Contact:
WEBSITE: rusticaproject.eu
EMAIL: info.rustica@kuleuven.be

Ref. Ares(2024)2357798 - 29/03/2024

RUSTICA Demonstration of circular bio-based fertilisers and implementation of optimized fertiliser strategies and value chains in rural communities

Deliverable 6.9:

Technical biofertiliser potential in EU-28

Project acronym	RUSTICA
Project title	Demonstration of circular bio-based fertilisers and implementation of optimized fertiliser strategies and value chains in rural communities
Grant agreement number	101000527
Call identifier	H2020-RUR-2020-1
Project start date	01/01/2021
Project duration	48 months
Revised due date	31 March 2024
Submission date	29 March 2024
Lead	DRANCO nv
Author(s)	Nathan Deman (DRANCO nv)
Dissemination level	Confidential, only for members of the consortium (Including the Commission Services)

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Please cite this RUSTICA deliverable as follows: Deliverable 6.9: Technical biofertiliser potential in EU-28. Author: Nathan Deman. RUSTICA - Demonstration of circular bio-based fertilisers and implementation of optimized fertiliser strategies and value chains in rural communities. EU Horizon 2020 project grant agreement No 101000527. https://rusticaproject.eu/

Table of Contents

Acronyms and abbreviations

BBF	Bio-Based Fertilisers
BP	Biochar Production
BSF	Black Soldier Fly
CAP	Carboxylic Acid Platform
CWB	Composting With Biochar
ED	Electrodialysis
IB	Insect Biomass
IC	Insect Cultivation
ID	Insect Digestion
IF	Insect Frass
LA	Lactic Acid
MB	Microbial Biomass
MP	Microbial Protein
NPK	Nitrogen-, Phosphor-, Potassium
pH	Potential of Hydrogen
sCOD	soluble Chemical Oxygen Demand
VFA	Volatile fatty acids

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List of Figures

List of Tables

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1. Introduction

The RUSTICA project, an initiative under the Horizon 2020 framework, aims for advancing sustainable agricultural practices through innovative technology. In this project, 5 technologies are being used to produce building blocks for the development of bio-based fertilisers (BBF) out of agro-industrial organic waste streams. Field trials will be performed with the RUSTICA BBF on different crops, grown on different soil types. Before these field trials can take place, large quantities of each building block must be produced. Therefore, pilots for each of the technologies have been developed. The pilots for the Carboxylic Acid Platform (CAP), Microbial Protein (MP) production and Electrodialysis (ED) are placed near Ghent, Flanders, Belgium. The pilot for Insect Cultivation (IC) will be placed at the TECNOVA site in Almeria (Spain) and at ENTOMO Agroindustrial facilities in Murcia (Spain). The pyrolysis pilot is placed on the TNO site in The Netherlands.

Table 1 - Overview of the RUSTICA technologies and their respective building blocks used in the pilot trials

RUSTICA partner	Technology	Feedstock	Building block
DRANCO	CAP	Fruit and vegetable residue	
AVECOM	MP production	CAP-effluent	MP
UGent	Electrodialysis	CAP-effluent	NPK solution
ENTOMO	Insect cultivation	Organic side stream	Insect Frass
ENTOMO	Insect cultivation	Organic side stream	Insect Biomass
TNO	Pyrolysis	Organic side stream	Biochar

The RUSTICA project focusses on 5 regions: Flanders (Belgium), Almeria (Spain), Pays de la Loire (France), Friuli-Venezia Giulia (Italy) and Valle del Cauca (Colombia). In work package 5, multiple agricultural side streams derived from all RUSTICA regions have undergone feasibility studies for the RUSTICA technologies. Moreover, the RUSTICA technologies are being demonstrated in Flanders and Almeria (task 6.3 of the RUSTICA project). These regions also serve as main case studies for the business case development. All RUSTICA regions will host field trials with the final RUSTICA biofertiliser blends, derived from the building blocks produced with the RUSTICA technologies.

For the RUSTICA regions without pilot demonstrators, hypothetical integration strategies have been formulated (deliverable 6.7).

This deliverable presents two case studies based on the RUSTICA project's work, specifically referencing the integration strategies outlined in deliverables 6.1, 6.2, and 6.7. These case studies aim to illustrate the process of identifying regions that could benefit from adopting RUSTICA technologies.

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2. Lab Integration and Pilot Demonstrator Outcomes

The RUSTICA project has produced significant outcomes from its lab integrations and pilot demonstrators, focusing on the production and optimisation of biofertilisers from fruit and vegetable waste. The lab integrations have explored various technologies for nutrient recovery and biofertiliser production, including the transformation of bio-residues into biochar, production of insect biomass, nutrient recovery using electrodialysis coupled to anaerobic fermentation (Carboxylic Acid Platform; CAP), and the conversion of CAP-effluent to microbial biomass. These efforts aim to close nutrient cycles and reduce the reliance on mineral fertilisers, contributing to more sustainable agricultural practices within the EU. Pilot demonstrators have further validated these technologies, demonstrating their practical application and potential for scalability.

Deliverable 5.1 presents a comprehensive study on the potential of various organic waste substrates for producing nutrient-rich solutions through the CAP. This deliverable highlights the use of anaerobic fermentation to convert waste into a solution rich in volatile fatty acids (VFAs) and nutrients. The study's efficiency improvements focus on optimising parameters such as substrate type, pH, and temperature to maximise soluble Chemical Oxygen Demand (sCOD) and VFA production, crucial for microbial protein production. This research underscores the potential of CAP to valorise agricultural waste into valuable biofertiliser components, contributing to a circular bioeconomy.

The conversion of CAP-effluent into microbial biomass is described in deliverable 5.3, assessing the efficiency of aerobic fermentation to produce microbial protein (MP) from various organic waste streams. It details the methodology, including physicochemical analyses and fermentation processes, and reports on experiments conducted with CAP-samples. The key outcomes demonstrate effective conversion of CAP-solutions into high-quality microbial biomass, emphasizing the role of substrate characteristics and fermentation conditions in optimising MP production. The deliverable highlights the potential of this approach for nutrient recovery and biofertiliser production, contributing to sustainable agricultural practices.

As an alternative use of the CAP-effluent, deliverable 5.4 showcases the use of electrodialysis (ED) to efficiently separate and recover nutrients (NPK) and VFAs from CAP-effluent derived from organic waste. It highlights the process's capability to achieve over 90% nutrient recovery with concentration factors of 1.6 to 5 fold, depending on the waste source. The separation efficiency between VFAs and nutrients reached up to 70%, showcasing ED's potential in nutrient recovery from waste streams for sustainable agriculture and waste management practices.

Deliverable 5.5 explores the potential of recovering nutrients from fruit and vegetable residues through insect production, focusing on the Black Soldier Fly (BSF) due to its higher capacity to convert plant material into valuable products such as frass (which can serve as a biofertiliser), proteins, and chitin. The report highlights technological innovations in insect rearing and nutrient recovery, emphasizing the efficiency of BSF in converting waste into valuable agricultural products. This process contributes to a circular economy by repurposing agricultural waste into high-value products for agricultural use (Insect Biomass, IB; Insect Frass, IF; Chitin), showcasing another innovative, sustainable approach to waste management and nutrient recycling.

Deliverable 5.2 delves into biochar production from lignocellulosic residues, which are not easily used by the above mentioned technologies. D5.2 emphasizes the transformation of agricultural bio-residues into a soil amendment ingredient via pyrolysis/gasification. The report highlights the process's efficiency in retaining essential minerals within the biochar, thereby offering a sustainable method for nutrient recovery and soil enhancement.

The various techniques mentioned are capable of transforming organic agricultural waste into valuable products, each with unique characteristics and beneficial properties for agriculture. These technologies were evaluated across a diverse range of agricultural substrates, revealing that the substrate type significantly influences the quality of the end product. Consequently, certain technologies are more apt for specific substrates than others. The final products -microbial protein (MP), NPK-solution, insect biomass (IB), insect frass (IF), and biochar- possess distinct properties. Through the integration of these products into customised blends, as demonstrated in work package 7, it is possible to enhance soil quality for various soil types or to tailor fertiliser mixes to meet the nutritional requirements of specific crops.

In the RUSTICA project, pilot demonstrations across three regions showcased the innovative approaches to convert agricultural waste streams into materials useful for biofertiliser production:

1. **Flanders, Belgium:** Demonstrated the Carboxylic Acid Platform (CAP), Microbial Protein (MP) technology, and Electrodialysis for NPK recovery, showing the potential for efficient nutrient extraction from agricultural waste.
2. **Almeria, Spain:** Focused on Insect Cultivation (IC) technology, turning agricultural waste into valuable insect biomass and insect frass, highlighting a novel waste-to-value conversion pathway.
3. **The Netherlands**: Utilised TNO's pilot for producing biochar from lignin-rich substrates from various regions, successfully converting woody side streams into biochar. The trials indicated that the quality of biochar, especially its salt content, significantly depends on the type of woody agricultural waste used.

Deliverable 6.5 from the RUSTICA project focuses on the continuous testing of CAP for MP-production and ED for nutrient recovery in Flanders. It showcases technological innovations like the efficient conversion of organic waste into CAP-solution, and the subsequent use of this solution for producing MP and recovering nutrients through ED. The pilot trial highlights the project's success in demonstrating a sustainable, circular approach to agricultural waste stream valorisation, emphasizing stable production over testing periods and the potential for scaling these technologies for broader application.

Deliverable 6.6 of the RUSTICA project highlights the valorisation of vegetable crop residues through Insect Digestion (ID), Composting with Biochar (CWB) in Almeria, Spain and Biochar Production (BP) in The Netherlands. The deliverable focuses on innovative techniques to transform agricultural waste into valuable biofertilisers. ID leverages the Black Soldier Fly to convert waste into nutrient-rich biomass and frass, while BP transforms lignocellulosic residues into biochar under controlled pyrolysis, enhancing soil properties and sequestering carbon. CWB combines biochar with organic waste to improve compost quality, accelerating decomposition and enriching nutrient content. These processes exemplify efficient waste valorisation, contributing to sustainable agriculture and circular economy principles.

In Flanders the pilot trials focused on the agricultural waste streams: fruit and vegetable residues, specifically derived from ALLGRO, a wholesaler of cut vegetables and fruits. These residues were primarily utilised in the production of CAP solution, which served as a feedstock for further microbial protein (MP) production and nutrient recovery through electrodialysis. However, during work package 5, multiple feedstocks were examined for their suitability in CAP technology. It was found that while most tested substrates were suitable for CAP processing, substrates rich in lignin, such as plant stems, were less favourable due to their difficult degradability. Conversely, softer plant tissues like fruits showed high suitability due to their easy degradability, producing high soluble Chemical Oxygen Demand (sCOD) levels essential for microbial protein production. This differentiation underscores the importance of selecting appropriate feedstocks for optimal CAP technology application. The feedstock for the CAP-technology also influenced the Microbial Biomass (MB) quality. CAP-effluents with high sCOD content and low calcium concentration seemed more suitable for MP. Yet all CAP-effluents could be relatively efficient converted into MB. For nutrient recovery using ED, CAP-effluent low in Lactic Acid (LA) were more suitable for ED. The LA fouled the membranes making the ED less efficient. However the LA could be avoided by changing the parameters in the CAP-process. Hence, ED is less dependent on the feedstock used for CAP.

In the Almeria pilot trials, the agricultural waste streams utilised were tomato, sweet pepper, cucumber, zucchini, watermelon, and melon for Insect Cultivation (IC); sweet pepper and eggplant for BP; and sweet pepper for CWB. The suitability of the feedstock for IC depends on the nutritional content of the residues and their digestibility by the insects, with factors such as moisture content, nutrient levels, and presence of harmful substances (like pesticides) affecting the outcomes. During the lab trials different insect species were tested for cultivation on agricultural waste streams. Black Soldier Fly (BSF) showed the highest productivity, effectively converting these waste streams into insect biomass and frass. The success of BSF in utilising a wide range of feedstocks highlights its versatility and efficiency in nutrient recovery from agricultural waste. BSF can be cultivated about anywhere in Europe. Hence, the use of this technology is limited to the feedstock, not to the insect type.

During work package 5, various feedstocks were tested for biochar production, including residues from fruits like eggplant and sweet pepper, as well as pruning from olive, almond, and pistachio trees. Woody residues showed a generally higher suitability for biochar production due to their lignocellulosic content. However, feedstocks with high fertigation elements, such as eggplant and sweet pepper residues, resulted in biochar with excessive ash content, making them less suitable without further processing to reduce ash levels. The efficiency of biochar production and its quality were directly influenced by the feedstock's intrinsic properties, like ash and moisture content (D5.2).

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3. Integration strategies for RUSTICA regions without a pilot

Deliverable 6.7 discusses technical integration strategies for regions without pilot plants within the RUSTICA project, focusing on Pays de la Loire (France), Friuli-Venezia Giulia (Italy), and Valle del Cauca (Colombia). It evaluates biomass availability, potential applications, and the adaptability of RUSTICA technologies in these regions. Despite the absence of pilot demonstrators, the deliverable identifies local stakeholders, including research institutes, companies, and universities, with expertise in composting, fermentation, pyrolysis, and insect cultivation, capable of valorising wastes into bio-based fertilisers, biochar, and bioenergy. For these regions, feedstocks were extensively tested in work package 5, making it more easy to determine whether or not the technologies can be implemented in these regions.

In Pays de la Loire, a wide variety of biomass is available, including fruits and vegetable wastes from a strong food processing sector, crop residues like straw and husks from cereals, and agro-industrial residues from activities such as sugar production. Additionally, green waste from landscaping and gardening activities is prevalent. These waste streams are currently valorised through fermentation or composting processes to produce biofertilisers, showcasing a regional commitment to sustainable waste management and agricultural practices.

In the Friuli-Venezia Giulia region and Northern Italy, various agricultural residues are available, including crop residues like straw, husks, and stalks from wheat, corn, rice, and barley. Olive pomace from the olive oil production and vineyard prunings are significant sources of biomass. These residues are currently valorised through composting, anaerobic digestion for biogas production, and as feedstock for bioenergy. The potential for implementing RUSTICA technologies such as CAP (Carboxylic Acid Platform), MP (Microbial Protein production), ED (Electrodialysis for nutrient recovery), Pyrolysis for biochar production, and insect cultivation is high, leveraging these biomass residues to enhance sustainable agricultural practices and biofertiliser production.

In Valle del Cauca, Colombia, significant agricultural and livestock activities generate biomass residues with potential for valorisation. Major sources include sugarcane residues (bagasse, vinasse, and filter cake), fruit and vegetable waste, coffee residues (husks and pulp), and rice husks. These are currently utilized mainly for energy production, composting, and as feed in various forms. RUSTICA technologies like composting, black soldier fly cultivation, and anaerobic digestion offer innovative pathways to enhance these residues' value, promoting sustainable agricultural practices and contributing to the circular economy in the region.

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4. Biomass feasibility assessment

Within the context of the RUSTICA project, particularly referencing work packages 5 and 6, a decision tree has been developed to evaluate the compatibility of various biomass types with RUSTICA technologies, including the CAP, BP and IC. It is important to note that the decision trees serve as preliminary guides for determining biomass suitability. Technologies such as MP and ED, were not individually modeled as their operational efficacy closely follows the parameters set by the CAP process, with the biomass's characteristics playing a secondary role.

This section presents the decision trees for the mentioned RUSTICA technologies, providing an initial framework for assessing the potential of different biomass sources. However, these trees should not be seen as definitive judgements on the viability of any particular biomass. To accurately ascertain the suitability of a biomass for these technologies, detailed feasibility studies at the laboratory scale are recommended. These assessments will offer concrete insights into the technical viability.

The subsequent section 5, will delve into broader considerations, presenting case studies that illuminate the economic and social implications of applying RUSTICA technologies to specific agricultural regions. Through these discussions, we aim to provide a comprehensive understanding of the factors that should be considered when evaluating biomass for use in RUSTICA technologies, ensuring a holistic approach to decision-making.

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4.1 Biomass feasibility model for CAP

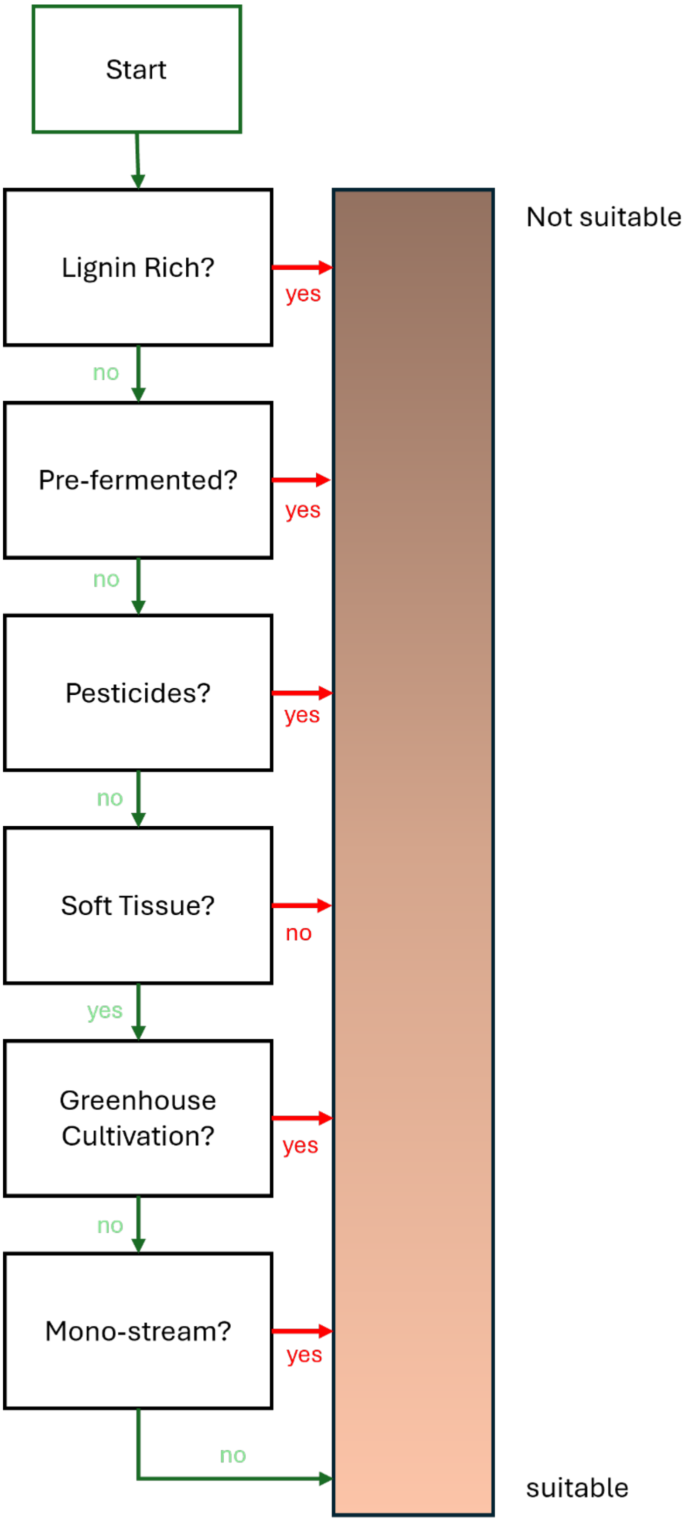

Figure 1 - Decision Model - suitability of biomass for CAP technology

1. **Lignin-rich?**: The first decision point assesses if the biomass is lignin-rich, as this is a critical factor for CAP technology suitability.
2. **Pre-fermented?**: Next, it considers whether the biomass has been pre-fermented, which affects the availability of nutrients and carbon for fermentation.
3. **Pesticides?**: Then, the presence of pesticides is evaluated, acknowledging that while not ideal, it may not necessarily disqualify the biomass.
4. **Soft Tissue?**: The preference for soft tissue (e.g., flowers, fruits) over harder parts (e.g., stems, leaves) is assessed, given its impact on fermentation efficiency.
5. **Mono-stream?**: The simplicity and control associated with mono-stream biomass are considered, aiming for a more straightforward processing route.
6. **Greenhouse Crop?**: Finally, the source of the biomass (greenhouse vs. non-greenhouse crops) is evaluated, with a preference for non-greenhouse crops due to their typically higher biodiversity, which benefits the fermentation process.

It is important to recognize that while the decision tree provides a structured approach for assessing biomass suitability for CAP technology, based on the profound factors identified in Work Package 5 (WP5) of the RUSTICA project, it does not encompass all possible variables that could influence the outcome. The factors included - lignin content, pre-fermentation status, pesticide presence, soft tissue preference, mono-stream benefits, and the distinction between greenhouse and non-greenhouse crops- are highlighted due to their significant impact as discovered in the project's research.

However, other factors might also affect the biomass's compatibility with CAP technology. These could include the moisture content of the biomass, its overall chemical composition, the presence of contaminants other than pesticides, and the specific types of microorganisms present, among others. The decision tree serves as a starting point, guiding the initial evaluation based on the most critical factors.

For a comprehensive assessment, additional variables should be considered alongside the technical feasibility, including economic viability, environmental impact, and social acceptability. Such a holistic approach ensures that the selection of biomass for CAP technology not only meets the technical requirements but also aligns with broader sustainability goals. Therefore, while this decision tree is a valuable tool for preliminary screening, it is part of a larger assessment process that includes detailed feasibility studies, laboratory testing, and analysis of economic and social factors to fully determine the suitability of a specific biomass for CAP technology application.

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WEBSITE: rusticaproject.eu
EMAIL: info.rustica@kuleuven.be

4.2 Biomass feasibility model for IC

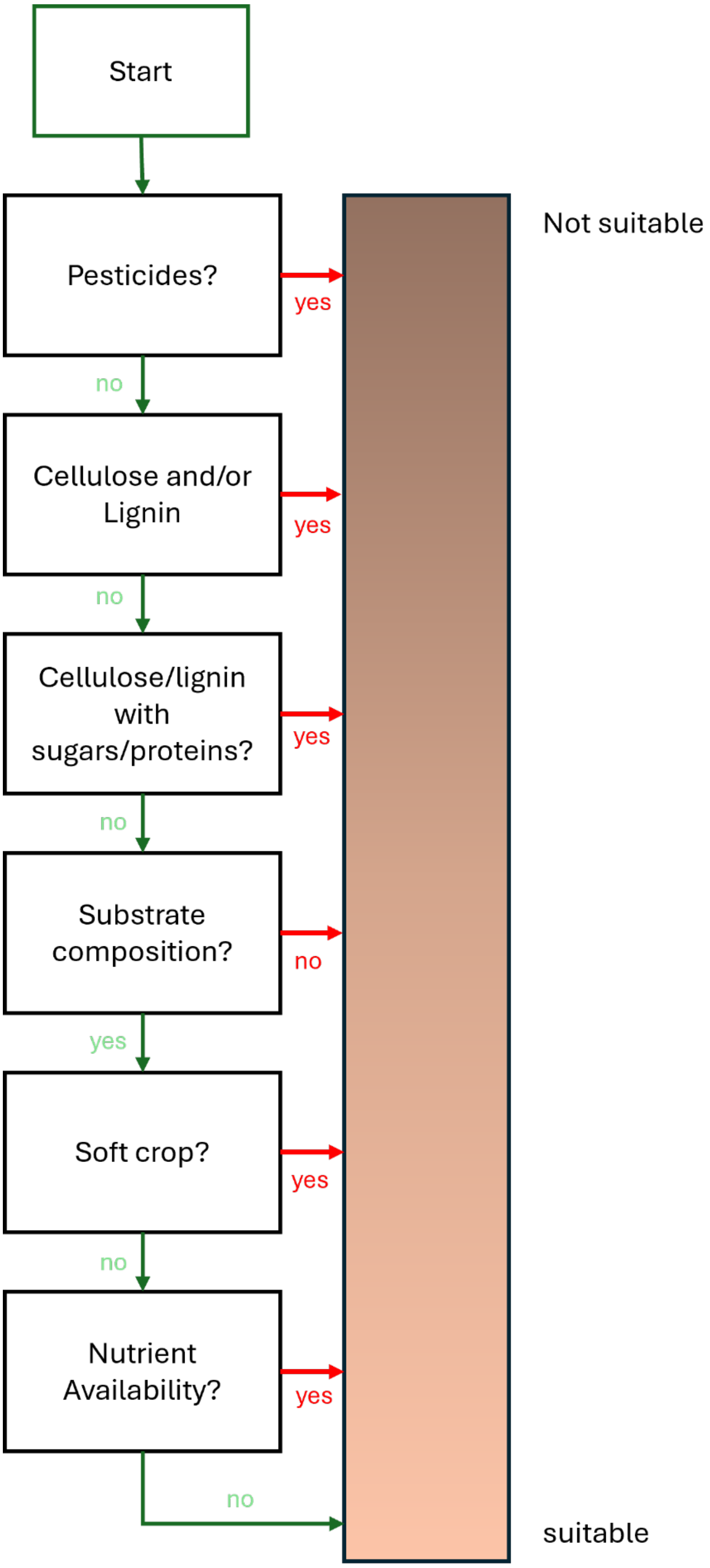

Figure 2 - Decision tree - suitability of biomass for IC technology

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1. **Pesticide Presence**: The presence of pesticides tops the list of concerns due to its severe negative impacts, including potential insect mortality or developmental delays. A substrate with detectable pesticide levels is generally deemed unsuitable for insect cultivation.
2. **Cellulose and Lignin Content**: We evaluate if the substrate contains cellulose and lignin, materials typically unfavorable for larval growth due to their complex structure and digestibility issues.
3. **Presence of Sugars and Proteins with Cellulose and Lignin**: While cellulose and lignin alone pose challenges, their coexistence with ample sugars and proteins can make a substrate viable for insect rearing, providing essential nutrients for growth.
4. **Substrate Composition**: The preference leans towards mixed substrates owing to their varied nutrient profile, which is believed to better support insect nutritional needs through complementarity.
5. **Type of Crop and By-products**: Suitability expands when considering soft crops and their by-products, such as olive pomace, provided they are rich in critical nutrients like sugars, oils, and proteins essential for insect development.
6. **Nutrient Availability**: The lack of readily digestible nutrients -sugars, oils, and proteins- could compromise insect biomass yield, although it does not necessarily affect the production of frass.

Following these criteria, the outcomes are twofold:

- **Suitable**: If a substrate fulfills the above criteria, it is considered apt for insect cultivation.
- **Frass Production OK / Limited Suitability**: This outcome suggests that, despite nutrient shortages possibly hindering optimal insect biomass growth, the substrate remains sufficient for frass production.

This approach, structured around pivotal factors identified in Work Package 5 (WP5) of the RUSTICA project, offers a foundational method for assessing biomass compatibility with CAP technology. It should be noted, however, that this framework does not capture every variable that might influence efficacy. Factors such as biomass moisture, chemical makeup, additional contaminants, and specific microbial profiles also warrant consideration.

Thus, while this decision model serves as an effective preliminary screening tool, a thorough evaluation of biomass for IC technology necessitates a broader analysis. This includes detailed feasibility studies, lab experiments, and evaluations of economic and social impacts, ensuring a comprehensive determination of biomass suitability that aligns with overarching sustainability objectives.

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4.3 Biomass feasibility model for BP

Based on the results of WP5 and WP6 of the RUSTICA project, a linear model is proposed for assessing the suitability of feedstock for biochar production. This model integrates key parameters essential for the efficient and effective conversion of biomass into biochar. This model serves as a practical tool for determining whether a given feedstock meets the necessary criteria for biochar production, emphasizing the importance of ligno-cellulosic content, moisture content, and ash content in the feedstock.

Biochar production requires feedstock with a high ligno-cellulosic share to ensure a stable and high-quality end product, beneficial for soil enhancement and carbon sequestration. The ideal feedstock should possess specific percentages of cellulose, hemicellulose, and lignin, as these components significantly influence the biochar's properties and yield. Moisture content is another critical factor, as too much moisture can hinder the pyrolysis process, necessitating pre-drying to optimal levels before the feedstock enters the reactor. Lastly, the ash content in the feedstock impacts the quality of the resulting biochar; a lower ash content is preferable to maintain the biochar's carbon content above a certain threshold.

This model visualizes the relationship between these parameters and the feedstock's overall suitability for biochar production. By setting benchmarks for each parameter, based on established research and industry standards, the model provides a clear, linear assessment method. Feedstocks that meet or exceed these benchmarks are considered suitable for biochar production, ensuring that the process is both efficient and produces a high-quality product.

The linear model for deciding whether a feedstock is suitable for biochar production includes the following key parameters, along with an example feedstock evaluation resulting in a normalized suitability score:

Parameters and their importance:

1. High Ligno-Cellulosic Share:
    - *Minimum Requirement:* 65% combined cellulose, hemicellulose, and lignin.
    - *Ideal Ranges:* 35-50% cellulose, 20-35% hemicellulose, 10-25% lignin.
2. Moisture Content:
    - *Maximum Before Drying*: 50%.
    - *Target After Drying*: 10-15%.
3. Ash Content:
    - *Maximum in Feedstock:* 15% to ensure the biochar has less than 50% ash after production, considering enrichment due to volume reduction.

Scoring Weights:

- High Ligno-Cellulosic Share: 40%
- Moisture Content: 30%
- Ash Content: 30%

Example Feedstock Evaluation:

- Ligno-Cellulosic Share: 70%
- Moisture Content: 45%
- Ash Content: 10%

Conclusion: Normalized Suitability Score: 0.6

This score is calculated based on the example feedstock's conformity to the parameters, where a higher score indicates greater suitability for biochar production. The score is normalized between 0 and 1, considering the predefined importance of each parameter.

In this example, with a score of 0.6, the feedstock is fairly suitable for biochar production, meeting the critical criteria for ligno-cellulosic share and ash content, and having a manageable moisture content that requires pre-drying to the target level (Figure 3).

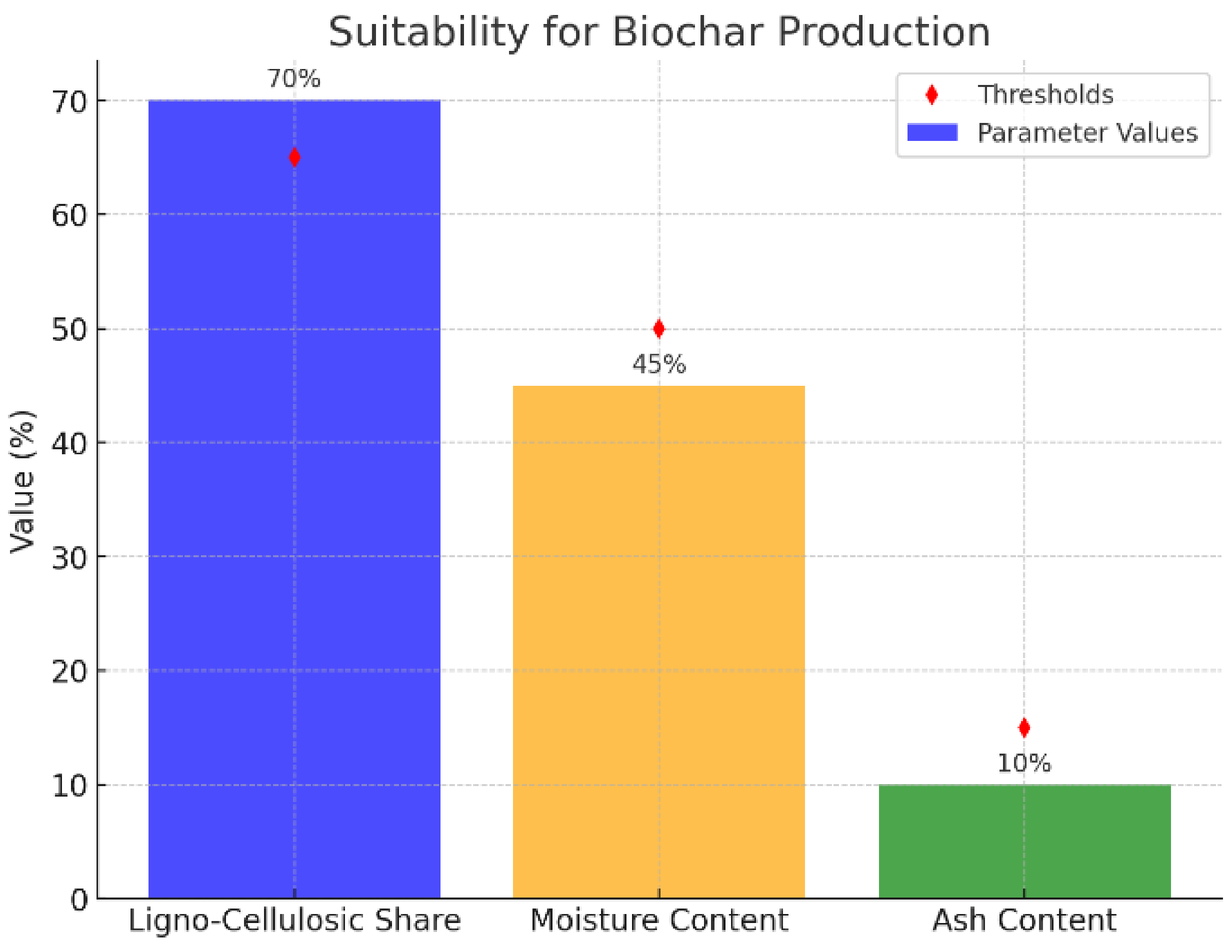

Figure 3 - Visualization for the linear model assessing suitability of BP.

The red dots indicate the threshold values for each parameter, serving as benchmarks for determining suitability.

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4.4 Combined Decision Model for RUSTICA Technologies

As example, the above mentioned feasibility models were used to create a combined decision model to determine which RUSTICA technology to use for a specific biomass feedstock involving the integration of key parameters from the CAP, IC and BP decision models. The aim is to offer a unified approach that guides the selection of the most suitable technology based on the characteristics of the biomass in question.

The decision model is structured around a series of questions that progressively narrow down the most suitable technology or technologies for a given biomass feedstock. This approach considers the unique requirements and optimal conditions for CAP, IC, and BP, as described in the document.

1. **Is the biomass lignin-rich?**
    - **Yes**: Consider BP for biochar production, as high lignin content is favourable.
    - **No**: Proceed to the next question.
2. **Has the biomass been pre-fermented?**
    - **Yes**: Favor CAP for further processing, as pre-fermentation enhances nutrient availability.
    - **No**: Proceed to the next question.
3. **Is there a presence of pesticides?**
    - **Yes**: Generally unsuitable for IC due to potential harm to insects.
    - **No**: IC remains a viable option; proceed with further evaluation.
4. **Does the biomass contain soft tissue, such as flowers or fruits?**
    - **Yes**: CAP is potentially more suitable due to easier fermentability.
    - **No**: If the biomass is woody or fibrous, BP for biochar production may be more appropriate.
5. **Is the biomass a mono-stream?**
    - **Yes**: Simplifies processing for all technologies but particularly benefits CAP for a more controlled fermentation process.
    - **No**: If mixed, IC and BP might still be viable, depending on other factors.
6. **Is the biomass from greenhouse crops or open-field crops?**
    - **Greenhouse Crops**: Preferentially consider CAP due to potential lower pesticide usage and biodiversity aspects.
    - **Open-field Crops**: All options remain viable; consider other factors.
7. **What is the moisture content of the biomass?**
    - **High**: Requires pre-drying for BP; IC and CAP may handle higher moisture levels, depending on specific tolerances.

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8. **What is the nutrient availability in the biomass?**
    - **High in digestible nutrients**: IC is favoured, especially if nutrients are readily available for insect growth.
    - **High in nutrients suitable for fermentation**: CAP is favoured.

Using the combined decision model for RUSTICA technologies, three distinct types of biomass feedstock are examined below: pinewood cuttings, spent brewery grains, and cutting waste from fruit and vegetables. Each example follows the decision path to suggest the most suitable technology for valorisation.

Example 1: Pinewood Cuttings

1. **Lignin-rich?** Yes, pinewood cuttings are rich in lignin.
2. **Biochar Production (BP) Suitability**: Given the high lignin content, pinewood cuttings are highly suitable for biochar production. The pyrolysis of pinewood can lead to a stable and high-quality biochar, beneficial for soil enhancement and carbon sequestration.

Decision: Pinewood cuttings are best processed using Biochar Production (BP) technology. This choice aligns with the goal of enhancing soil health and sequestering carbon, leveraging the lignin-rich nature of the wood.

Example 2: Spent Brewery Grains

1. **Nutrient-rich:** Despite the sugars being extracted, spent grains remain rich in proteins and fibres, essential nutrients for the growth and development of insects.
2. **Low Pesticide Presence:** Brewery grains typically have low levels of pesticides, making them safer for insect rearing and subsequent use of the insects or their byproducts (e.g., frass) as biofertilisers or animal feed.
3. **High Moisture Content:** Spent grains have a high moisture content, which is conducive to the breeding and growth of insects like the BSF. However, moisture levels can be adjusted to meet specific requirements of different insect species.
4. **Sustainability:** Utilizing spent brewery grains for insect cultivation contributes to waste reduction and promotes a circular economy. It provides an excellent example of valorising industrial byproducts that would otherwise be discarded or underutilised.
5. **Economic and Environmental Benefits:** Transforming spent brewery grains into valuable products like insect biomass (for animal feed or aquaculture) and biofertilisers (from insect frass) not only offers economic advantages but also supports environmental sustainability.

Decision: Spent brewery grains are most suitable for the IC. These grains are rich in proteins and fibers, making them a highly suitable substrate for insect cultivation, particularly for species like the BSF, which can thrive on a wide range of organic waste materials.

Example 3: Cutting Waste of Fruit and Vegetables

1. **Lignin-rich?** No, fruit and vegetable cuttings are not lignin-rich.
2. **Pre-fermented?** No, but they are rich in sugars and other easily fermentable materials.
3. **Soft Tissue?** Yes, which facilitates quick and efficient fermentation.

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4. **Presence of Pesticides?** Assuming they are from a mix of sources, the pesticide content could vary, but let's assume for this example that they are primarily organic or have been washed.

5. **Carboxylic Acid Platform (CAP) Suitability**: Given their high nutrient content and soft, easily degradable nature, fruit and vegetable cuttings are ideal for CAP. This process can convert these materials into valuable components for biofertiliser production, such as microbial protein and nutrient-rich solutions.

Decision: The cutting waste from fruit and vegetables is best processed using the CAP due to their high nutrient content and biodegradability, making them perfect candidates for efficient valorisation into biofertilisers.

Considering local conditions, such as the availability of technology, expertise, and infrastructure, is crucial when determining the most suitable RUSTICA technology for processing a specific type of biomass feedstock. Economic viability also plays a significant role, as the costs associated with processing and the market value of the end product must be carefully weighed. Compliance with both local and EU regulatory frameworks regarding biofertiliser production and use is mandatory, ensuring that chosen technologies adhere to legal standards.

Additionally, the environmental impact of the technology must align with sustainability goals, prioritising methods that contribute to the circular economy. This decision model acts as an initial guide for stakeholders to identify appropriate RUSTICA technologies for their biomass feedstocks. It underscores the importance of conducting comprehensive feasibility studies, including laboratory-scale testing and economic analyses, to ascertain the practicality and effectiveness of the selected technology.

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5. Discussion

This document serves as an initial framework for formulating a region-specific integration strategy for RUSTICA technologies. The overarching objective of these technologies is to facilitate the transition towards a localised circular bioeconomy. However, it is important to recognize that the cases discussed above may present a simplified perspective on this complex issue.

When formulating an integration strategy for the RUSTICA technologies in a certain region, several key parameters should be taken into account to ensure the effective and sustainable valorisation of agricultural side streams into bio-based fertilisers. These parameters are essential for tailoring the strategy to local conditions and maximizing the potential benefits. Below a breakdown of these crucial parameters is given:

1. **Agricultural Practices and Crop Types**:
    - Identify the main crops and agricultural practices in the region to understand the types and quantities of agricultural side streams available for valorisation.
    - Consider seasonal variations in agricultural production, which may affect the availability of side streams.
2. **Climate and Environmental Conditions**:
    - Assess the region's climate, as it influences agricultural practices and the feasibility of certain technologies.
    - Consider environmental regulations and sustainability goals that may impact the adoption of technologies.
3. **Availability and Composition of Agricultural Side Streams**:
    - Analyse the chemical and physical composition of available side streams, as this affects their suitability for different valorisation technologies.
    - Evaluate the volume and consistency of side stream availability throughout the year.
4. **Technological Feasibility and Efficiency**:
    - Assess the technical feasibility of implementing RUSTICA technologies, considering local expertise, infrastructure, and technological readiness.
    - Evaluate the efficiency and output of these technologies in converting side streams into valuable biofertilisers.
5. **Economic Viability**:
    - Analyse the economic aspects, including the cost of technology implementation, operation, and maintenance, alongside the potential market value of the biofertilisers produced.
    - Consider the availability of financial incentives, subsidies, or funding that could support technology adoption.
6. **Regulatory and Policy Framework**:
    - Review local and national regulations regarding waste management, biofertiliser production, and use to ensure compliance.

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- Consider policies that could influence the adoption of sustainable agricultural technologies, such as environmental regulations or agricultural support programs.

7. **Social Acceptance and Cultural Factors**:
    - Evaluate the social acceptance of using bio-based fertilisers among farmers, consumers, and other stakeholders.
    - Consider cultural aspects and traditional practices that may influence the adoption of new technologies.
8. **Infrastructure and Logistics**:
    - Assess the availability of necessary infrastructure for the collection, transportation, and processing of agricultural side streams.
    - Consider logistics related to the distribution and application of the produced biofertilisers.
9. **Market Demand and Competitiveness**:
    - Analyse the demand for bio-based fertilisers within the region and potential markets beyond.
    - Evaluate the competitiveness of the produced biofertilisers compared to conventional fertilisers and other bio-based alternatives.
10. **Partnerships and Stakeholder Engagement**:
    - Identify potential local partners, including research institutes, agricultural cooperatives, businesses, and government agencies, that could support the implementation and adoption of RUSTICA technologies.
    - Engage with stakeholders throughout the process to ensure their needs and concerns are addressed.

By considering these parameters, a comprehensive integration strategy for RUSTICA technologies can be developed, tailored to the specific needs and conditions of a region, thereby enhancing the sustainability of agricultural practices and contributing to the circular economy.

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