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ERA HDHL: ERA-NET Cofund in the field of nutrition and health

EVALUATOR'S ASSESSMENT OF THE FINAL REPORT OF *SYSTEMIC* PROJECT

JOINT CALL BETWEEN HDHL, OCEANS AND FACCE JPIs

Date of review: 31/01/2025

Timeline

Task / event	Due Date
Evaluators access to project reports	07.10.2024
Evaluators to prepare individual assessment reports	15.01.2025
Evaluator in charge to prepare assessment consensus report	31.01.2025
Consensus report approved by KH on FNS CSC	15.02.2025

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The ERA-HDHL Joint Funding Action 2019 launched a Knowledge Hub on Food and Nutrition Security which resulted in the funding of a transnational project called "SYSTEMIC" (Adaptative and mitigatory strategies to address climate change and malnutrition). This call was a joint action of the JPIs FACCE, OCEANS and HDHL.

Project title: *Adaptative and mitigatory strategies to address climate change and malnutrition*
Acronym: *SYSTEMIC*
Project coordinator: Habtamu Alen, Marco Bindi and Duarte Torres

Project duration: 48 months
Start date: July 01, 2020
End date: June 30, 2024

Reporting period: from July 01, 2020 to June 30, 2024.

1. Executive summary

The SYSTEMIC project was funded by the ERA-NET ERA-HDHL and supported by JPI HDHL, JPI Oceans, and FACCE-JPI. This transnational initiative lasted 48 months (1st of July 2020 to 30th of June, 2024) and involved 41 research groups from eight European countries, across various disciplines including agronomy, food science, environmental science, consumer behaviour and market dynamics, nutrition and public health. The project aimed to implement adaptive and mitigatory strategies to address climate change and malnutrition, by a food system approach. The project aligned with key Sustainable Development Goals, including zero hunger, good health, responsible consumption, and climate action.

The SYSTEMIC project has contributed significantly to research on food security, sustainable agriculture and effects of climate change, with outcomes including policy recommendations, peer reviewed publications and dissemination activities.

Key achievements of the project:

- **SYSTEMIC has fostered a transnational and multidisciplinary collaboration** for a holistic understanding and transfer of knowledge and technology: Researchers from eight countries and 41 research groups participated in the network, encouraging knowledge integration through regular meetings and workshops with stakeholders.
- **Understanding Climate Change Impacts on Food and Nutrition Security (FNS):** The SYSTEMIC project has contributed significantly to research on food security, sustainable agriculture and effects of climate change. The project highlighted the effects of climate change on crop yields, soil degradation, and aquaculture systems. It proposed the development of climate-resilient crops and the introduction of sustainable agricultural practices. It analysed the sustainability impact of different types of diets.
- **Developing Adaptive and Mitigation Strategies:** The project applied circular economy principles to food production and explored consumer acceptance of sustainable diets. It assessed European food policies and produced a white paper with actionable recommendations for policymakers. The SYSTEMIC project has proposed adaptive strategies to mitigate global climate change and malnutrition.

- **Fostering Transdisciplinary Collaboration:** The project built a network of researchers from eight countries, encouraging knowledge integration through regular meetings and workshops with stakeholders.
- **Promoting Policy and Societal Impact:** SYSTEMIC has identified gaps in impact assessments and sustainability considerations and produced a white paper with recommendations for policymakers at local, national and international levels.
- **Contribution to the Knowledge Hub on Food and Nutrition Security goals.** SYSTEMIC made a substantial contribution to the Knowledge Hub on Food and Nutrition Security goals. The project outcomes have been actively promoted through over seventy-five scientific publications and thirty-five conference presentations, webinars and open platforms, through engagement with stakeholders and through capacity building of Master and PhD students.
- **A solid groundwork** has been laid for further advancements and applications in sustainable food systems.

Despite these achievements, the project faced challenges such as limited region-specific adaptation strategies, practical implementation of proposed solutions, and early engagement with policymakers. Overall, the SYSTEMIC project significantly contributed to the objectives of the Knowledge Hub on Food and Nutrition Security, providing a strong foundation for future work in sustainable food systems.

2. Project's development

2.1 To what extent did the project contribute to the call objectives of the KH on FNS and how?

The SYSTEMIC project addressed food and nutrition security (FNS), a critical socioeconomic issue intensified by climate change. The SYSTEMIC project made significant achievements towards the objectives by developing strategies for a sustainable, resilient, and nutritious food supply. The project advanced the knowledge of climate change impacts on food systems. The project thus contributed to the call objectives of the Knowledge Hub on Food and Nutrition Security (KH on FNS) by addressing the global challenge of ensuring a sufficient and healthy food supply while minimizing environmental impacts.

The following includes a synthesis of the most relevant results in relation to the call Objectives:

Understanding Climate Change Impacts on FNS

The project underscored the significant impacts of climate change on various aspects of food production, including crop yields, soil health, and aquaculture systems. For instance, studies revealed that elevated levels of CO2 in the atmosphere led to a reduction in the micronutrient content. This reduction poses a heightened risk of nutrient deficiencies, particularly among vulnerable populations.

In response to these challenges, the project explored the potential of climate-resilient crops as a means to mitigate the adverse effects of climate change. Research within the project proposed strategies such as crop rotation and the development of stress-tolerant crop varieties. These strategies aim to address the yield losses that are often caused by changing precipitation patterns, thereby enhancing the resilience of food production systems to climate variability.

Developing Adaptive and Mitigation Strategies

The project proposed the development of sustainable diets that incorporate novel protein sources such as algae, insects, and cultured meat. This approach was supported by case studies that assessed consumer acceptance of these alternative protein sources. The studies found that insect-

based protein and algae-derived foods could serve as viable alternatives to traditional animal products, potentially reducing the environmental impact of food production.

Additionally, the project applied circular economy principles to food production. This involved integrating strategies in both aquaculture and agriculture to minimize waste and enhance resource use efficiency. For example, waste streams from aquaculture were repurposed as fertilizers in agricultural systems, demonstrating a practical application of circular economy concepts to improve sustainability in food production.

Fostering transnational and multidisciplinary collaboration and networking

SYSTEMIC built a strong network of researchers from 41 research groups in eight European countries, with the expertise from various scientific disciplines. The network organized regular meetings, including project management meetings, consortium board meetings and workpackage meetings. The majority of meetings were held digitally. In addition, they organized workshops with stakeholders, and webinars, courses, and summer schools. The SYSTEMIC network submitted 18 research proposals and three educational proposals. The consortium did not establish new collaborations during the period.

Managing the impact of climate change on FNS

SYSTEMIC emphasized the significant impact of climate change on crop production and addressed research gaps in impact assessments and sustainability considerations in the European food policies. The project constructed a climatic database representative of the national context (Italy) and assessed the impact of altered rainfall patters, availability of arable land due to desertification and rising sea levels. The project standardized environmental guidelines and promoted plant-based diets, Mediterranean modelled.

Proposing adaptive strategies and measures to ensure FNS

SYSTEMIC proposed adaptive strategies and measures to ensure FNS. For instance, SYSTEMIC established guidelines to mitigate risks in extensive fishing and aquaculture, proposed to replace ruminant meat with alternative protein-rich foods produced through low-energy, environmentally friendly processes, developed bioactive-rich food products and assessed biodiversity to create crops with high nutritional value. The project identified sensible target groups and defined criteria to develop balanced nutritious diets.

Promoting Policy and Societal Impact

In terms of promoting policy and societal impact, the project undertook a comprehensive assessment of European food policies, identifying critical gaps in sustainability and impact assessments. This effort culminated in the production of a white paper that provided actionable recommendations for policymakers, aimed at addressing these identified gaps and improving existing food and nutrition security (FNS) policies.

Innovating in Food Production and Consumption

The project also focused on innovating in food production and consumption by exploring the feasibility and sensory challenges associated with novel foods. Consumer behavior studies were conducted to understand the cultural and sensory barriers to the acceptance of algae-based and insect-based foods. These studies offered valuable insights and recommendations for improving consumer acceptance through targeted education and product development.

The main strengths and weaknesses of SYSTEMIC project were identified as follows:

Table of Strengths and Weaknesses

Aspect	Strengths	Weaknesses
Understanding Climate Impacts	Comprehensive analysis of climate risks to food systems.	Limited focus on region-specific adaptation strategies.
Adaptive and Mitigatory Strategies	Innovative proposals for sustainable diets and production systems.	Practical implementation and scalability of solutions not fully explored.
Transdisciplinary Collaboration	Strong engagement across multiple disciplines, fostering holistic approaches.	Challenges in effective integration of disciplines and data sharing across fields.
Policy and Societal Impact	Produced policy-focused outputs like a white paper and policy gap analysis.	Limited engagement with policymakers during early project phases.
Food Production and Consumption Innovation	Practical insights into novel foods, focusing on sustainability and consumer preferences.	A top-down approach to consumers' behavior. Focus on novel foods too narrow.

2.2 To what extent did the project achieve the desired goals and how?

The SYSTEMIC project made significant contributions to the objectives of the Knowledge Hub on Food and Nutrition Security (KH on FNS). It successfully advanced understanding of climate impacts on food systems, proposed innovative adaptive strategies, and fostered interdisciplinary research. These achievements laid a strong foundation for future work in developing sustainable food systems, despite certain challenges in policy adoption and practical implementation.

The project made significant achievements towards its goals, by developing strategies for creating a sustainable, resilient, and nutritious food supply that integrates both land and sea resources. The project underscored the significant impacts of climate change on aspects of food production, including crop yields, soil health, and aquaculture systems. The SYSTEMIC project developed a unified vision for an integrated food system that promotes sustainability across production, consumption, and public health.

SYSTEMIC also provided actionable solutions to address risks, e.g. SYSTEMIC developed dietary scenarios emphasizing plant-based protein alternatives to reduce environmental impact and emphasized the importance of agronomic research to support sustainable food production. Crop modelling studies provided insights into climate adaptation strategies. SYSTEMIC further proposed waste valorization strategies, to enhance sustainability across agricultural and aquaculture systems. The project investigated consumer behaviour and strategies to promote behavioural shifts toward sustainable consumption. SYSTEMIC provided valuable insights into policy frameworks, emphasizing the need to integrate sustainability metrics and promote climate-resilient food systems.

Goal 1: Understanding and Addressing Climate Risks

One of the project's key achievements was a comprehensive analysis of the impacts of climate change on food systems. The research particularly highlighted the vulnerabilities of aquaculture to rising ocean temperatures. In response to these risks, SYSTEMIC proposed adaptive strategies such as species diversification to enhance the resilience of aquaculture systems. By emphasizing adaptive measures, the project not only identified risks but also provided actionable solutions to address

them, contributing to a deeper understanding of how climate change affects both terrestrial and aquatic food production systems.

Goal 2: Promoting Sustainability

The project also made notable progress in promoting sustainability through its focus on food production, consumption, and environmental impact.

Sustainability in Food Production

The SYSTEMIC project explored the feasibility of integrating novel protein sources like algae, insects, and cultured meat into sustainable food systems. These alternatives were found to use fewer natural resources such as land and water and to produce lower greenhouse gas emissions compared to conventional livestock farming. Additionally, the project emphasized the importance of agronomic research to support sustainable food production. Crop modeling studies provided insights into climate adaptation strategies, such as optimizing planting schedules and introducing stress-tolerant crop varieties to enhance agricultural resilience under changing environmental conditions. The project also promoted agroecological practices, including biodiversity-friendly cropping systems and soil conservation techniques, which align with the broader goals of sustainable food systems.

Circular economy principles were also a key focus, with the project proposing waste valorization strategies, such as repurposing nutrient-rich aquaculture byproducts as fertilizers for agriculture. These approaches not only reduced resource dependency but also showcased practical applications of circular economy concepts to enhance sustainability across agricultural and aquaculture systems.

While these innovations demonstrated significant potential, the project faced challenges in translating some of these concepts into actionable solutions within its timeframe. Barriers such as scalability, affordability, and the need for region-specific implementation strategies highlighted the importance of further efforts to integrate agronomic research and sustainable innovations into broader food production systems.

Sustainability in Food Consumption

SYSTEMIC developed dietary scenarios that emphasized plant-based diets and alternative protein sources to reduce environmental impact while meeting nutritional needs. For instance, blending insect-based proteins into commonly consumed foods, such as burgers, was proposed to enhance their acceptance among consumers. Additionally, the project investigated consumer behavior to identify barriers, such as neophobia, sensory aversion, and cultural perceptions, which limit the adoption of novel foods. These findings informed strategies to promote behavioral shifts toward sustainable consumption. However, persistent resistance among certain consumer groups remained a significant challenge, particularly due to deeply rooted cultural biases and negative sensory expectations associated with novel foods like algae and insects.

Moreover, the project dedicated limited attention to addressing the affordability and accessibility of sustainable food options, making them less feasible for low-income populations. The focus was primarily on consumer acceptance rather than actively engaging with consumers to understand their specific dietary needs and economic constraints. Additionally, the top-down approach to promoting novel foods failed to account for the need for more participatory methods, which might have allowed consumers to co-create solutions and feel more invested in the transition to sustainable diets. These gaps highlighted areas that require further exploration and more inclusive strategies in future initiatives.

Environmental Impact and Ecosystem Health

The project assessed how sustainable production methods and dietary changes could reduce greenhouse gas emissions and mitigate climate change. For example, replacing a portion of red meat consumption with algae-based products demonstrated a significant potential to lower carbon footprints. Moreover, aquaculture studies emphasized preserving marine biodiversity through sustainable fishing practices and alternative feed sources. While SYSTEMIC aligned its work with global goals, such as SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), region-specific recommendations for ecosystem preservation could have added value to the project.

Goal 3: Advancing Policy Recommendations

SYSTEMIC partially achieved its goal of advancing policy recommendations. The project provided valuable insights into policy frameworks, emphasizing the need to integrate sustainability metrics and promote climate-resilient food systems. However, limited scalability of proposed solutions and delayed engagement with stakeholders are obstacles to an early integration of these findings into policy decisions. This underscored the importance of timely and robust collaboration between researchers and policymakers in future initiatives.

2.3 Were the different research disciplines involved in the consortium appropriate to achieve the desired goals?

The SYSTEMIC project successfully integrated a range of disciplines, each contributing to its overall objectives. The different research disciplines involved in the consortium were appropriate to achieve the desired goals. This project brought together experts in a range of different disciplines including agronomy, food science, environmental science, economic, consumer and market science, nutrition and public health. By integrating such diverse fields, SYSTEMIC achieved a comprehensive analysis of food and nutrition security (FNS) challenges.

Collaboration across eight European countries further enriched the research and expanded the project's reach and impact. By aligning with key Sustainable Development Goals specifically (2) zero hunger, (3) good health and well-being, (12) responsible consumption and production, (13) climate action, and (17) partnerships for the goals SYSTEMIC aimed to contribute significantly toward the creation of a sustainable and equitable global food system.

However, the final report and an analysis of the outputs show that disciplinary integration was a relatively secondary task compared to discipline-focused research, with discipline-focused research being more prominent compared to the disciplinary integration.

Agronomy and environmental science played a critical role in addressing production challenges and enabling climate adaptation. For instance, research on crop modelling provided valuable data to enhance agricultural resilience to climate stress, offering concrete solutions for mitigating the effects of environmental changes.

From a socio-economic perspective, the project explored consumer behaviour and market dynamics, ensuring that technology-oriented research addressed real-world applications and adoption barriers. By focusing on these socio-economic concerns, SYSTEMIC highlighted critical issues like consumer acceptance of novel foods and market feasibility for alternative proteins.

Food science and biotechnology made significant contributions by identifying innovative avenues for production systems and developing insights on alternative protein sources, such as algae, insects,

and cultured meat. These innovations aligned with the project's goals of promoting sustainable food systems. Public health experts examined the dietary impacts of proposed solutions to enhance nutrition security and address malnutrition.

3. Collaboration, coordination and mobility

3.1 How was the efficiency of the coordination and organization among the partners?

The SYSTEMIC project consisted of partners from eight European countries (Norway, Belgium, Germany, France, Spain, Portugal, Latvia and Italy). The project coordination and organization were very well structured. The project management team and work package (WP) leaders met every three months to ensure progress and alignment of activities. Additionally, the consortium board convened biannually to review milestones and assess deliverables. Leadership was shared across three institutions—the Norwegian Institute of Bioeconomy Research, the University of Florence, and the University of Porto—providing clear direction for the project. Governance was further supported by a Consortium Agreement that outlined structured guidelines for decision-making.

The efficiency of the coordination and organization among the partners was disrupted particularly in the early phase of the project, and some reorganisation of WP leaders was required, due to the COVID-19 pandemic, which ultimately led to a one-year extension of the project, with most research tasks and milestones diverging from the original plan. The project was affected by the COVID-19 pandemic, but adapted well using digital platforms like Zoom and Teams for coordination and communication. This reduced the interdisciplinary integration and mobility. Regular meetings both virtual and in person (when pandemic allowed) ensured continuous progress monitoring, management and alignment of activities among the partners. Despite disruptions caused by the COVID-19 pandemic, the project adapted seamlessly to remote work, utilizing digital platforms like Zoom and Teams to maintain coordination and communication. This adaptability ensured that progress across work packages remained consistent. However, the reliance on virtual meetings, especially early in the project, slowed interdisciplinary integration and reduced engagement among some partners. These challenges underscored the importance of physical interactions, which were limited during the pandemic.

However, the project adapted to the new way of working and progress across work packages remained consistent but with some delays, and in some cases, reduced engagement among some partners.

3.2 How was the quality of the transnational collaboration and its added value?

The SYSTEMIC project demonstrated high-quality transnational collaboration, involving researchers from eight European countries. Participants brought expertise from diverse fields including metrology, environmental chemistry, human health, food science, behavioural-economics and marine biology and ecology. By leveraging regional strengths—for instance, aquaculture research in Norway and crop modeling in Italy—the project addressed context-specific challenges while adopting a holistic approach to food system vulnerabilities under climate change. The collaboration between the different disciplines described in the application is highly unique and the consortium has the right combined set of expertise and skills to answer the research question(s) put forward in the application. SYSTEMIC project addressed national and context-specific challenges while adopting a holistic approach to food system vulnerabilities under climate change. This cross-cultural and interdisciplinary network generated comprehensive insights into food and nutrition security (FNS).

SYSTEMIC's involvement in related initiatives, such as the JPI-HDHL global conference, further amplified its impact by sharing findings and building on synergies with other projects. This collaborative framework ensured regional diversity and generated comprehensive insights into food and nutrition security (FNS). However, language and cultural differences occasionally slowed the collaborative process, and the lack of in-person interactions hindered informal knowledge exchange, which is often critical in transnational projects.

3.3 How was the mobility of the researchers among the partners?

The planned mobility, such as exchange visits, collaborative workshops, and hands-on training events, were negatively affected by the COVID-19 pandemic. The project mitigated the impact of reduced mobility by organizing virtual training sessions, workshops and stakeholder engagements via webinars. However, the informal networking and spontaneous collaboration opportunities were limited.

The planned mobility of researchers, in particular young researchers, among the partners was negatively impacted by the COVID-19 pandemic, and for a large part, was replaced with virtual interactions. Therefore there were less opportunities for these researchers to directly interact and gain on-site learning and network-building. Instead, a greater reliance on virtual training sessions and webinars was used.

4. Academic Impact

4.1 Will the publications, oral presentations, participation in conferences and other scientific dissemination activities reported produce knowledge and innovative solutions in the scientific area of the three JPIs?

The SYSTEMIC project made significant contributions to advancing academic understanding and fostering innovation in the fields aligned with the three JPIs (FACCE, HDHL, Oceans). The project outcomes include policy recommendations, peer reviewed publications and dissemination activities.

The project results achieved are impressive and have demonstrated excellence and high innovation potential. Dissemination and Communication activities are very good/excellent, with seventy-five peer-reviewed publications and thirty-five contributions at conferences having been reported. With over 75 peer-reviewed articles, the project focused on critical areas such as climate-resilient food systems, sustainable diets, and the development of novel proteins.

These publications provided valuable insights into addressing global food and nutrition security challenges while promoting sustainability. In addition policy recommendations have been disseminated. The findings offer valuable contributions to sustainable food production and long-term food and nutrition security solutions. Eighteen research projects (not all funded) and three educational projects (all funded) have been initiated.

The project's academic dissemination extended beyond publications, with active participation in 35 international conferences, including events organized by JPI-HDHL. These conferences served as platforms for sharing research findings, fostering collaboration among stakeholders, and amplifying the project's impact within the scientific community.

Moreover, SYSTEMIC introduced innovative tools and methodologies to assess sustainability trade-offs in food systems. The development of scenarios for sustainable food production and

consumption further exemplified its commitment to providing actionable solutions, ensuring that academic research translates into practical applications for real-world challenges.

5. Stakeholders/industry engagement

5.1 Involvement of stakeholders in the project (main groups: producers, agriculture and food industry and consumers, according to the call text)

The SYSTEMIC project engaged a diverse group of stakeholders, including producers, agricultural experts, food industries, and consumer groups, to ensure the practical applicability of its findings. Through targeted workshops and webinars, the project disseminated research outcomes and gathered valuable feedback. These sessions focused on key areas such as sustainable farming practices and the adoption of alternative protein products, fostering a collaborative environment for addressing food system challenges.

Farmers and agricultural producers were engaged through workshops, demonstrations and field visits.

Food industry stakeholders were engaged through industry conferences, direct outreach and collaboration networks, they participated in steering committees and were given opportunities to pilot new technologies in real-world settings.

Consumers were engaged through seminars, media-outreach, awareness-raising campaigns, and were actively participating in decision-making providing feedback during processes.

The research findings led to new industry collaborations and innovation.

5.2 Added value of stakeholders/industry participation / Impact on these groups?

For producers and the agricultural sector, the project provided insights into resource efficiency and waste valorization, which supported the transition to circular economy models. These findings emphasized strategies for minimizing waste while optimizing resource use, making farming systems more sustainable and economically viable.

The food industry benefited from SYSTEMIC's recommendations on integrating alternative proteins into their product lines. By focusing on consumer-friendly product development, the project added value to industrial innovation, enabling the food industry to meet evolving consumer demands for sustainable and nutritious food options. The SYSTEMIC recommendations provided the food industry with valuable insight into consumer behaviour and food choices in Europe which may evolve in response to climate change. Hence the industry can be more prepared for market shifts and adapting their food production and distribution systems towards more sustainable and nutritious food products.

Behavioral research conducted during the project offered actionable insights into reducing food neophobia and promoting sustainable consumption habits. By addressing cultural and sensory barriers, SYSTEMIC helped pave the way for broader acceptance of novel foods, such as algae and insect-based products, among consumers. In addition, a wider knowledge among consumers of alternative protein sources, including algae, cultured meat, and insects was achieved. In some cases, a top-down approach to consumers' acceptance has limited the possibility of exploring avenues for dietary change.

6. Policy Impact and valorisation

6.1 To what extent may the exploitable outcomes support the generation of standardisation and regulation?

The SYSTEMIC project identified significant regulatory gaps, particularly in the commercialization of novel foods such as insects and algae. These gaps posed challenges to the widespread adoption of sustainable food solutions. To address this, the project developed a white paper proposing frameworks to harmonize standards across Europe. These recommendations aimed to streamline regulatory processes and facilitate the entry of innovative food products into the market.

The SYSTEMIC project has contributed to research on climate change adaptation, food security, and sustainable agriculture, influencing academic discourse and future research directions. SYSTEMIC's evidence-based research has informed policymakers, encouraging the adoption of climate-smart agricultural policies at local, national, and international levels.

6.2 To what extent will the exploitable outcomes enable better-informed public policies?

SYSTEMIC provided substantial contributions to the development of better-informed policies and recommendations regarding sustainable diets, resource efficiency and climate-smart agriculture, at local, national and international levels. The project made substantial contributions to the development of better-informed policies by providing actionable recommendations focused on sustainable diets, resource efficiency, and climate-smart agriculture. By integrating these findings, policymakers were offered practical pathways to incorporate sustainability metrics into food system frameworks, ensuring that policies align with environmental and societal goals.

6.3 To what extent did the project valorised results from previous projects?

SYSTEMIC valorised results from previous projects and thereby maximized the impact of the prior research, and avoiding redundant research. For instance, SYSTEMIC initially aimed to study different *in vitro* models to study digestion. As the INFOGEST consortium had already addressed this, this task was cancelled.

Building on the findings of earlier initiatives, such as the NOURISHING database, SYSTEMIC assessed existing policy gaps and used these insights to develop evidence-based strategies. This approach ensured continuity and maximized the impact of prior research, enabling the project to build a strong foundation for its recommendations.

6.4 Evaluate the general dissemination and valorisation activities also with regard of future opportunities.

SYSTEMIC successfully implemented a multifaceted dissemination strategy, leveraging scientific publications, conferences, stakeholder events, and digital platforms to maximize the reach and impact of its research. Within the consortium, 75 peer-reviewed articles were published, and 35 conference presentations were delivered. The project website served as a central hub for dissemination activities, providing access to webinars and research updates. SYSTEMIC prioritized effective dissemination of its findings through various channels, including a dedicated project website, newsletters, and media outreach. These efforts ensured that the project's outputs reached a wide audience, including industry stakeholders, policymakers, and the public.

Looking ahead, SYSTEMIC highlighted potential opportunities for innovation and commercial applications in sustainable food systems. Additionally, ongoing engagement with policymakers was emphasized as crucial to translating research findings into actionable legislation.

7. Impact on Public health and environment

7.1 To what extent do you anticipate the exploitable outcomes to improve the environment (land, air, water ecosystems)?

The SYSTEMIC project has provided information on environmentally sustainable agricultural practices of food production, including focusing on alternative proteins, such as insects and algae. The project actively promoted sustainable agricultural practices to reduce the environmental footprint of food production. This included advocating for the adoption of alternative proteins, such as insects and algae, which offer significant environmental advantages. Compared to traditional animal farming, these proteins require fewer natural resources like water and land and produce lower greenhouse gas emissions.

Additionally, the project focused on aquaculture innovations, which were specifically designed to protect marine ecosystems and enhance biodiversity. These efforts collectively aimed to create food systems that are both environmentally sustainable and resilient to climate change.

7.2 To what extent will the exploitable outcomes create benefits for public health, safety and/or quality of life?

The SYSTEMIC project has provided recommendations for balanced and sustainable dietary patterns. This project has delivered nutritional information and new guidelines for nutritious sustainable food production.

The project emphasized the importance of public health by encouraging the integration of nutrient-rich alternative proteins into diets. Through its recommendations for balanced and sustainable dietary patterns, SYSTEMIC aimed to address major health challenges, including the prevalence of non-communicable diseases like obesity and malnutrition. By aligning environmental and health objectives, the project provided actionable strategies for improving quality of life while promoting food system sustainability.

A white paper has been developed which outlines socioeconomic aspects of FNS, crop models and climate data, leading to policy recommendations for improving food system resilience, and sustainability and incorporating climate policies into a broader framework.

8. Perceived Gaps

Identify perceived gaps and weaknesses in SYSTEMIC and how they might be addressed in future by the JPIs FACCE, HDHL and Oceans programmes or HEU partnerships.

The SYSTEMIC project has delivered significant contributions to advancing sustainable food systems, with impressive results spanning multiple disciplines. It successfully addressed critical challenges in climate adaptation, sustainability, and innovation by integrating novel protein sources, promoting circular economy principles, and fostering interdisciplinary collaboration. However, these achievements also reveal areas of untapped potential, paving the way for further research to build upon the project's successes.

One of SYSTEMIC's key strengths lies in its use of crop modeling to explore climate adaptation strategies, offering actionable solutions such as optimizing planting schedules and developing stress-tolerant crop varieties. While these advances can strengthen agricultural resilience, the project opened opportunities to further leverage advanced data science tools like artificial intelligence and machine learning. These technologies could provide deeper insights into complex food system interactions and support more precise regional analyses.

The project also made significant steps in economic sustainability by exploring cost-efficient alternatives. Yet, the economic feasibility of scaling these solutions remains underexplored. Future research could expand on SYSTEMIC's findings by conducting cost assessment.

On the socio-cultural front, SYSTEMIC made valuable contributions by addressing consumer resistance to novel foods and sustainable diets, identifying barriers such as food neophobia and sensory preferences. This work has laid a solid foundation for understanding consumer behaviour, but it also highlights the need for deeper engagement with cultural, religious, and social dynamics that influence dietary choices. Participatory approaches involving local communities could further enhance the co-creation of solutions, ensuring greater acceptance and adoption.

The project's focus on sustainable diets represents a significant achievement in aligning public health and environmental goals. Its promotion of nutrient-rich alternative proteins and balanced diets provides a roadmap for tackling malnutrition and reducing non-communicable diseases. However, the long-term health implications of transitioning to alternative proteins and plant-based diets remain an area for future research, particularly for vulnerable populations such as children and the elderly. Investigating potential health risks, like allergenicity or contamination in novel foods, could further ensure the safety and nutritional adequacy of these dietary shifts.

SYSTEMIC's environmental innovations, including aquaculture practices designed to protect biodiversity, were another highlight of the project. These efforts underscore the potential for sustainable production systems to mitigate climate change. However, scaling these solutions could present new challenges, such as balancing resource efficiency with ecosystem health. Exploring these trade-offs more comprehensively would deepen the environmental impact of future initiatives.

Regional adaptation strategies were a key area of focus in SYSTEMIC, yet the project's findings often generalized recommendations across diverse contexts. Tailoring these strategies to address the unique socio-economic and environmental realities of specific regions—particularly those disproportionately affected by climate change—offers a promising avenue for future work.

The project's behavioral insights also open doors for further exploration. SYSTEMIC's identification of barriers to sustainable consumption can serve as a starting point for studying long-term behavioral shifts and the impact of interventions such as nudging techniques.

The SYSTEMIC project has made remarkable progress in reimagining sustainable food systems, and its critical points serve as a springboard for future research. By building on its achievements and exploring these untapped areas, subsequent initiatives can continue to drive innovation, resilience, and equity in addressing global food and nutrition security challenges.

A stronger and more active engagement of food industry and consumers could enhance the co-creation of solutions, understanding dietary needs and economic constraints and thus ensuring a stronger acceptance and adoption.

Alternative, sustainable protein sources have been investigated, however also increased food resource utilization/side streams-utilization could have been addressed as a sustainable approach. This could however, be an area for future research.

A stronger inclusion/engagement of students could have strengthened the reach and impact and enhanced the continuation of transnational and interdisciplinary mindset, educating candidates highly employable.

9. Recommendations for Future Initiatives

A threat to future FNS is the significant amounts of food and nutrients that are lost along the value chains. Lost and underutilized food resources also negatively impact environmental, economic and social sustainability. Expanding the scope will require collaboration with new partners, disciplines, institutions and countries. One relevant aspect to address is the advanced technological competence needed to ensure utilization of our food resources. In order to address this, interdisciplinary collaboration is crucial, co-creating to find solutions to ensure this future oriented competence.

SYSTEMIC's success in fostering interdisciplinary collaboration has demonstrated the value of integrating multiple disciplines to tackle food system challenges. Strengthening these connections even further, particularly by incorporating advanced data science and exploring cross-sectoral synergies (e.g., water management and energy use), could yield transformative systems-level solutions.

To address the gaps identified in the SYSTEMIC project, several targeted actions can enhance its impact while building on its successes. Building local multidisciplinary groups, with the purpose of producing multidisciplinary scientific outputs, is crucial to advance systemic approaches. Early engagement with users is crucial to increase awareness of the specificities of the contexts and to address problems from different angles. Engagement of policymakers is crucial to ensure findings are integrated into regulatory frameworks.

Consumer resistance to sustainable diets can be addressed through participatory approaches such as focus groups and co-creation workshops. Improving the sensory appeal of alternative proteins and tailoring messaging to different demographics will further enhance acceptance.

Affordability and accessibility of sustainable food options should be prioritized by exploring cost-reduction strategies, scaling production technologies, and introducing subsidies or community-based programs for low-income populations. Region-specific analyses and tailored strategies can address the unique socio-economic and environmental realities of vulnerable areas, ensuring locally relevant solutions.

Researcher mobility and interdisciplinary collaboration can be strengthened through hybrid exchanges and long-term internships, fostering deeper connections and knowledge sharing. Piloting circular economy models, such as using aquaculture byproducts as fertilizers, and creating practical guidelines for stakeholders will enhance the applicability of circular solutions.

Improved communication is key to broader impact. Accessible dissemination, such as videos and infographics, alongside deeper collaboration with industry, can bring findings to non-academic audiences. Long-term studies on environmental and health impacts of alternative proteins, including risk assessments, will ensure scalability and safety.

By addressing these gaps, future initiatives can expand SYSTEMIC's legacy, delivering more inclusive and transformative solutions for global food security and sustainability.