEA)	not later than 2021	Indicator should **increase** from status quo to bioeconomy situation

References of Annex I

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9 Annex II – Upscaling values

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Option_ID	Scaling variable	Unit	Year	Data source	Bulgaria	Croatia	Czech Republic	Greece	Hungary	Poland	Romania	Serbia	Slovakia	Slovenia
_GENERAL	Inhabitants		2019	Eurostat	7.0E+06	9.8E+06	1.1E+07	1.1E+07	4.1E+06	3.8E+07	1.9E+07	7.0E+06	5.5E+06	2.1E+06
BIOB1	**Packaging production (EPS)**	**kg**	**n.a.**	**Secondary literature**	**2.4E+06**	**3.4E+06**	**3.7E+06**	**3.7E+06**	**1.4E+06**	**1.3E+07**	**6.7E+06**	**2.4E+06**	**1.9E+06**	**7.2E+05**
BIOB2	**Food packaging production (PP, PS, PET (7%) - konservative Schätzung)**	**kg**	**n.a.**	**Secondary literature**	**6.6E+07**	**9.3E+07**	**1.0E+08**	**1.0E+08**	**3.9E+07**	**3.6E+08**	**1.8E+08**	**6.6E+07**	**5.2E+07**	**2.0E+07**
BIOB3	**Mulch film**	**kg**	**n.a.**	**APE Europe**	**2.5E+06**	**2.5E+06***	**2.0E+06**	**2.5E+06**	**2.2E+06**	**6.0E+06**	**5.0E+06***	**1.8E+06***	**2.6E+05**	**5.3E+05***
ENERG1	**Heat production from natural gas**	**MJ**	**2022**	**Eurostat**	**2.3E+10**	**1.1E+10**	**3.7E+10**	**3.0E+08**	**3.6E+10**	**3.4E+10**	**4.5E+10**	**2.6E+10**	**1.9E+10**	**3.2E+09**
ENERG2	**Electricity and heat production**	**MJ**	**2022**	**Eurostat**	**1.8E+11**	**5.1E+10**	**3.1E+11**	**1.9E+11**	**1.3E+11**	**2.5E+11**	**6.5E+11**	**2.0E+11**	**4.9E+10**	**9.7E+10**
ENERG3	**Average distance per country and year**	**pkm**	**n.a.**	**calculated**	**1.8E+10**	**1.8E+10**	**3.0E+10**	**1.3E+10**	**3.0E+10**	**1.4E+11**	**5.9E+10**	**5.2E+10**	**4.0E+10**	**5.0E+09**
ENERG3_1	Average distance per person and day	km/person and day	**n.a.**	Eurostat	1.1E+01*	7.6E+00	1.1E+01*	5.6E+00	1.1E+01*	1.7E+01	1.5E+01	1.1E+01*	1.1E+01*	8.2E+00
ENERG3_2	Travel distance per person per day by main travel mode	% passenger car	**n.a.**	Eurostat	6.6E-01*	6.6E-01*	7.3E-01	6.0E-01	1.9E+00*	5.9E-01	5.7E-01	1.9E+00*	1.9E+00*	8.1E-01
ENERG4	**Heat production from oil**	**MJ**	**2021**	**International Energy Agency (IEA)**	**7.1E+07**	**1.4E+08**	**1.3E+09**	**1.2E+09***	**4.6E+07**	**5.2E+09**	**2.8E+09**	**3.1E+09**	**4.3E+08**	**1.7E+08**
ENERG5	**Travel distance per person per day by main travel mode**	**kg**	**2023**	**EU trade statistics (Access2Markets)**	**4.4E+07**	**3.1E+07**	**2.5E+07**	**1.3E+07**	**1.4E+07**	**1.3E+08**	**8.8E+06**	**1.7E+04***	**1.9E+06**	**3.1E+06**
FEED1	**Fish meal (Import), 70% protein content**	**kg protein**	**2023**	**EU trade statistics (Access2Markets)**	**1.9E+05**	**5.7E+04***	**3.4E+02**	**8.5E+03**	**4.2E+04**	**1.6E+05**	**3.0E+01**	**4.1E+04***	**1.3E+04**	**3.3E+03**
FEED2	**Soya meal (Import)**	**kg**	**MJ 2023/2024**	**EU DG AGRI**	**5.0E+06**	**1.1E+07**	**1.7E+06**	**4.9E+08**	**1.3E+08**	**2.9E+09**	**4.8E+08**	**4.7E+08***	**4.3E+05**	**8.8E+08**
FOOD1	**Land use overview by NUTS 2 regions, Agriculture**	**hectare**	**2018**	**Eurostat**	**4.7E+06**	**1.6E+06**	**3.9E+06**	**4.9E+06**	**5.7E+06**	**1.6E+07**	**1.3E+07**	**3.7E+06***	**2.0E+06**	**5.5E+05**
FOOD2	**Wheat production**	**kg**	**2022**	**FAOstat**	**6.4E+09**	**9.7E+08**	**5.2E+09**	**1.2E+09**	**4.4E+09**	**1.3E+10**	**8.7E+09**	**3.1E+09**	**2.0E+09**	**1.5E+08**
FOOD3	**Wheat production**	**kg**	**2022**	**FAOstat**	**6.4E+09**	**9.7E+08**	**5.2E+09**	**1.2E+09**	**4.4E+09**	**1.3E+10**	**8.7E+09**	**3.1E+09**	**2.0E+09**	**1.5E+08**
FOOD4	**Consumption of fisheries and aquaculture products (frozen fish)**	**kg (frozen fish)**	**2019**	**Eurostat**	**5.7E+07**	**2.2E+08**	**7.0E+07**	**2.4E+08**	**2.8E+07**	**5.5E+08**	**1.7E+08**	**8.9E+07***	**5.8E+07**	**2.8E+07**
FOOD5	**Fresh or chilled fish fillets imports**	**kg**	**2021**	**Worldbank**	**5.7E+05**	**8.3E+05**	**3.8E+11**	**4.2E+11**	**9.4E+05**	**2.1E+12**	**1.7E+11**	**6.4E+05**	**1.7E+11**	**7.6E+05**
FOOD6	**Food waste levels**	**kg (food waste)**	**2021**	**Eurostat**	**7.1E+08**	**9.7E+08**	**2.0E+09**	**2.8E+08**	**8.8E+08**	**4.3E+09**	**2.2E+09***	**8.0E+08***	**5.4E+08**	**1.4E+08**
FOOD7	**Food consumption (only animal products) (based on calorie supply, animal products)**	**kg**	**2018/2019**	**calculated**	**1.3E+09**	**2.3E+09**	**2.5E+09**	**2.2E+09**	**1.1E+09**	**9.8E+09**	**4.7E+09**	**1.6E+09***	**1.2E+09**	**4.3E+08**
FOOD7	Daily calorie supply per capita by source animal products	kcal/cap/d	2018	Eurostat	7.0E+02	9.3E+02	9.2E+02	8.1E+02	1.1E+03	1.0E+03	9.4E+02		8.5E+02	8.2E+02
SUST1	**Overnight stays**	**guest and night**	**2023**	**Eurostat, data from 2023**	**2.2E+07**	**2.3E+07**	**3.8E+07**	**1.0E+08**	**2.2E+07**	**1.3E+08***	**2.2E+07**	**5.6E+06**	**9.1E+06**	**7.5E+06**
SUST1_1	Overnight stays	Mio.	2023	Eurostat, data from 2023	2.2E+01	2.3E+01	3.8E+01	1.0E+02	2.2E+01		2.2E+01	5.6E+00	9.1E+00	7.5E+00
SUST2	**Construction of new buildings (residential)**	**m2**	**n.a.**	**calculated**	**2.0E+06**	**3.3E+06**	**2.9E+06**	**2.2E+06**	**1.0E+06**	**1.4E+07**	**4.1E+06**	**2.2E+06**	**1.5E+06**	**2.3E+05**
SUST2_1	Number of construction starts of new residential properties	No/1000 capita	**2022**	Statista	4.7E+00	4.9E+00	3.9E+00	2.8E+00	3.6E+00	5.3E+00	4.0E+00*	5.7E+00	3.8E+00	1.5E+00
SUST2_2	Average floor area per capita	m2	2008	Enerdata 2008	2.6E+01	2.5E+01	3.0E+01	2.9E+01	3.0E+01	2.5E+01	2.1E+01	2.2E+01	2.5E+01	3.0E+01
SUST2_3	number of persons per household	No/HH	2021	Eurostat, 2021	2.4E+00	2.7E+00	2.3E+00	2.6E+00	2.3E+00	2.8E+00	2.5E+00	**2.5E+00**	2.9E+00	2.5E+00
SUST3	**Total computers (laptops) in use**	**pieces**	**2017-2023**	**National statistics**	**1.8E+06**	**1.2E+06**	**4.0E+06**	**2.9E+06**	**3.2E+06**	**1.2E+07**	**5.4E+06**	**2.0E+06**	**1.5E+06**	**6.6E+05**
SUST4	**Amount of municipal organic waste fraction (food waste + green waste)**	**kg wet**	2018	EU dashboard	**9.3E+08**	**4.8E+08**	**1.5E+09***	**1.5E+09***	**1.0E+09**	**4.8E+09**	**1.6E+09**	**1.2E+09****	**9.8E+08**	**3.1E+08**
WOOD1	**Roundwood (wood in the rough); under bark**	**m3**	**2021**	**Eurostat**	**5.5E+06**	**5.0E+06**	**3.0E+07****	**2.1E+06****	**6.0E+06**	**4.3E+07**	**1.8E+07**	**1.2E+06****	**7.7E+06**	**3.7E+06**
WOOD2	**Forest area**	**hectare**	**2021**	**Worldbank**	**3.9E+06**	**1.9E+06**	**2.7E+06**	**3.9E+06**	**2.1E+06**	**9.5E+06**	**6.9E+06**	**2.7E+06**	**1.9E+06**	**1.2E+06**
WOOD3	**Roundwood (wood in the rough); under bark**	**m3**	**2021**	**Eurostat**	**5.5E+06**	**5.0E+06**	**3.0E+07****	**2.1E+06****	**6.0E+06**	**4.3E+07**	**1.8E+07**	**1.2E+06****	**7.7E+06**	**3.7E+06**

*… data gaps were filled with average values from other targeting countries

** … data was provided by partners, as no information in common statistics was available.

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10 Annex III – Realisation potential

Option_ID	Bulgaria	Croatia	Czechia	Greece	Hungary	Poland	Romania	Serbia	Slovakia	Slovenia
BIOB1	0.80	0.20	0.40	0.10	0.36*	0.45	0.40	0.35	0.20	0.36*
BIOB2	0.80	0.60	0.55	0.80	0.60*	0.69	0.40	0.41	0.58	0.60*
BIOB3	0.80	0.60	0.58	0.80	0.63*	0.75	0.55	0.40	0.54	0.63*
SUST1	1.00	0.90	0.58	0.90	0.77*	0.78	0.85	0.59	0.56	0.77*
SUST2	0.70	0.70	0.58	1.00	0.66*	0.61	0.75	0.45	0.52	0.66*
SUST3	0.90	0.70	0.60	0.70	0.63*	0.64	0.60	0.44	0.48	0.63*
SUST4	0.90	0.70	0.58	1.00	0.74*	0.82	0.70	0.49	0.72	0.74*
FEED1	0.28*	0.20	0.28*	0.28*	0.28*	0.27	0.28*	0.55	0.10	0.28*
FEED2	0.46*	0.50	0.46*	0.46*	0.46*	0.54	0.46*	0.50	0.30	0.46*
FOOD1	0.46*	0.50	0.46*	0.46*	0.46*	0.43	0.46*	0.50	0.40	0.46*
FOOD2	0.68*	0.80	0.68*	0.68*	0.68*	0.77	0.68*	0.45	0.70	0.68*
FOOD3	0.66*	0.80	0.66*	0.66*	0.66*	0.54	0.66*	0.50	0.80	0.66*
FOOD4	0.46*	0.80	0.46*	0.46*	0.46*	0.43	0.46*	0.50	0.10	0.46*
FOOD5	0.44*	0.70	0.44*	0.44*	0.44*	0.47	0.44*	0.50	0.10	0.44*
FOOD6	0.63*	0.70	0.63*	0.63*	0.63*	0.56	0.63*	0.55	0.70	0.63*
FOOD7	0.34*	0.20	0.34*	0.34*	0.34*	0.47	0.34*	0.20	0.50	0.34*
WOOD1	0.50	0.62*	0.62*	0.62*	0.62*	0.80	0.60	0.58	0.62*	0.62*
WOOD2	0.63	0.69*	0.69*	0.69*	0.69*	0.70	0.70	0.73	0.69*	0.69*
WOOD3	0.55	0.52*	0.52*	0.52*	0.52*	0.60	0.60	0.32	0.52*	0.52*
ENERG1	0.54*	0.54*	0.80	0.54*	0.54*	0.70	0.50	0.17	0.54*	0.54*
ENERG2	0.64*	0.64*	1.00	0.64*	0.64*	0.63	0.70	0.23	0.64*	0.64*
ENERG3	0.66*	0.66*	1.00	0.66*	0.66*	0.73	0.70	0.20	0.66*	0.66*
ENERG4	0.66*	0.66*	0.90	0.66*	0.66*	0.65	1.00	0.10	0.66*	0.66*
ENERG5	0.57*	0.57*	0.80	0.57*	0.57*	0.65	0.70	0.13	0.57*	0.57*

*... data gaps were filled with average values from other targeting countries

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