CHEERS

Producing novel non-plant biomass feedstocks and bio-based products through upcycling and the cascading use of brewery side-streams

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Abbreviations and Acronyms

CH_4	=	Methane
CO_2	=	Carbon dioxide
EPR	=	Extended Producer Responsibility
EU	=	European Union
JRC	=	Joint Research Council
LCA	=	Life Cycle Assessment
SCP	=	Single Cell Protein
SME	=	Small Medium Enterprise
TEA	=	Techno-Economic Assessment
TRL	=	Technology Readiness Level
VFA	=	Volatile Fatty Acids
WP	=	Work Package

Executive Summary

CHEERS Project: Towards a Circular and Sustainable Biorefinery

The CHEERS project presents an innovative biorefinery inspired by biodiversity, using insect and microbial platforms to optimize resource use and convert waste streams into high-value bio-based products.

Objectives:

Develop a pioneering biorefinery integrating insect and microbial platforms.

Upgrade underused or waste side streams (spent grain, wastewater, CO_2, and CH_4).

Empower bio-based industries to increase feedstock use efficiency and overall sustainability.

Achieve a minimum 45% carbon footprint reduction.

Generate bio-based products for industrial applications (insect protein, disinfectant, microbial protein, ectoine, and caproic acid).

Align with the European Green Deal, Circular Economy Action Plan, and Bioeconomy Strategy.

Foster collaboration among stakeholders across Europe.

Contribute to the understanding of biotechnology-based value chains.

Methodology:

Side-stream mapping and optimization.

Insect and microbial platform development and start-up.

Integration and cascading of biomass downstream processing.

Bio-based product development and validation.

Environmental and economic impact assessment and exploitation strategies.

Expected Results:

Novel biomass platforms:

- production of 13.5 tons/year of insect protein from 40 tons/year of spent grain. Conversion of CO_2 and CH_4 into valuable ingredients.
- Circular and sustainable bio-based products: 12 kg of protein drink, 100 kg of VFA mixture, 17 kg of chlorine-based product, 20 g of ectoine cosmetic, and 15 kg of SCP pet food.

Technological advancements (TRL7): spent grain to insect protein conversion, CO_2 bioconversion to caproic acid and bioCH_4, CO_2 bioconversion to hypochlorite and bioCH_4, CH_4 bioconversion to ectoine, and CH_4 bioconversion to high-quality SCP.

Installation of 100 valorization plants in the EU after 5 years of commercialization.

Transfer of scientific knowledge to industrial stakeholders, society, and the European Joint Research Centre (JRC).

Conclusions:

The CHEERS project has enormous potential to transform the biorefinery industry towards a more sustainable and circular future. The implementation of the recommended policies, along with continued technology development and collaboration among key stakeholders, can drive this change.

Keywords: Biorefinery, circular economy, sustainability, bio-based, CO_2, CH_4, spent grain, insect protein, microbial protein, ectoine, caproic acid.

1 Introduction

The first version of the Policy Brief is a pivotal component developed under ***Work Package 6 (WP6): "Environmental & Economic Impact and Exploitation Strategy"*** within the CHEERS project. Serving as a comprehensive compilation, this document distils crucial information from the results obtained in the project. Its core lies in the meticulous execution of tasks under WP6, namely:

- Task 6.1: Modelling and integration of sustainability analysis of the CHEERS biorefinery.
- Task 6.2: Techno-economic assessment (TEA) of the processes.
- Task 6.3: Life Cycle Sustainability Assessment.
- Task 6.4: Comprehensive assessment and future actions within the CHEERS biorefinery concept.
- Task 6.5: Exploitation strategy.

Among other outputs and information as a result of the research and development activities carried out within the frame of the other WPs that compose this Project:

- *WP1 "Side-streams mapping and optimisation according to circular economy needs"*
- *WP2 "Insect platform"*
- *WP3 "Microbial platform"*
- *WP4 "Integration and cascading processing"*
- *WP5 "Bio-based product development and validation"*

This Policy Brief encapsulates mid-term inputs and findings from these tasks and WPs, crafting a document that translates the complexities of the CHEERS Project into a clear and concise format. Aimed at a non-specialized audience, it distils evidence-based policy advice, ensuring a seamless integration of the project's progress and insights into wider policy initiatives. In its format, the brief encompasses an executive summary, introduction, an overview of the CHEERS Project and a concluding section outlining policy recommendations and the implications of the demonstration.

2 CHEERS Project

The CHEERS Project, funded under the Horizon Europe Programme (Project Nº 101060814), is at the forefront of biotechnological innovation with the goal of mitigating the impact of human activities on the environment.

Led by the beer company MAHOU, serving as the project coordinator and exploitation leader, CHEERS involves collaboration with 11 partners across five European countries. These partners include technology suppliers, end-users, and research entities, fostering a comprehensive approach towards a ***"zero waste" biorefinery***. ***CHEERS aligns seamlessly with the EU Green Deal, Circular Economy Action Plan, and Bioeconomy Strategy***, contributing significantly to the understanding of biotechnology-based value chains across diverse stakeholders, from small bio-based industries to consumers.

2.1 Why was the CHEERS Project born?

The inception of the CHEERS Project is rooted in the imperative to address the pressing need for sustainable solutions in the biorefinery landscape. This initiative is fundamentally driven by the development of an inventive biorefinery concept, drawing inspiration from biodiversity and harnessing the potential of insect and microbial platforms.

In response to the escalating challenges faced by bio-based industries, ***CHEERS strategically focuses on the efficient upgrading of underused or wasted side-streams, encompassing materials like spent grain, wastewater, CO_2, and CH_4.***

The essence of ***the project lies in the creation of a modular biorefinery solution that empowers bio-based industries to optimize feedstock utilization and bolster overall sustainability***. Through the exploration of five pioneering biotechnological routes, CHEERS yields bio-based products tailored for industrial applications. ***These include insect protein, disinfectant, microbial protein, ectoine, and caproic acid***, presenting lucrative market opportunities for forward-thinking industries.

The project's innovation extends to the design of value chains, underpinned by cutting-edge bioprocesses and biofermentors, all rigorously validated at demo-scale within an industrial brewery. With a commitment to environmental responsibility, each value chain within CHEERS is poised to achieve a noteworthy minimum of 45% reduction in carbon footprint. What sets this initiative apart is its holistic impact assessment, surpassing traditional Life Cycle Assessment (LCA) methodologies. CHEERS considers broader factors, including biodiversity and land use, and social aspects ensuring a comprehensive evaluation of its sustainability footprint.

In essence, ***the CHEERS Project emerges as a response to the urgent demand for sustainable practices in the biorefinery sector***. By marrying innovation with environmental stewardship, it not only addresses the immediate challenges faced by bio-based industries but also paves the way for a more circular and ecologically conscious industrial future.

2.2 What are the objectives of the CHEERS Project?

The CHEERS Project sets ambitious global objectives to revolutionize the biorefinery sector, pioneering sustainable practices, focusing in:

- Innovative Biorefinery Concept:
  Develop a pioneering biorefinery inspired by biodiversity, utilizing insect and microbial platforms to optimize resource use. This includes engineering and commissioning CO_2 and CH_4 bioconversion platforms to facilitate the transformation of waste streams into valuable bio-based products.
- Waste Upgrading:
  Efficiently upgrade underused or wasted side-streams (spent grain, wastewater, CO_2, and CH_4) from bio-based industries for a more circular and sustainable industrial landscape.
- Empower Bio-based Industries:
  Enable bio-based industries to enhance feedstock use efficiency and overall sustainability.
- Carbon Footprint Reduction:
  Achieve a minimum of 45% reduction in carbon footprint across value chains through innovative bioprocesses and biofermentors.
- Market-Driven Products:
  Generate bio-based products (insect protein, disinfectant, microbial protein, ectoine, and caproic acid) for industrial applications, creating attractive market opportunities.
- EU Green Deal Alignment:
  Align seamlessly with the EU Green Deal, Circular Economy Action Plan, and Bioeconomy Strategy to contribute to a more sustainable future.
- Stakeholder Collaboration:
  Foster collaboration with institutions from all Europe, involving technology suppliers, end-users, and research entities, to advance the understanding of biotechnology-based value chains.
- Educational Impact:

Contribute to the broader understanding of biotechnology-based value chains, engaging stakeholders ranging from small bio-based industries to consumers.

- Strategic Market Positioning:
  Develop strategies for discreet communication about project deliverables and successes to protect joint business chances, especially concerning competitive market positioning for new bio-based products.

2.3 Main challenges and how we face them

The CHEERS Project faces significant technical challenges aligned with EU priorities in the circular economy, hindering the efficient utilization of spent grain and the conversion of CO_2 and CH_4 emissions into value-added products. These challenges, addressed within the context of circular economy objectives, shape the project's approach to sustainable bio-based product development in Europe.

2.3.1 Technical Challenges in Spent grain Utilization:

- High Moisture Content: Fresh spent grain, a potential feedstock, contains 75-80% water, limiting its shelf life and suitability for animal feed beyond the first few days after collection.
- Bacterial and Fungal Growth: Rapid deterioration due to microbial activity restricts spent grain utilization, emphasizing the need for innovative preservation methods.

2.3.2 Spent grain Preservation Methods:

- Time and Energy Consumption: Dehydration and ensiling, while effective in preventing spoilage, present challenges due to their time and energy-consuming nature.

2.3.3 Bioprocess Limitations in CO_2 and CH_4 Conversion:

- Low Aqueous Solubility: Specialized microbial cultures are required for converting CO_2 and CH_4 emissions into valuable products, posing challenges due to the low aqueous solubility of these gases.
- Volume Requirements: The poor water solubility necessitates large biofermentor volumes, escalating both the investment and operating costs of CO_2 and CH_4 bioconversions.

2.3.4 Addressing Technical Challenges in the CHEERS Project:

- Innovative Preservation Techniques: The project aims to explore and develop innovative preservation techniques for spent grain, extending its viability as a sustainable feedstock beyond the initial days of collection.
- Enhanced Bioconversion Processes: Research efforts focus on overcoming aqueous solubility challenges by optimizing microbial cultures and bioprocess conditions for efficient CO_2 and CH_4 conversion.
- Circular Economy Integration: The CHEERS Project aligns with EU circular economy priorities by emphasizing resource efficiency, waste reduction, and the creation of value from underutilized or waste materials.

2.3.5 Market Introduction limitations:

- Limited Market Awareness: The discreet communication strategy may result in limited public awareness of the CHEERS Project and its innovative bio-based products. This could hinder early market engagement and demand.
- Certification Dependency for Market Entry: Relying heavily on rigorous validation processes and EU standards for product certification may extend the time required for market entry. This delay can impact the project's ability to respond quickly to market demands and capitalize on emerging opportunities.

2.3.6 Market Introduction Strategies:

- Strategic Positioning: The project emphasizes discreet communication to protect joint business chances and market positioning, acknowledging the competitive landscape for emerging bio-based products.
- Validation and Certification: Rigorous validation processes ensure the quality and market readiness of bio-based products, aligning with EU standards and certifications for sustainable and circular economy practices.

In overcoming these challenges, the CHEERS Project strives to contribute to the circular economy in Europe by transforming waste streams into valuable, sustainable bio-based products. The integration of innovative solutions and adherence to circular economy principles position the project at the forefront of sustainable practices and market innovation.

2.4 How are the objectives of the CHEERS Project achieved?

The following activities were stated to have a significant impact in the achievement of the project's main objectives:

2.4.1 Side-streams Mapping and Optimization:

- Objective Contribution: Efficiently upgrade underused or wasted side-streams (e.g., spent grain, wastewater, CO_2, and CH_4) to feed the innovative biorefinery concept, aligning with circular economy principles.
- Impact: Enhances resource utilization, contributing to a more sustainable industrial landscape.

2.4.2 Insect Platform Development and Start-Up:

- Objective Contribution: Develops a pioneering biorefinery by utilizing the insect platform, contributing to waste upgrading, and generating insect protein for industrial applications.
- Impact: Empowers bio-based industries by diversifying feedstock sources and increasing overall sustainability.

2.4.3 Microbial Platform Development and Start-Up:

- Objective Contribution: Engineering and commissioning CO_2 and CH_4 bioconversion platforms contribute to the innovative biorefinery concept, transforming waste streams into valuable bio-based products.
- Impact: Advances bioprocesses to achieve a minimum of 45% reduction in carbon footprint, aligning with the EU Green Deal and Circular Economy Action Plan.

2.4.4 Integration and Cascading of Biomass Downstream Processing:

- Objective Contribution: Integrates downstream processing within the insect and microbial platforms, ensuring efficient use of resources and enhancing feedstock use efficiency.
- Impact: Facilitates the development of market-driven products, such as insect protein and microbial protein, contributing to strategic market positioning.

2.4.5 Bio-Based Product Development and Validation:

- Objective Contribution: Develops bio-based products (e.g., protein drinks, VFA mixture, chlorine-based, ectoine cosmetic, and pet food applications) for industrial use, aligning with market-driven products.
- Impact: Creates attractive market opportunities and contributes to stakeholder collaboration by engaging technology suppliers, end-users, and research entities.

2.4.6 Environmental & Economic Impact and Exploitation Strategies:

- Objective Contribution: Evaluates the environmental and economic impact of the project, aligning with the EU Green Deal and contributing to strategic market positioning.

- **Impact**: Supports the development of exploitation strategies, ensuring the successful market introduction of bio-based products and fostering educational impact by engaging a broad range of stakeholders.

Overall, these activities directly contribute to achieving the CHEERS Project objectives by driving innovation in biorefinery concepts, upgrading waste streams, empowering bio-based industries, reducing carbon footprint, generating market-driven products, aligning with EU policies, fostering stakeholder collaboration, and creating educational impact.

2.5 Expected results of the CHEERS Project?

2.5.1 Novel Biomass Platforms:

- ***Insect Platform***: Development of a bioconversion unit utilizing spent grain (40 tons/year) to produce insects with high nutritional value (13.5 tons/year) as a Protein (P1) ingredient.
- ***Microbial Platform***: Creation of biological units to bioconvert CH_4, CO_2, and wastewater into ingredients (P2, P3, P4, and P5).

2.5.2 Circular Bio-Based Sustainable Products (Validation and Market Acceptance):

- P1 Ingredient: ***Protein drinks*** from spent grain+insects (12 kg).
- P2 Ingredient: ***VFA mixture*** from CO_2+WW+bacteria (100 kg).
- P3+P4 Ingredients***: Chlorine-based*** (17 kg) and ***Ectoine cosmetic*** (20 g) from CO_2+bacteria.
- P5 Ingredient: SCP ***pet food*** from CH_4+bacteria (15 kg).

2.5.3 Technological Advancements (TRL7):

Successful achievement of the conversion processes:

- Spent grain to Insect Protein.
- CO_2 Bioconversion to Caproic Acid and BioCH_4.
- CO_2 Bioconversion to Hypochlorite and BioCH_4.
- CH_4 Bioconversion to Ectoine.
- CH_4 Bioconversion to High-Quality SCP.

Successful definition and start up of the main processes:

- Biomass Downstream Processing within Insect Platform.
- Biomass Downstream Processing within Microbial Platform.

2.5.4 Other Relevant Results:

- ***Installation of Valorization Plants***: Establishing a route to install 100 valorization plants in the EU after five years of commercialization.
- ***Scientific Knowledge Transfer***: Developing an ad-hoc roadmap for the transfer of scientific knowledge related to new biotechnology value chains validated in CHEERS to major industrial stakeholders, society, and the European Joint Research Centre (JCR).

The anticipated results showcase the project's commitment to creating sustainable, circular bio-based products, advancing key technologies to high TRL levels, and establishing a pathway for widespread industrial implementation and knowledge dissemination.

The CHEERS Project anticipates generating significant and multifaceted results, both in terms of technological advances and environmental and economic impact. Some of the key expected results are:

Innovations in Insect and Microbial Production: CHEERS is implementing insect production from brewery by-product spent grain. This initiative is expected to transform 1 million tons of spent grain and yeast into

65,000 tons of fresh insects. This not only offers an alternative and sustainable protein source but also results in significant water savings and minimizes the carbon footprint of the brewing sector.

CO_2 and CH_4 Bioconversion: The project aims to convert fermentation CO_2 into caproic acid and disinfectants, and CH_4 into high-value single-cell protein (SCP) and ectoine. These innovations aim to reduce greenhouse gas emissions and improve the environmental performance of these products.

Contribution to Biodiversity: CHEERS also focuses on increasing food availability and reducing pressure on land and intensive agriculture through the cultivation of edible insects. This promotes biodiversity preservation and represents a step forward in food sustainability.

Technical Challenges and Advances: Challenges such as the rapid degradation of fresh spent grain and the low aqueous solubility of CO_2 and CH_4 are being addressed, which are crucial for the efficiency of bioprocesses. CHEERS is working to overcome these technical limitations by optimizing technologies and processes.

Results in Terms of Products and Technology: Significant advances beyond the current state-of-the-art are expected in insect production, CO_2 conversion to caproic acid and disinfectants, and CH_4 transformation to high-quality biomass and ectoine.

Impact on the Brewing Industry and Beyond: These advances represent an opportunity to transform not only the brewing industry but also related sectors towards more sustainable and efficient practices. This includes creating new business opportunities for SMEs and promoting biodiversity.

3 Policy pathways for the future

This chapter explores a range of policy pathways that can be implemented to promote the development and adoption of bio-based products within a circular economy framework. By fostering a sustainable bio-based economy, we can reduce our reliance on fossil fuels, minimize environmental impact, and contribute to a more resource-efficient future.

The following policy recommendations highlight various approaches to support a thriving bio-based sector:

3.1 Circular Economy Certification:

Advocate for the development and implementation of a Circular Economy Certification for bio-based products, ensuring that these products meet specific sustainability criteria throughout their lifecycle.

3.2 Bio-Based Public Procurement:

Promote policies that encourage public procurement practices favoring bio-based products, creating a market demand, and stimulating innovation in the production and use of sustainable materials.

3.3 Extended Producer Responsibility (EPR) for Bio-Based Products:

Introduce policies that establish Extended Producer Responsibility for bio-based products, compelling producers to take responsibility for the environmental impact of their products throughout their entire life cycle, including end-of-life management.

3.4 Green Public Investments:

Advocate for increased public investments in green and bio-based industries, supporting research, development, and deployment of sustainable technologies to produce new bio-based products.

3.5 Eco-Design Standards and Labels:

Work towards the establishment of eco-design standards and labels for bio-based products, guiding manufacturers to create products that are environmentally friendly, easily recyclable, and resource-efficient.

3.6 Bio-Based Feedstock Availability:

Collaborate with policymakers to ensure a stable and sustainable supply of bio-based feedstock, exploring incentives for farmers and industries to adopt practices that contribute to the availability of raw materials for bio-based product manufacturing.

3.7 Waste-to-Resource Programs:

Support policies that facilitate the transition from a linear to a circular economy, encouraging waste-to-resource programs that promote the reuse, recycling, and upcycling of bio-based materials.

3.8 Research and Innovation Funding:

Advocate for increased funding for research and innovation in bio-based industries, with a focus on developing new technologies, processes, and materials that align with circular economy principles.

3.9 Green Public Awareness Campaigns:

Support policies that promote public awareness and education on the benefits of bio-based products and their role in the circular economy, fostering consumer demand for sustainable alternatives.

3.10 International Collaboration on Standards:

Work towards international collaboration on developing common standards for bio-based products, facilitating cross-border trade and ensuring consistency in sustainability criteria.

4 Conclusions

The CHEERS Project has made significant progress in developing an innovative and sustainable biorefinery that utilizes insect and microbial platforms to convert waste streams into high-value bio-based products.

To achieve significant and lasting impact, the implementation of the following policy pathways is recommended:

Prioritize policy pathways directly relevant to the project's achievements:

- Circular bio-based product certification: This certification should consider the project's holistic life cycle sustainability assessment methodology, which encompasses not only traditional LCA but also biodiversity as well as social aspects..
- Public procurement of circular bio-based products: Promote public procurement that prioritizes products aligned with the CHEERS Project principles, such as a minimum of 45% carbon footprint reduction and resource efficiency.
- Extended Producer Responsibility (EPR) for bio-based products: Advocate for EPR schemes that consider the project's life cycle approach, including the unique characteristics of its bio-based feedstocks and products (e.g., insect protein, microbial protein).
- Green public investments: Target public investments towards research and development that builds upon the CHEERS Project's achievements, focusing on scaling up its technologies, optimizing feedstock utilization, and exploring new applications for its bio-based products.

Consider broader policy pathways to enable circular bio-based economies:

- Eco-design standards and labels: Develop standards and labels that incorporate the project's learnings on resource efficiency, waste reduction, and biodiversity considerations.
- Waste-to-resource programs: Support policies that incentivize the use of the project's innovative waste-upgrading technologies (e.g., spent grain preservation, CO_2/CH_4 bioconversion) across various industries.
- Green public awareness campaigns: Educate the public about the project's bio-based products and their contribution to a circular economy, highlighting their environmental benefits and potential in various applications.

Additional options to consider:

- Financial incentives for bio-based feedstock production: Advocate for policies that incentivize farmers and industries to adopt practices that increase the availability of sustainable feedstocks compatible with the project's technologies (e.g., circular agriculture practices for spent grain production).
- Streamlined regulatory frameworks: Facilitate the regulatory approval process for innovative bio-based products developed through projects like CHEERS, ensuring safety and sustainability while expediting market entry.
- International collaboration on circular bioeconomy: Advocate for international collaboration and knowledge sharing on best practices and standards for circular bio-based economies, leveraging the project's learnings and promoting its wider adoption.

The implementation of these policies, along with continued technology development and collaboration among key stakeholders, can help create a more sustainable and circular future for the biorefinery industry.

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