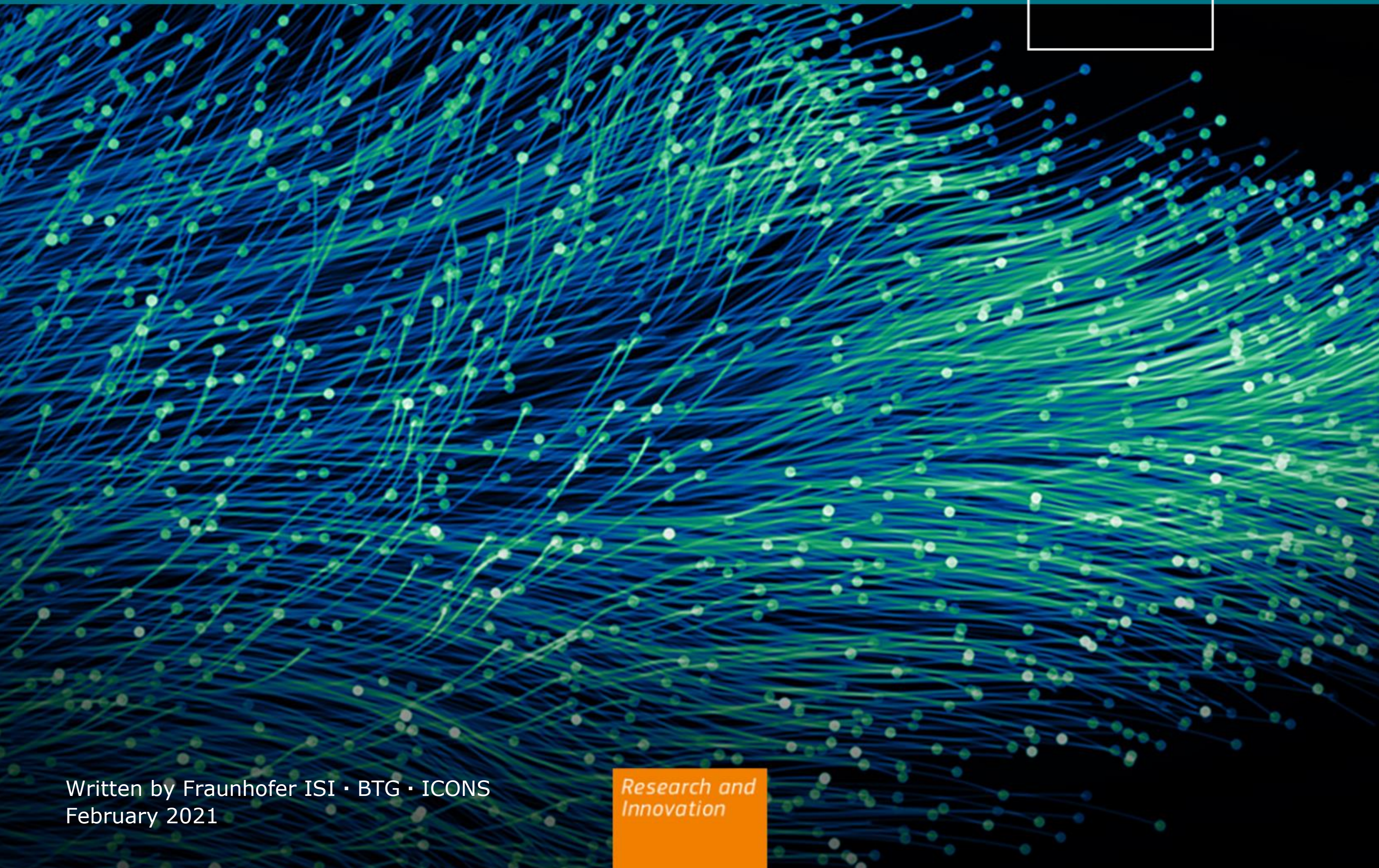
European Commission

Life and biological sciences and technologies as engines for bio-based innovation

Studies on support to research and innovation policy in the area of bio-based products and services

Independent Expert Report



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Research and Innovation

Life and biological sciences and technologies as engines for bio-based innovation (Lot 2)

Studies on support to research and innovation policy in the area of bio-based products and services

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Life and biological sciences and technologies as engines for bio-based innovation

Studies on support to research and innovation in the area of bio-based products and services

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ABSTRACT

Life and biological sciences and technologies are enablers for bio-based innovations that bear the potential to use natural resources sustainably, by reducing dependence on fossil fuels, by protecting the environment and climate, ensuring food security, and maintaining international competitiveness. This study presents the 50 most significant bio-based innovations for the next 5-20 years. The portfolio of top 50 bio-based innovations covers on the one hand cross-cutting technologies and approaches, enabling many different applications, on the other hand innovation areas or solutions to challenges, which may be enabled by different technologies or approaches. Together with a policy and innovation ecosystem analysis and four bio-based innovation scenarios for Europe in 2030, the study provides strategic knowledge for policy makers, innovation stakeholders and society. It reveals that in order to fully exploit the potential of bio-based innovations stakeholders have to implement strategic approaches and various actions. Potential measures are ranging from further support of Research & Development, to knowledge transfer and collaboration, demand-oriented measures as well as to strive for higher coherence between different regions in the European Union.

RÉSUMÉ

Les sciences de la vie et biologiques ainsi que les technologies sont les principaux moteurs pour les innovations bio-basées. Ils ont le potentiel d'utiliser les ressources naturelles de manière durable, en réduisant la dépendance des combustibles fossiles, en protégeant l'environnement et le climat, en garantissant la sécurité alimentaire et en maintenant la compétitivité internationale. Cette étude présente les 50 innovations bio-basées est plus significatives pour les 5 à 20 années à venir. Le portefeuille des 50 meilleures innovations bio-basées couvre d'une part les technologies et approches transversales, permettant de nombreuses applications différentes, d'autre part les domaines d'innovation ou les solutions aux défis. Associée à une analyse de l'écosystème des politiques et de l'innovation et à quatre scénarios d'innovation biologique pour l'Europe en 2030, cette étude fournit des connaissances stratégiques aux responsables politiques, aux acteurs de l'innovation bio-basée et à la société. Pour exploiter le potentiel des innovations bio-basées, pleinement, il faut que les acteurs misent en œuvre des approches stratégiques et des actions différentes comme par exemple un soutien à la recherche et au développement, le transfert de connaissances et la collaboration, et les mesures axées sur la demande pendant que visant d'une plus grande cohérence entre les régions différentes de l'Union européenne.

EXECUTIVE SUMMARY

Introduction

Life and biological sciences and technologies are among the key drivers and enablers for bio-based innovations. They bear the potential to use natural resources sustainably, by reducing dependence on fossil fuels, by protecting the environment and climate, ensuring food security, and maintaining international competitiveness.

This study presents - in a forward-looking perspective for the next 5-20 years – the 50 most significant bio-based innovations, driven by advances in life and biological sciences and technologies, and the use of these technologies to produce bio-based products and services. Together with a policy and innovation ecosystem analysis and four bio-based innovation scenarios for Europe in 2030, this study provides strategic knowledge for policy makers, innovation stakeholders and society. It points out the potential and opportunities of the life and biological sciences and technologies as main enabler of bio-based innovation, and of how to overcome hurdles to realize their potential. This knowledge will enable informed decisions regarding further strategic R&I activities to boost the potential of bio-based innovation.

The results build on a thorough and comprehensive understanding of the latest knowledge and data in the scientific literature, foresight studies, strategic documents and roadmaps, and from analysing EU-funded projects as well as patent and publication indicators. It has been refined and validated by expert interviews, an EU-wide online expert survey and three stakeholder workshops.

Portfolio of top 50 bio-based innovations

The portfolio of top 50 bio-based innovations (Table 1) covers on the one hand cross-cutting technologies and approaches, enabling many different applications, on the other hand innovation areas or solutions to challenges, which may be enabled by different technologies or approaches.

The cross-cutting technologies comprise analytical techniques, which are used to probe biological systems and deepen our understanding of their components and functions, as well as tools to engineer these biological systems on demand for desired functions. A major innovation push is expected from the convergence with digital technologies. They are indispensable for analysing and interpreting the vast amount of biological data generated by modern analytical techniques, by complementing and enhancing the established "wet lab" approaches with in silico modelling, and by supporting the digitalisation of the bio-based industry. From a forward-looking perspective, it is required to complement the presently dominating bio-based production paradigms which rely heavily on organic molecules (e.g. sugars) as carbon and energy source by novel concepts which use e.g. greenhouse gases or waste as carbon and sunlight or green electricity as energy sources. Moreover, cross-cutting approaches for scale-up of bio-based processes to industrial scale are currently developed.

The innovation areas or solutions to challenges, which may be enabled by different technologies or approaches, reflect a value-chain perspective, comprising feedstock provision, industrial bioprocessing, and several product groups and applications. However, traditional bio-based applications and products, such as food and feed, pulp and paper, wood were excluded from this study, as well as biomass as energy source, advanced therapies and biopharmaceuticals.

Innovations enabling efficient and sustainable land- and aquatic-based primary production, industrial production with minimised environmental impact as well as bio-based and sustainable products are at the core of the innovation areas: innovations have been chosen for their potential to significantly contribute to reducing and valorising waste, to a more sustainable agri- and aquaculture, to mitigating climate change, to monitor and prevent loss of biodiversity, to remediate environmental pollution, to establishing a circular bioeconomy and to improve citizens' quality of life. With respect to well-being and health, innovations are included in the portfolio, which provide alternatives to disease treatment by preventing disease and maintaining health, and by combatting the emergence of multi-resistant pathogens.

Table 1. Portfolio of top 50 bio-based innovations

Cross-cutting technologies or approaches, enabling many different applications						
Subfield	Analytical techniques and bioprospecting		Design and engineering of biomolecules for desired functions		Design and engineering of biological systems, cell factories; synthetic biology	
Innovation	1	Screening biodiversity	6	Macromolecular design	9	Precision genome editing
	2	-omics technologies	7	Multi-enzyme biocatalysis	10	Synthesis and assembly of long DNA fragments
	3	Analysing microbial consortia	8	New enzymes	11	Modular cloning systems
	4	Lab-on-a-chip			12	Minimal cells
	5	Biosensing			13	Expansion of the genetic code
Subfield	Digital technologies		Novel industrial production concepts		Enabling bio-based production at industrial scale	
Innovation	14	FAIR principle for databases	19	Novel microbial cell factories	22	Optimising biorefineries
	15	Deep Learning	20	Engineering microbial consortia and biofilms	23	Biorefineries for new feedstocks
	16	Computational protein design	21	Microbial electrosynthesis	24	Reactor design and process monitoring
	17	Computational cell factory engineering			25	Cell heterogeneity
	18	Process models			26	Stress-tolerant production organisms

Innovation areas or solutions to challenges, which may be enabled by different technologies or approaches						
Subfield	Sustainable exploitation of novel feedstocks		Efficient and sustainable industrial production and products with minimised environmental impact		Bio-based intermediates, materials and product groups	
Innovation	27	Novel feedstock	30	Resource- and energy efficient bioprocesses	36	Smart drop-ins
	28	Using side and waste streams	31	Carbon-neutral bioprocesses	37	Dedicated bio-based chemicals
	29	Supply and pretreatment of novel feedstock	32	CO_2-based chemicals	38	Bio-based materials
			33	Climate-gas mitigation of microbial activities	39	Bio-functional materials
			34	Biodegradable plastics	40	Novel algae products
			35	Plastic degrading enzymes		
Subfield	Contributions to sustainable agriculture		Health and well-being			
Innovation	41	Crop improvement targeting genome and epigenome	47	Health-promoting ingredients		
	42	de novo domestication	48	Novel antimicrobial agents		
	43	Asexual reproduction of seeds	49	Probiotic sanitation strategies		
	44	Increasing and maintaining soil fertility	50	Veterinary DNA vaccines		
	45	Novel farming concepts				
	46	Novel protein sources				

Regarding the likely timeline of the top 50 bio-based innovations, they were allocated to the maturity levels of mainly basic, lab scale research (3 innovations in 2020), application-oriented Research and Development (R&D) up to pilot scale (20 innovations in 2020), scale-up and demonstration (21 innovations in 2020) and fully implemented, ready for market introduction (6 innovations in 2020). Nearly all innovations will develop in a way that they will reach a higher maturity level by 2030. Twenty of the top 50 bio-based innovations are expected to experience a highly dynamic development, i.e. leapfrogging over two maturity levels. However, only relatively few innovations are expected to reach broad use, the highest maturity level in this study, by 2030. This highlights the need to not only focus on R&D, but also create markets and implement demand-side support measures for innovations to enhance their broad use.

Most of the top 50 bio-based innovations fall into one of the following three categories of relevance: (1) Innovations which are of high relevance in 2020, and will remain highly relevant also in the next decade (18 innovations), (2) Innovations which are of medium relevance in 2020, but will become highly relevant by 2030 (20 innovations), and (3) Innovations which are of medium relevance in 2020 and remain so in 2030 (9 innovations).

The top 50 bio-based innovations are expected to deliver positive impacts for expanding the knowledge base, for the economy, the environment and for society. They also contribute to the UN Sustainable Development Goals (SDGs) which must be achieved by 2030. 80% of the top 50 bio-based innovations contribute to SDG 9 Industry, innovation and infrastructure. Moreover, many of the top 50 bio-based innovations contribute to SDG 12 responsible consumption and production and SDG 13 climate action, which are regarded of particular importance in EU strategies linked to the European Green Deal.

Policy mapping and assessment

Main European initiatives and strategies such as the European Green Deal, the Circular Economy Action Plan, EU Industrial Strategy, provide a challenge-based overall perspective to combat climate change and to move toward a circular economy. Life and biological sciences and technologies as engines for bio-based innovation are addressed in the updated EU Bioeconomy Strategy, and more in detail in Horizon Europe – the new EU research and innovation framework programme, and play a pivotal role in broad lines of cluster "Food, Bioeconomy, Natural Resources, Agriculture and Environment".

Horizon 2020 has provided substantial funding for development of the top 50 bio-based innovations. A selection of 111 Horizon 2020-projects that have a direct link to the top 50 bio-based innovations has contributed 544 million Euro, of which 256 million Euro (47%) was used for Research and Development (TRL 1-5), 182 million Euro (33%) for demonstration scale research (TRL 6-7) and 106 million Euro (19%) to Flagships (TRL 8)[1]. It is expected that new EU funding programmes such as Horizon Europe and the new European Circular Bioeconomy Fund will continue the trend of supporting companies to overcome the valley of death of innovations toward commercialisation. This trend is in general welcomed by the private sector. Academia point out that the whole framework or challenge-based innovation should not result in financing only application-driven innovations that can be commercialised by 2030. NGOs stress the relevance of taking into account the ecological boundaries of the bioeconomy.

At national level, 11 Member States have a bioeconomy strategy, but only six of them have also an action plan with concrete measures, even though action plans are regarded as the key resource for effective strategy execution. Five countries have a separate bioscience related policy. There is still a lack of coherent, detailed and realistic bioeconomy strategies, especially in the Central and Eastern European (CEE) countries. This is also reflected in the budget distribution of the EU contribution of the analysed H2020-funded projects: Countries with a high level of EU biotechnology funding per capita have a bioeconomy strategy (Ireland, Netherlands) or a separate bioscience related policy (Denmark) in place. Regarding the differences between regions, based on the assessment of 111 H2020 projects with a direct link to the top 50 bio-based innovations Western European countries dominate the EU contribution allocation at all TRL levels, and that the CEE countries only receive 7% of the available EU contribution, of which 59% is part of a few big Flagship projects.

The EU Bioeconomy Strategy and its Action Plan lays great emphasis on the circular character of the bioeconomy. Application-driven bio-based innovations contribute to several circular economy targets, such as resource efficiency and use of waste, supply of green carbon to the economy, greenhouse gas savings.

[1] Technology readiness levels (TRL), Commission Decision C(2014)4995

Innovation ecosystem in the EU-27: Status quo and future outlook

According to expert assessments, online survey and patent analysis, the EU-27 is highly competitive in exploiting bio-based innovations. The EU is leading in environmentally beneficial or sustainable solutions, as well as in non-food feedstock, bioprocess engineering and bio-based products in general. By contrast, the EU is rather lagging behind other world regions in innovations related to digital technologies, genome editing or synthetic biology.

Moreover, the commercialization of bio-based innovations in the EU-27 remains challenging. Growth of SMEs and scale-up of production is often hampered by limited financial resources. Various and diverse regulations (e.g. technical regulations, missing environmental standards) restrict the exploitation of bio-based innovations, e.g. valorisation of bio-waste, genome editing, or commercialising bio-based products. Still, the EU-27 possesses high competencies and capabilities in various sectors and has made progress to establish integrated bio-based value chains across Europe.

To summarize, the EU-27 shows strengths, but also weaknesses. Moreover, there are external factors that favour or hinder bio-based innovation and commercialisation in the EU-27 and thus pose opportunities and threats. A SWOT analysis contains these factors (Figure 1).

STRENGTHS

Relevant knowledge base and skills

Strong actor orientation towards sustainability

Strong clustering (both on national and international level)

WEAKNESSES

Trans- and interdisciplinarity of research

Financing start-up initiation and growth of SMEs

Inclusion of the entire value chain

Scattered demand-side measures for market creation

Lack of integration of Central and Eastern European countries in innovation activities and networks

OPPORTUNITIES

Positioning within circular economy

Availability of diverse feedstock streams

Explosive growth of digitalisation, automation, and AI

Increased involvement of distant industries into new VCs.

THREATS

Restricting regulations

Negative public perception

Figure 1. SWOT analysis for the EU-27 for bio-based innovations

Taking a forward-looking perspective, four scenarios for bio-based innovations in the EU-27 for 2030 were developed. They are based on the key influencing factors technology, policy, cooperation, societal attitude towards sustainability and the role of different actors in the actor landscape. The scenarios reveal that broader geopolitical and societal trends will significantly affect the future development paths for bio-based innovations:

Cooperation and competition between different EU Member States and between the EU and other world regions as well as the societal attitude towards sustainability may have a strong impact on bio-based innovations. They will partly influence the type of policies for bio-based innovations and actions of stakeholders. This may lead e.g. to different future paths. One scenario, for example, illustrates an intensified global competition in high-tech fields, an alternative scenario is strongly sustainability-oriented in which bio-based innovations can significantly contribute, but at the same time have to prove superiority over other solutions to environmental challenges. Another scenario starts from a difficult economic situation, e.g., caused by the Covid 19-pandemic, with a focus on short-term economic recovery. In this scenario, more support is given to traditional industries whereas high-tech fields, such as bio-based innovations, hardly get attention.

The scenarios demonstrate that depending on the framework conditions and dynamics of the field, some of the top 50 bio-based innovations may gain more importance than others. This implies for current policy-making that there is no a-prio list of top 50 bio-based innovations that is more favourable to foster for exploitation and commercialization than another. Rather, the specific, tailored choice of the most promising innovations from the portfolio of the top 50 bio-based innovations depends on the (political, economic, social) context and the prioritized policy goals.

Conclusions and recommendations

This study presents a portfolio of 50 bio-based innovations, enabled by advances in life and biological sciences and technologies. The portfolio of top 50 bio-based innovations represents important developments and innovation needs and is of major importance for a successful transition towards sustainable bio-based sectors and for achieving impacts in SDGs. To fully exploit their potential the following actions should be taken (see also table 2):

Decision-makers in the European Commission, Member States and regional policy makers are encouraged to further develop strategic approaches to science, technology and innovation to address societal goals. They may set up specific strategies, if they do not exist yet, or translate existing ones in concrete tailor-made action plans. The information presented in this report is intended to be used as information base for such activities. Decision-makers are encouraged to pay specific attention is paid to sustainability supporting innovations, digital technologies as well as to the controversial issue of the use of New Genomic Techniques. However, the concrete selection of innovations that are in the focus of policies should rely on the respective capacities and goals of the EU and Member States.

Generally, innovation policies increasingly focus on solutions to grand challenges and mission-oriented support measures whereas this study started from a science and technology-oriented perspective. Therefore, a good balance should be found between actively supporting the integration of biological sciences and technologies expertise into application-oriented communities on the one hand, and maintaining critical mass in (non-application-oriented) biological sciences and technologies expertise on the other hand. Technology roadmaps are recommended as means to support orientation of bio-based sectors towards coherent long-term technology developments and goals.

In order to increase and speed up commercialisation of bio-based innovations, coherent support for financing and cooperation and market uptake would be needed. Cooperation and interdisciplinary research in life and biological sciences and technologies has already been in the focus of R&D&I policy for many years. However, challenges in the bio-based sectors, such as the transition to a circular bioeconomy and use of novel feedstocks require the active initiation and continuous support of new types of cooperation and the complementation of interdisciplinary R&D by transdisciplinary approaches. Specific attention should be paid to intensify the interaction between providers of various novel feedstocks (e.g. waste, CO_2, feedstocks of marine origin) and converters and the collaboration between core bio-based and more distant sectors (e.g. community waste treatment). Clusters on regional, national and supranational level could be platforms for productive interaction of the respective stakeholder groups and for swift knowledge transfer. If action plans and roadmaps spell out concrete quantitative targets, e.g. concerning costs, profits, emission targets, this will attract actors from more distant industries, who are not interested in bio-based innovations in the first place, but in implementing promising solutions.

Next to better cooperation along the value chain and between industrial sectors, further harmonisation of Member State policies could support the full exploitation of the potential of bio-based innovations in the EU. Although the Central and Eastern European (CEE) countries have made substantial progress in the development of their bio-based sectors over the past decade, they are still lagging behind Western European countries in terms of uptake of, contribution to and benefiting from bio-based innovations. Urgently required and promising steps have already been taken to increase inclusiveness and to reduce geographical imbalances. These efforts need to be at least maintained, increasing them should be considered. Related policies could comprise different actions, e.g. increased funding for establishing or upgrading technologies, infrastructures and clusters in CEE countries. In order to achieve higher value added in the CEE countries themselves, e.g. by valorisation of locally produced biomass, striving for the establishment of value chains at local, regional or national level in these countries is a promising goal. Moreover, in rather all Member States and at EU level, better integration of bioeconomy policies with other related policies (e.g. renewable energy policy, bio-waste regulation) is needed. At the same time there is a need of international coordination of bioeconomy strategies between EU member states and action plans to fully exploit the potential of bio-based innovations.

Table 2. Recommendations

Strategic approach to bioeconomy	**Bio-based innovations as starting point**	**Areas of specific innovation focus**	**Clusters, knowledge transfer and collaboration**	**Commercialization and market uptake of bio-based innovations**	**Striving for higher European coherence and cooperation**
Take a strategic approach to bioeconomy	Transform the "default" portfolio of top50 bio-based innovations into tailor-made actions plans and roadmaps	Maintain the leading position in sustainability and a circular bioeconomy	Foster cross-industry collaborations	Finance growth of SMEs and other actors	Continue and intensify actions to achieve higher European coherence and reduce geographical imbalances
	Balance technology-focussed and mission-oriented programmes	Promote digitalisation, automation, and AI	Foster transdiscipli-narity and co-creation/co-innovation processes	Implement demand-side incentives for market creation	Ensure international coordination of strategies, actions and framework conditions in the bioeconomy
		Elaborate a strategy on use of New Genomic Techniques	Foster bioeconomy clusters on regional, national and supranational levels		

NOTE DE SYNTHÈSE

Introduction

Les sciences de la vie et biologiques ainsi que les technologies comptent parmi les principaux moteurs et catalyseurs des innovations bio-basées. Ils ont le potentiel d'utiliser les ressources naturelles de manière durable, en réduisant la dépendance aux combustibles fossiles, en protégeant l'environnement et le climat, en garantissant la sécurité alimentaire et en maintenant la compétitivité internationale.

Cette étude présente - dans une perspective prospective pour les 5 à 20 années à venir - les 50 innovations bio-basées es plus significatives, portées par le progrès des sciences et technologies de la vie et biologiques, et l'utilisation de ces technologies pour produire des biens et des services. Associée à une analyse de l'écosystème des politiques et de l'innovation et à quatre scénarios d'innovation biologique pour l'Europe en 2030, cette étude fournit des connaissances stratégiques aux responsables politiques, aux acteurs de l'innovation bio-basée et à la société. Il souligne le potentiel et les opportunités des sciences et technologies de la vie et biologiques en tant que principal catalyseur de l'innovation bio-basée, et comment surmonter les obstacles pour réaliser leur potentiel. Ces connaissances permettront de prendre des décisions éclairées concernant d'autres activités stratégiques pour accroître le potentiel de l'innovation biologique.

Les résultats s'appuient sur une compréhension approfondie et complète des dernières connaissances et données de la littérature scientifique, des études prospectives, des documents stratégiques et des feuilles de route, et de l'analyse des projets financés par l'UE ainsi que des indicateurs de brevets et de publications. Il a été affiné et validé par des entretiens d'experts, une enquête d'experts en ligne à l'échelle de l'UE et trois ateliers de parties prenantes.

Portefeuille des 50 meilleures innovations bio-basées

Le portefeuille des 50 meilleures innovations bio-basées (tableau 1) couvre d'une part les technologies et approches transversales, permettant de nombreuses applications différentes, d'autre part les domaines d'innovation ou les solutions aux défis, qui peuvent être rendues possibles par différentes technologies ou approches.

Les technologies transversales comprennent des techniques analytiques, qui sont utilisées pour sonder les systèmes biologiques et approfondir notre compréhension de leurs composants et fonctions, ainsi que des outils pour concevoir ces systèmes biologiques à la demande pour les fonctions souhaitées. Une poussée d'innovation majeure est attendue de la convergence avec les technologies numériques. Ils sont indispensables pour analyser et interpréter la grande quantité de données biologiques générées par les techniques analytiques modernes, en complétant et en améliorant les approches «wet lab» établies avec la modélisation in silico, et en soutenant la numérisation de la bio-industrie. Dans une perspective prospective, il est nécessaire de compléter les paradigmes de bioproduction actuellement dominants qui reposent fortement sur des molécules organiques (par exemple les sucres) comme source de carbone et d'énergie par de nouveaux concepts qui utilisent par ex. les gaz à effet de serre ou les déchets comme carbone et le soleil ou l'électricité verte comme sources d'énergie. En outre, des approches transversales pour l'extension des bioprocédés à l'échelle industrielle sont actuellement développées.

Les domaines d'innovation bio-basée ou les solutions aux défis, qui peuvent être rendus possibles par différentes technologies ou approches, reflètent une perspective de chaîne de valeur, comprenant la fourniture de matières premières, le biotraitement industriel et plusieurs groupes de produits et applications. Cependant, les applications et produits biosourcés traditionnels, tels que les denrées alimentaires et les aliments pour animaux, les pâtes et papiers, le bois ont été exclus de cette étude, ainsi que la biomasse comme source d'énergie, les thérapies avancées et les produits biopharmaceutiques.

Les innovations bio-basées permettant une production primaire terrestre et aquatique efficace et durable, la production industrielle à impact environnemental minimisé ainsi que les produits biobasées et durables sont au cœur des domaines d'innovation: les innovations ont été choisies pour leur potentiel à contribuer de manière significative à la réduction et valoriser les déchets, pour une agriculture et une aquaculture plus durables, pour atténuer le changement climatique, pour surveiller et prévenir la perte de biodiversité, pour remédier à la pollution de l'environnement, pour établir une bioéconomie circulaire et pour améliorer la qualité de vie des citoyens. En matière de bien-être et de santé, des innovations bio-basées sont incluses dans le portefeuille, qui offrent des alternatives au traitement des maladies en prévenant la maladie et en maintenant la santé, et en luttant contre l'émergence de pathogènes multi-résistants.

Table 1 – Portefeuille des 50 meilleures innovations bio-basées

Technologies ou approches transversales, permettant de nombreuses applications différentess						
Sous-champ	Techniques analytiques et bioprospection		Conception et ingénierie de biomolécules pour les fonctions souhaitées		Conception et ingénierie de systèmes biologiques, usines de cellules; la biologie de synthèse	
Innovation	1	Criblage de la biodiversité	6	Conception macromoléculaire	9	Édition précise du génome
	2	-omics technologies	7	Biocatalyse multi-enzymes	10	Synthèse et assemblage de longs fragments d'ADN
	3	Analyse des consortiums microbiens	8	Nouvelles enzymes	11	Systèmes de clonage modulaires
	4	Lab-on-a-chip			12	Cellules minimales
	5	Détection biologique			13	Expansion du code génétique
Sous-champ	Technologies numériques		Nouveaux concepts de production industrielle		Permettre la production biosourcée à l'échelle industrielle	
Innovation	14	Principe FAIR pour les database	19	Nouvelles usines de cellules microbiennes	22	Optimiser les bioraffineries
	15	Deep Learning	20	Ingénierie des consortiums microbiens et des biofilms	23	Bioraffineries pour nouvelles matières premières
	16	Conception de protéines informatiques	21	Electrosynthèse microbienne	24	Conception de réacteur et surveillance des processus
	17	Ingénierie d'usine de cellules informatiques			25	Hétérogénéité cellulaire
	18	Modèles de processus			26	Organismes de production tolérants au stress

Domaines d'innovation ou solutions aux défis, qui peuvent être rendus possibles par différentes technologies ou approches						
Sous-champ	Exploitation durable de nouvelles matières premières		Production industrielle et produits efficaces et durables avec un impact environnemental réduit		Intermédiaires, matériaux et groupes de produits biosourcés	
Innovation	27	Nouvelle matière première	30	Bioprocédés économes en ressources et en énergie	36	Drop-ins intelligents
	28	Utilisation de flux secondaires et de déchets	31	Bioprocédés neutres en carbone	37	Produits chimiques biosourcés dédiés
	29	Fourniture et prétraitement d'une nouvelle matière première	32	Produits chimiques à base de CO_2	38	Matériaux biosourcés
			33	Atténuation du climat-gaz des activités microbiennes	39	Matériaux bio-fonctionnels
			34	Plastiques biodégradables	40	Nouveaux produits d'algues
			35	Enzymes de dégradation du plastique		
Sous-champ	Contributions to sustainable agriculture		Santé et bien-être			
Innovation	41	Amélioration des cultures ciblant le génome et l'épigénome	47	Ingrédients favorisant la santé		
	42	la domestication de novo	48	Nouveaux agents antimicrobiens		
	43	Reproduction asexuée des graines	49	Stratégies d'assainissement probiotique		
	44	Augmenter et maintenir la fertilité des sols	50	Vaccins ADN vétérinaires		
	45	Nouveaux concepts agricoles				
	46	Nouvelles sources de protéines				

En ce qui concerne l'échéancier probable des 50 principales innovations bio-basées, elles ont été allouées aux niveaux de maturité de la recherche principalement fondamentale à l'échelle des laboratoires (3 innovations en 2020), de la R&D orientée vers les applications jusqu'à l'échelle pilote (20 innovations en 2020), de la mise à l'échelle et de la démonstration (21 innovations en 2020) et entièrement implémentées, prêtes pour l'introduction sur le marché (6 innovations en 2020). Presque toutes les innovations bio-basées se développeront de manière à atteindre un niveau de maturité plus élevé d'ici 2030. Vingt des 50 meilleures innovations bio-basées devraient connaître un développement très dynamique, c'est-à-dire un bond sur deux niveaux de maturité. Cependant, seules quelques innovations bio-basées devraient atteindre une large utilisation, le niveau de maturité le plus élevé de cette étude, d'ici 2030. Cela souligne la nécessité non seulement de se concentrer sur la R&D, mais également de créer des marchés et de mettre en œuvre des mesures de soutien de la demande pour les innovations afin de renforcer leur large utilisation.

La plupart des 50 principales innovations bio-basées relèvent de l'une des trois catégories de pertinence suivantes: (1) Innovations qui sont d'une grande pertinence en 2020 et resteront très pertinentes également au cours de la prochaine décennie (18 innovations), (2) Innovations qui sont pertinence moyenne en 2020, mais deviendra très pertinente d'ici 2030 (20 innovations), et (3) innovations qui sont de pertinence moyenne en 2020 et le resteront en 2030 (9 innovations).

Les 50 principales innovations bio-basées devraient avoir des effets positifs sur l'élargissement de la base de connaissances, pour l'économie, l'environnement et la société. Ils contribuent également aux objectifs de développement durable (ODD) qui doivent être atteints d'ici 2030. 80% des 50 principales innovations bio-basées contribuent à l'ODD 9 Industrie, innovation et infrastructure. De plus, bon nombre des 50 principales innovations bio-basées contribuent à la consommation et à la production responsables de l'ODD 12 et à l'action climatique de l'ODD 13, qui sont considérées comme particulièrement importantes dans les stratégies de l'UE liées au Green Deal.

Cartographie et évaluation des politiques

Les principales initiatives et stratégies européennes telles que le Green Deal européen, le plan d'action pour l'économie circulaire et la stratégie industrielle de l'UE offrent une perspective globale axée sur les défis pour lutter contre le changement climatique et évoluer vers une économie circulaire. Les sciences et technologies de la vie et de la biologie en tant que moteurs de la innovation bio-basée sont abordées dans la stratégie actualisée de la bioéconomie de l'UE, et plus en détail dans Horizon Europe, la nouvelle recherche de l'UE et le programme-cadre de l'innovation et jouent un rôle central dans les grandes lignes du cluster "l'alimentation, la bioéconomie, les resources naturelles, l'agriculture et l'environnement".

Horizon 2020 a fourni un financement substantiel pour le développement des 50 principales innovations bio-basées. Une sélection de 111 projets H2020 ayant un lien direct avec les 50 premières innovations bio-basées a contribué à hauteur de 544 millions d'euros, dont 256 millions d'euros (47%) ont été utilisés pour la recherche et le développement (TRL 1-5), 182 millions d'euros (33%)) pour la recherche à l'échelle de démonstration (TRL 6-7) et 106 millions d'euros (19%) à Flagships (TRL 8). On s'attend à ce que les nouveaux programmes de financement de l'UE, à savoir Horizon Europe et le nouveau Fonds européen de bioéconomie circulaire, poursuivent la tendance consistant à aider les entreprises à surmonter la vallée de la mort des innovations vers la commercialisation. Cette tendance est en général bien accueillie par le secteur privé. Les universitaires soulignent que l'ensemble du cadre ou de l'innovation bio-basée fondée sur les défis ne devrait pas aboutir à financer uniquement des innovations axées sur les applications qui peuvent être commercialisées d'ici 2030. Les ONG soulignent la pertinence de prendre en compte les limites écologiques de la bioéconomie.

Au niveau national, 11 États membres ont une stratégie de bioéconomie, mais seuls six d'entre eux ont également un plan d'action avec des mesures concrètes, même si les plans d'action sont considérés comme la ressource clé pour une exécution efficace de la stratégie. Cinq pays ont une politique distincte relative aux biosciences. Il existe encore un manque de stratégies bioéconomiques cohérentes, détaillées et réalistes, en particulier dans les pays d'Europe centrale et orientale (PECO). Cela se reflète également dans la répartition du budget de la contribution de l'UE aux projets financés par H2020 analysés: les pays avec un niveau élevé de financement biotechnologique de l'UE par habitant ont mis une stratégie bioéconomique en place (Irlande, Pays-Bas) ou une politique distincte liée aux biosciences (Danemark). En ce qui concerne les différences entre les régions, sur la base de l'évaluation de 111 projets H2020 ayant un lien direct avec les 50 principales innovations bio-basées, les pays d'Europe occidentale dominent l'allocation des contributions de l'UE à tous les niveaux de TR, et que les PECO ne reçoivent que 7% de la contribution disponible de l'UE, dont 59% font partie de quelques grands projets phares.

La stratégie bioéconomique et plan d'action de l'UE pour la bioéconomie met fortement l'accent sur le caractère circulaire de la bioéconomie. Les innovations bio-basées sur les applications contribuent à plusieurs objectifs d'économie circulaire, tels que l'utilisation efficace des ressources et l'utilisation des déchets, la fourniture de carbone vert à l'économie, les économies de gaz à effet de serre.

Écosystème d'innovation dans l'UE-27: statu quo et perspectives futures

Selon des évaluations d'experts, des enquêtes en ligne et des analyses de brevets, l'UE-27 est très compétitive dans l'exploitation des innovations d'origine biologique. L'UE est leader dans les solutions respectueuses de l'environnement ou durables, ainsi que dans les matières premières non alimentaires, l'ingénierie des bioprocédés et les produits biosourcés en général. En revanche, l'UE est plutôt en retard par rapport à d'autres régions dans le monde en matière d'innovations liées aux technologies numériques, à l'édition du génome ou à la biologie synthétique.

De plus, la commercialisation des innovations issues de la biotechnologie dans l'UE des 27 reste difficile. La croissance des PME et l'accroisement de la production sont souvent entravées par des ressources financières limitées. Des réglementations diverses et variées (par exemple, des réglementations techniques, des normes environnementales manquantes) limitent l'exploitation des innovations d'origine biologique, par exemple valorisation des déchets, modification du génome ou commercialisation de produits biosourcés. Néamoins, l'UE des 27 possède des compétences et des capacités élevées dans divers secteurs et a progressé dans la mise en place de chaînes de valeur biosourcées fondées sur la biotechnologie dans toute l'Europe.

Pour résumer, l'UE-27 présente des forces, mais aussi des faiblesses. En outre, il existe des facteurs externes qui favorisent ou entravent l'innovation bio-basée et la commercialisation des produits biologiques dans l'UE des 27 et présentent donc en même temps des opportunités comme des menaces. Une analyse SWOT contient ces facteurs (figure 2).

FORCES

Base de connaissances et compétences pertinentes

Une forte orientation des acteurs vers le developpement durable

Une forte concentration (tant au niveau national qu'international)

FAIBLESSES

Trans- et interdisciplinarité de la recherché

Financer le démarrage et la croissance des startup/PME

L'intégration de l'ensemble de la chaîne de valeur

Des mesures dispersées de création de marché axées sur la demande

Le manque d'intégration des pays d'Europe centrale et de l'est dans les activités et les réseaux d'innovation

OPPORTUNITES

Positionnement dans l'économie circulaire

La disponibilité de divers flux de matières premières

Croissance explosive de la numérisation, de l'automatisation et de l'IA

Implication accrue d'industries éloignées dans de nouvelles sociétés de capital-risque

MENACES

Réglementations restrictives

Faible perception du public

Figure 2. SWOT analyse pour l'UE des 27 de l'innovation biologique

Dans une perspective prospective, quatre scénarios d'innovations bio-basées dans l'UE des 27 pour 2030 ont été élaborés. Ils sont basés sur les principaux facteurs d'influence: la technologie, la politique, la coopération, l'attitude de la société envers le developpement durable et le rôle des différents acteurs dans le paysage des acteurs. Les scénarios révèlent que les tendances géopolitiques et sociétales plus larges affecteront de manière significative les futures voies de développement des innovations bio-basées:

La coopération et la concurrence entre les différents États membres de l'UE et entre l'UE et d'autres régions dans le monde, ainsi que l'attitude de la société à l'égard du developpement durable, peuvent avoir un impact important sur les innovations fondées sur la biologie. Ils influenceront en partie le type de politiques pour les innovations bio-basées et les actions des parties prenantes. Cela peut conduire par ex. à des voies d'avenir différentes. Par exemple, un scénario illustre une concurrence mondiale intensifiée dans les domaines de haute technologie, un autre scénario est fortement axé sur la durabilité dans lequel les innovations bio-bassés peuvent apporter une contribution significative, mais doivent en même temps prouver leur supériorité par rapport à d'autres solutions aux défis environnementaux. Un autre scénario part d'une situation économique difficile, causée par exemple par la pandémie de Covid 19, et met l'accent sur la reprise économique à court terme. Dans ce scénario, un de soutien accru est accordé aux industries traditionnelles alors que les domaines de haute technologie, tels que les innovations biotechnologiques, ne retiennent guère l'attention.

Les scénarios démontrent qu'en fonction des conditions-cadres et de la dynamique du domaine, certaines des 50 premières innovations bio-basées peuvent gagner plus d'importance que d'autres. Cela implique pour l'élaboration des politiques actuelles qu'il n'existe pas de liste a-prio des 50 meilleures innovations bio-basées qui soit plus favorable à l'exploitation et à la commercialisation qu'une autre. Le choix spécifique et sur mesure des innovations les plus prometteuses du portefeuille des 50 premières innovations bio-basées dépend plutôt du contexte (politique, économique, social) et des objectifs politiques prioritaires.

Conclusions et Recommendations

Cette étude présente un portefeuille de 50 innovations biosourcées, rendues possibles par les progrès des sciences et technologies du vivant et de la biologie. Le portefeuille des 50 principales innovations bio-basées représente des développements et des besoins d'innovation importants et est d'une importance majeure pour une transition réussie vers des secteurs biosourcés durables et pour obtenir des impacts dans les SDG. Pour exploiter pleinement leur potentiel, les mesures suivantes doivent être prises (voir également le tableau 2):

Les décideurs de la Commission européenne, des États membres et des responsables de la politique régionale sont encouragés à développer davantage des approches stratégiques de la science, de la technologie et de l'innovation bio-basée pour répondre aux objectifs sociétaux. Ils peuvent mettre en place des stratégies spécifiques, si elles n'existent pas encore, ou traduire les stratégies existantes en plans d'action concrets sur mesure. Les informations présentées dans ce rapport sont destinées à servir de base d'information pour de telles activités. Les décideurs sont encouragés à accorder une attention particulière aux innovations bio-basées soutenant la durabilité, aux technologies numériques ainsi qu'à la question controversée de l'utilisation des nouvelles techniques génomiques. Cependant, la sélection concrète des innovations bio-basées qui sont au centre des politiques devrait s'appuyer sur les capacités et les objectifs respectifs de l'UE et des États membres.

En général, les politiques d'innovation se concentrent de plus en plus sur des solutions aux grands défis et des mesures de soutien axées sur la mission, alors que la présente étude est partie d'une perspective axée sur la science et la technologie.Il convient donc de trouver un bon équilibre entre le soutien actif à l'intégration de l'expertise en sciences et technologies biologiques dans les communautés axées sur les applications d'une part, et le maintien d'une masse critique d'expertise en sciences et technologies biologiques (non axées sur les applications), d'autre part. Les feuilles de route technologiques sont recommandées comme moyen de soutenir l'orientation des secteurs biologiques vers des développements et des objectifs technologiques cohérents à long terme.

Afin d'accroître et d'accélérer la commercialisation des innovations d'origine biologique, un soutien cohérent au financement et à la coopération et à l'adoption par le marché serait nécessaire. La coopération et la recherche interdisciplinaire dans le domaine des sciences et technologies de la vie et biologiques sont déjà au cœur de la politique de R & D & I depuis de nombreuses années. Toutefois, les défis dans les secteurs bio-basés, tels que la transition vers une bioéconomie circulaire et l'utilisation de nouvelles matières premières, nécessitent le lancement actif et le soutien continu de nouveaux types de coopération et la complémentation de la R&D interdisciplinaire par des approches transdisciplinaires.

Une attention particulière doit être accordée à l'intensification de l'interaction entre les fournisseurs de diverses matières premières nouvelles (par exemple, les déchets, le CO_2, les matières premières d'origine marine) et les transformateurs, ainsi qu'à la collaboration entre les principaux secteurs biosourcés et les secteurs plus éloignés (par exemple, le traitement des déchets communautaires). Les clusters aux niveaux régional, national et supranational pourraient constituer des plates-formes pour une interaction productive des groupes de parties prenantes respectifs et pour un transfert rapide des connaissances. Si les plans d'action et les feuilles de route définissent des objectifs quantitatifs concrets, par exemple concernant les coûts, les bénéfices, les objectifs d'émission, cela attirera des acteurs industriels plus éloignées, qui ne sont pas intéressés par les innovations bio-basées au départ, mais par la mise en œuvre de solutions prometteuses.

Outre une meilleure coopération tout au long de la chaîne de valeur et entre les secteurs industriels, une harmonisation plus poussée des politiques des États membres pourrait favoriser la pleine exploitation du potentiel des innovations issues de la biotechnologie dans l'UE. Bien que les pays d'Europe centrale et orientale (PECO) aient fait des progrès considérables dans le développement de leurs secteurs d'origine biologique au cours de la dernière décennie, ils sont toujours en retard par rapport aux pays d'Europe occidentale en termes d'adoption, de contribution et de bénéfice innovations biologiques. Des mesures urgentes et prometteuses ont déjà été prises pour améliorer l'intégration et réduire les déséquilibres géographiques. Ces efforts doivent être au moins maintenus, leur augmentation devrait être envisagée. Les politiques associées pourraient comprendre différentes actions, par exemple un financement accru pour la création ou la mise à niveau des technologies, des infrastructures et des groupements dans les PECO. Afin d'obtenir une plus grande valeur ajoutée dans les PECO eux-mêmes, par ex. par la valorisation de la biomasse produite localement, lutter pour la mise en place de chaînes de valeur au niveau local, régional ou national dans ces pays est un objectif prometteur.

En outre, dans presque tous les États membres et au niveau de l'UE, une meilleure intégration des politiques de bioéconomie avec d'autres politiques connexes (par exemple, politique en matière d'énergie renouvelable, réglementation des biodéchets) est nécessaire. Dans le même temps, il est nécessaire de coordonner au niveau international les stratégies de bioéconomie entre les États membres de l'UE et les plans d'action afin d'exploiter pleinement le potentiel des innovations bio-basées dans le domaine de la bioéconomie.

Table2 – Recommandations

Approche stratégique vers une bioéconomie	Les innovations bio-basées comme point de départ	Domaines d'innovation spécifiques	Clusters, transfert de connaissances et collaboration	Commercialisation et adoption par le marché des innovations bio-basées	La recherche d'une plus grande cohérence et d'une meilleure coopération européenne
Adopter une approche stratégique de la bioéconomie	Transformer le portefeuille "par défaut" des 50 principales innovations bio-basées en plans d'action et feuilles de route sur mesure	Maintenir la position de leader en matière de développement durable et de bioéconomie circulaire	Favoriser les collaborations intersectorielles	Financer la croissance des PME et d'autres acteurs	Poursuivre et intensifier les actions visant à atteindre une plus grande cohérence européenne et à réduire les déséquilibres géographiques
	Équilibrer les programmes axés sur la technologie et ceux axés sur la mission	Promouvoir la numérisation, l'automatisation et l'IA	Favoriser la transdisciplinarité et les processus de co-création/co-innovation	Mettre en place des incitations à la création de marchés du côté de la demande	Assurer la coordination internationale des stratégies, des actions et des conditions cadres dans le domaine de la bioéconomie
		Élaborer une stratégie sur l'utilisation des nouvelles techniques génomiques	Favoriser les pôles de bioéconomie aux niveaux régional, national et supranational		

1 Introduction

1.1 Background

The bio-based economy is expected to contribute strongly to addressing economic, social and environmental challenges, by the sustainable use of natural resources, by reducing dependence on fossil fuels, by protecting the environment and climate, ensuring food security, generating economic growth, especially in rural areas, and maintaining international competitiveness. Already now, the total bioeconomy of the EU-27 has a value-added of 614 billion euro in 2017, of which 320 billion euro is generated by the bio-based industries (Ronzon et al. 2020). Meanwhile, the bioeconomy employed a total of 17 million people, just over half of them are employed in primary biomass production (agriculture, forestry and fisheries).

The development of biological sciences and technologies for the valorisation of biomass components and the commercialisation of such innovations will enable a further boost to the transition from fossil to renewable sources, and at the same time generate added value to the European bioeconomy. An outlook was presented by EuropaBio and revealed that the turnover of the industrial biotechnology sector alone could reach almost 100 billion euros in 2030 (EuropaBio 2016).

Foresight looking activities on life and biological sciences and technologies are of considerable importance to identify focal point and needs for action. There have been several initiatives on the European level to identify innovative products and markets, and to analyse related drivers, barriers as well as potentials for the future. For instance, the EC commissioned a study to identify the key benefits and development needs for the sugar platform. This was complemented by the BIOSPRI tender study on the identification on the top 20 innovative bio-based products (Fabbri et al. 2018). This study had a partial focus on the market outlook of key bio-based products under current development that use other feedstock than sugar. Such research is accompanied by information about current trends and the policy landscape in the bioeconomy, provided by the European Commission's Knowledge Centre for Bioeconomy.

This report aims to complement the above-mentioned insights on a product or market level by a science and technology-based innovation focus, while keeping industry and societal needs in focus. It aims to identify, which life and biological sciences and technologies are required as main enablers and engines for innovations for the bioeconomy and how will the EU and its Member States be able to realize their potential for economy and society.

This study was carried out in the framework of the tender „Study on support to R&I policy in the area of bio-based products and services, Lot 2: Life and biological sciences and technologies as engines for bio-based innovation" implemented by a Consortium led by Fraunhofer Institute for Systems and Innovation Research ISI together with BTG Biomass Technology Group B.V. and iCons srl for the European Commission, Directorate General for Research & Innovation (DG RTD), Directorate F – Bioeconomy, Unit F2 – Bio-based Products and Processes under contract N°2018/RTD/F2/OP/PP-07281-2018.

1.2 Aim of the study

The overall objective of this tender is to provide strategic knowledge for policy-makers, innovation stakeholders and society to be aware of the potential and opportunities of the life and biological sciences and technologies as main enabler of bio-based innovation, as well as overcoming hurdles to realize their potential. This knowledge will enable them to make informed decisions regarding further activities to boost the potential of bio-based innovation.

1.3 Approach

The results built on a thorough and comprehensive understanding of the latest knowledge and data in the scientific literature, foresight studies, strategic documents and roadmaps, and from analysing EU-funded projects as well as patent and publication indicators. It has been refined and validated by expert interviews, an EU-wide online expert survey and three stakeholder workshops. Figure summarizes the approach. Details of the applied methodology are given in Annex I.

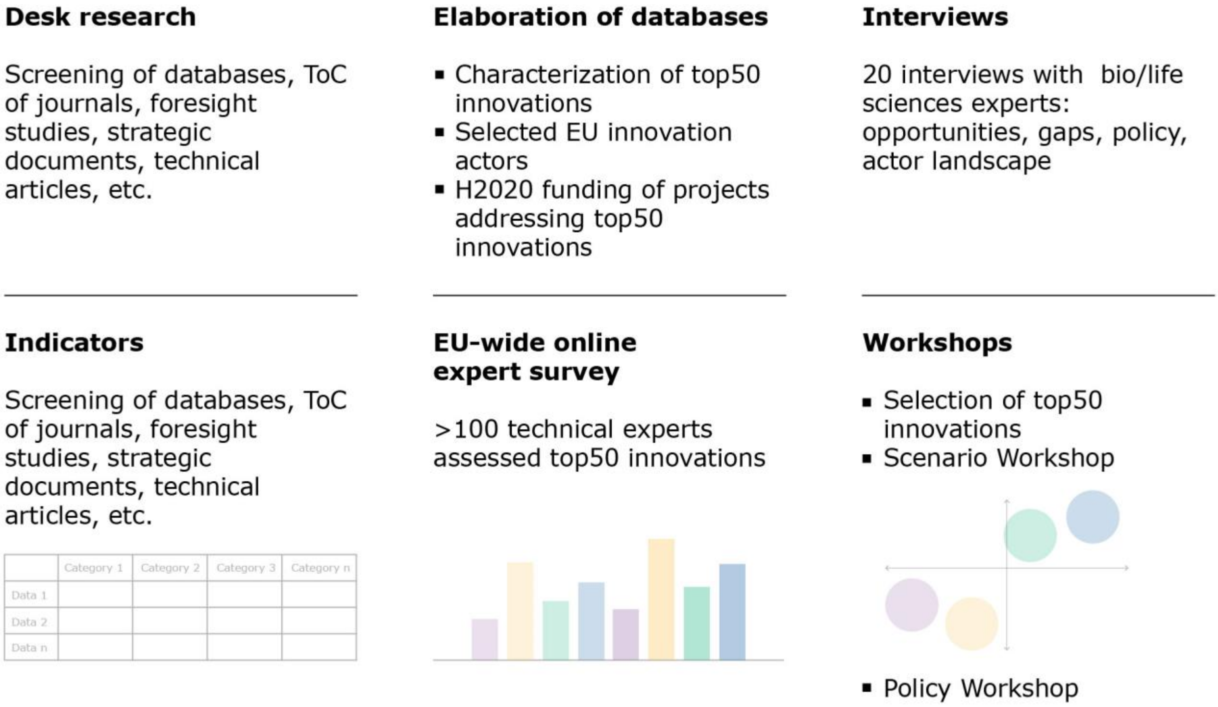


Figure 3. Metholodogical approach

1.4 Reading guide

This study identified the top50 most significant life and biological sciences and technologies and reports on the policy landscape at EU-level and national level, as well as the innovation ecosystem to identify opportunities that enable implementation and commercialisation of the identified bio-based innovations. Furthermore, this study elaborates on bio-based innovation scenarios.

Section 2: 50 most significant life and biological sciences and technologies driven bio-based innovations. Life and biological sciences and technologies are among the key drivers and enablers for a successful transition away from a fossil-based economy towards a sustainable bio-based economy. But which innovations are most important for advancing the EU bio-based sectors? This section provides a portfolio of 50 bio-based innovations that deliver the intended impacts for economy, environment and society, and are therefore essential to advance the thriving EU bio-based sectors.

Section 3: Policy mapping and assessment. The transition towards a sustainable bioeconomy requires advances in life and biological sciences and the implementation of policies thereof. This Section presents key EU strategies and implementation programmes, as well as national bioeconomy and bioscience related policies and how they support life science and biotechnology in the EU.

Section 4: Innovation ecosystem. For successful innovation and commercialisation in life and biological science and technologies, a well-functioning innovation ecosystem is required. This Section assesses the actor landscape and addresses the current and future outlook of key innovation and commercialisation factors in the EU-27. These factors are summarised in a SWOT model.

Section 5: Bio-based Innovation in 2030 – Scenario Approach. All previous sections analyse the status quo and outlook to 2030. This section elaborates on these finding and provides forward-looking reflections. Four different probability scenarios are developed and show how the innovation and commercialisation in life and biological sciences may develop in the EU by 2030.

Section 6: Conclusion and Recommendations. Findings from prior sections that have the potential to improve the EU bio-based sectors and innovation are stated in this section.

Annex: In the Annex I various methodological approaches are presented in more detail. Annex II contains the full report of Work Package 2. In Annex III, additional background analyses and explanations about the policy mapping and assessment are mentioned. Annex IV contains results of the patent and publication analysis. In Annex V, 27 Country Fiches are presented. Annex VI contains the top 50 bio-based innovations Factsheets.

2 Fifty most significant life and biological sciences and technologies driven bio-based innovations

2.1 Innovations are key enablers for the future of a bio-based economy, for the European economy and society

For a successful transition away from a fossil-based economy towards a sustainable bio-based economy, innovations are of major importance. Life and biological sciences and technologies are among the key drivers and enablers for such urgently required innovations. Their important role has been pointed out and acknowledged in bioeconomy strategies and action plans, on both EU and Member State level. But the innovations go well beyond mere biomass processing: They are based on the massive knowledge explosion observed in life and biological sciences and on unprecedented advances in bio- and digital technologies. The innovations harness the potential of living organisms from land, aquatic and marine habitats, of nature's biological functions and processes for the sustainable sourcing, industrial processing and conversion of biomass into bio-based materials, products, services and practices. These innovative processes, products and applications offer new economic activities for all bio-based sectors and contribute to the renewal of the EU industrial base, strengthening its sustainability (Box 1). Moreover, significant impact on the capacity to mitigate and adapt to climate change, to protect and restore the integrity of terrestrial, aquatic and marine ecosystems and biodiversity and on the improvement of EU citizens' well-being and quality of life are expected, thus contributing to reaching the UN Sustainable Development Goals (SDGs).

But which innovations are most important for advancing the EU bio-based sectors? Which innovations will deliver the intended impacts for the economy, the environment and for society? Which advances in life and biological sciences and technologies lay the foundation for these innovations and are main enablers and engines for these innovations? This study presents a portfolio of 50 bio-based innovations, which are considered to deliver exactly this. These innovations will be referred to as „top50 bio-based innovations".

Box 1: What is the bioeconomy?

A sustainable bioeconomy is an improved and innovative way how food, products and materials are produced and consumed within healthy ecosystems.

The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, microorganisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources, i.e. agriculture, forestry, fisheries and aquaculture; and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services. It cuts across these sectors and systems, interlinking them and creating synergies.

To be successful, the European bioeconomy needs to have sustainability and circularity at its heart. This will drive the renewal of our industries, the modernisation of our primary production systems, the protection of the environment and will enhance biodiversity.

While biotechnology is at the heart of bio-based processes, health biotechnology and biological medicines are not included in the bioeconomy definition.

European Commission (2018)

2.2 How were the top 50 bio-based innovations selected, which scope do they cover?

The portfolio of top 50 bio-based innovations has been elaborated by a future-oriented, multi-method, expert-based approach. It has been built on a thorough and comprehensive understanding of the latest knowledge and data in the scientific literature, foresight studies, strategic documents and roadmaps, and from analysing EU-funded projects as well as patent and publication indicators. It has been refined and validated by expert interviews, an EU-wide online expert survey and three stakeholder workshops (Figure 3). Details of the applied methodology are given in Annex I.

What is the scope of this portfolio? It covers cross-cutting technologies in the life and biological sciences and their convergence with digital technologies as main enablers for innovations. It also comprises the use of these technologies to produce goods and services (Box 2). This study and thus the portfolio focusses on bio-based sectors which are part of the bioeconomy. They produce and use renewable biological resources and/or apply innovative biological processes and principles to deliver bio-based products, processes and services (European Commission2018, p. 41). The portfolio takes a forward-looking perspective. Therefore, „traditional uses" of biomass for food and feed, for using wood as such or as feedstock in the pulp and paper industry, as well as biomass-based energy technologies are not covered. As health biotechnology and biological medicines are not included in the EU bioeconomy definition, health-related innovations are only covered if they contribute to broadening the relevant knowledge base and tool box, or enable health-related preventive, analytic or diagnostic approaches or preclinical research. However, innovative and advanced therapies and medicinal products are not covered.

Box 2: Which scope does the portfolio of top 50 bio-based innovations cover?

Life and bio sciences and technologies and their convergence with digital technologies as main enablers of bio-based innovation, including

- cutting-edge biotechnology such as bioinformatics, synthetic biology or nanobiotechnologies
- improving bioengineering or building novel biological systems
- prospecting, understanding and sustainably exploiting biological resources

Use of those technologies to produce goods and services, including

- use of biomass as feedstock (biomass of plant, algae, crop, tree, marine origin, biological waste from households, animals and food production).
- bio-based products, i.e., non-food products derived from biomass, such as
  - high-value added fine chemicals, e.g., bioactive compounds, food and feed additives
  - high volume materials such as bio-based building blocks as chemical feedstock or bio-polymers
  - biotechnology driven consumer applications
- industrial biotechnology
- reducing the environmental impact of industrial processes, biotechnology driven environmental services
- Agricultural, industrial, marine and environmental bio-based innovations

Excluded:

- traditional bio-based products, such as pulp and paper, wood products, food and feed
- biomass as energy source
- biopharmaceuticals, advanced therapies

How were the top 50 bio-based innovations selected? Given the cross-cutting character of enabling life and biological sciences and technologies and their broad application spectrum, selecting only 50 bio-based innovations is a challenging task. Box 3 gives an overview of the selection criteria that were applied. Moreover, intensive expert consultations in workshops and an EU-wide online expert survey were performed to validate the choices made (Annex I).

Box 3: What were the selection criteria for the top 50 bio-based innovations?
High impact expected for knowledge generation, economy, environment, society, contribution to SDGs
Time horizon 5 - 20 years
Actual technology readiness level (TRL) of the innovation within the range of TRL 3 to TRL 7
Innovation can be emerging today, but should gain substantial relevance in 5-20 years
Well-balanced portfolio, covering the complexity and potential of the field
High relevance for implementation of EU strategies and policies (Bioeconomy strategy, Green Deal, Horizon 2020/Horizon Europe)

2.3 Which innovations does the portfolio of top 50 bio-based innovations comprise?

In accordance with the scope of the portfolio, it is structured into two fields which are closely interlinked with each other:

- Cross-cutting technologies or approaches, enabling many different applications
- Innovation areas or solutions to challenges, which may be enabled by different technologies or approaches.

Each field is structured into six and five subfields, respectively. Each subfield comprises three to six innovations (Table 3). In the following paragraphs, a short overview of the two fields with their subfields is given, also mentioning selected innovations.

Table 3. The portfolio of top 50 bio-based innovations is structured into 2 fields and subdivided into 11 subfields

Field	Cross-cutting technologies or approaches, enabling many different applications		Innovation areas/solutions to challenges, enabled by different technologies/approaches	
Subfield	Analytical techniques and bioprospecting	(5) *	Sustainable exploitation of novel feedstock	(3)
	Digital technologies	(5)	Efficient and sustainable industrial production and products with minimised environmental impact	(6)
	Novel industrial production concepts	(3)	Bio-based intermediates, materials and product groups	(5)
	Design and engineering of biological systems, cell factories; synthetic biology	(5)	Contributions to sustainable agriculture	(6)
	Design and engineering of biomolecules for desired functions	(3)	Health and well-being	(4)
	Enabling bio-based production at industrial scale	(5)		

* Numbers in brackets give the numbers of innovations in the respective subfield

The field *Cross-cutting technologies or approaches, enabling many different applications* (Table 4) contains the subfield *Analytical techniques and bioprospecting*. *Screening technologies* for bioprospecting tap *biodiversity* and will replenish the innovation pipeline with novel organisms, biomolecules, biomaterials, metabolic and regulatory functions. Since the Human Genome Project, *-omics technologies* are essential for large-scale holistic experiments which probe the entirety of e.g., genes, proteins, metabolites in an organism. They have only recently been applied to *analysing* all organisms in an environment - *microbial consortia (microbiomes)* had been largely elusive to analysis before. Biosensing represents innovations using biomolecules in analytical systems, and *labs-on-a-chip* represent the trend of miniaturisation, enabling even complex analyses being carried out without the need for well-equipped laboratories or qualified staff.

Life and biological sciences and technologies increasingly converge with *digital technologies*. This is on the one hand driven and required by the digitalisation of industry (industry 4.0), as exemplified by the innovation *process models*. On the other hand, large-scale experiments and analyses with *-omics technologies* yield vast amount of data, which can only be analysed and interpreted with bioinformatics and *digital technologies*, making biological sciences and technologies a data-driven science. Classical statistical analyses are increasingly complemented by artificial intelligence, machine and *deep learning* approaches. *Computational protein design* and *computational cell factory engineering* are model-based approaches, which broaden the tool boxes for *design and engineering of biomolecules for desired functions* as well as *engineering of cell factories, i.e.* production organisms. These innovations are expected to speed up the design-build-test cycles in bioengineering significantly, because only those variants will be tested in vitro or in vivo which were promising in silico. Genetic engineering has been at the core of bioengineering for decades, and now novel tools (*precision genome editing, synthesis and assembly of long DNA fragments, modular cloning systems*) are being improved which enable precise, defined alterations of very large DNA fragments, even genomes. They provide the technological basis for synthetic biology approaches which aim - among others - at rationally constructing biosystems not found in nature, such as *minimal organisms* or organisms with an *expanded genetic code*. Today, the large majority of industrial bioprocesses depend on the metabolic activities of organisms which require organic compounds (such as sugars) as carbon and energy source for growth and production of the target products. However, dynamically developing bio-based sectors inevitably imply larger consumption of feedstock and energy. Against this background, innovations in the subfield *novel industrial production concepts* aim at providing alternatives to this dominant bioproduction design: They aim at developing *novel microbial cell factories* and bioprocesses which can use sunlight or „green" electricity (*microbial electrosynthesis*) as energy source, and/or which do not only use pure cultures of production organisms, but also the synergistiTc metabolic activities of *microbial consortia* (microbiomes) and *biofilms*. Most of the above-mentioned cross-cutting technologies or approaches are mainly relevant in R&D at lab scale. However, the ability to scale up the approaches and processes, thereby *enabling bio-based production at industrial scale* is also very important for the bio-based sectors. Innovations in this subfield aim at developing integrated concepts for bioproduction (*biorefineries*) within a circular economy which are economically competitive, highly efficient, robust and which yield products of reliable quality. *Enabling industrial scale production* does not only apply to established approaches and technologies, but has to provide solutions for *novel industrial production concepts*.

Innovations in the field *Innovation areas, solutions to challenges* are to a large extent enabled by technologies and approaches in the field *Cross-cutting technologies or approaches*. The subfields cover the value chain from primary production and feedstock provision (subfields *sustainable exploitation of novel feedstock, contributions to sustainable agriculture*) via bioprocessing (subfield *efficient and sustainable industrial production and products with minimised environmental impact*) to products (subfield *bio-based intermediates, materials and product groups*). Moreover, two subfields cover biological sciences and technologies driven innovations in agriculture (*contributions to sustainable agriculture*) and for *well-being and health* (Table 5).

Table 4. The field cross-cutting technologies or approaches comprises 26 top 50 bio-based innovations divided into six subfields

Subfield	Analytical techniques and bioprospecting		Design and engineering of biomolecules for desired functions		Design and engineering of biological systems, cell factories; synthetic biology	
Innovation	1	Screening biodiversity	6	Macromolecular design	9	Precision genome editing
	2	-omics technologies	7	Multi-enzyme biocatalysis	10	Synthesis and assembly of long DNA fragments
	3	Analysing microbial consortia	8	New enzymes	11	Modular cloning systems
	4	Lab-on-a-chip			12	Minimal cells
	5	Biosensing			13	Expansion of the genetic code
Subfield	**Digital technologies**		**Novel industrial production concepts**		**Enabling bio-based production at industrial scale**	
Innovation	14	FAIR principle for databases	19	Novel microbial cell factories	22	Optimising biorefineries
	15	Deep Learning	20	Engineering microbial consortia and biofilms	23	Biorefineries for new feedstock
	16	Computational protein design	21	Microbial electrosynthesis	24	Reactor design and process monitoring
	17	Computational cell factory engineering			25	Cell heterogeneity
	18	Process models			26	Stress-tolerant production organisms

Innovations in the subfield *sustainable exploitation of novel feedstock* (Table 5) aim at making large amounts of non-food feedstock available, which are required for thriving bio-based sectors. Land use competition for food and feed production and for environmental services must be avoided or at least minimised. Therefore, innovations aim at exploiting currently underused biomass resources, especially from waste and freshwater and marine sources (e.g. by-catch, macro- and microalgae), and at closing material cycles. In addition, the greenhouse gas carbon dioxide (CO_2) is gaining importance as feedstock, requiring *novel microbial cell factories* (e.g. algae), *novel industrial production concepts* and *novel bioreactor concepts* (e.g. *microbial electrosynthesis,* bioreactors for non-vertebrate aquaculture). These novel feedstock and production concepts have to be developed into industrially relevant processes: Innovations in the subfield *efficient and sustainable industrial production and products with minimised environmental impact* provide solutions to enable the transition to a carbon-neutral and circular economy. Bio-based products in the subfield *bio-based intermediates, materials and product groups* cover the spectrum from high volume low value product groups (e.g. *smart drop-ins*) to low volume high value product groups (e.g. *bio-functional materials*, *novel algae products*). They also reflect the trend to bring products to commercialisation which do not only replace fossil feedstock by biomass (e.g. *smart drop-ins*) and have a more favourable sustainable footprint (*bio-based materials*), but which provide unique functionalities (e.g. *bio-functional materials*).

Table 5. The field „Innovation areas, solutions to challenges" comprises 24 top 50 bio-based innovations divided into five subfields

Subfield	**Sustainable exploitation of novel feedstock**		**Efficient and sustainable industrial production and products with minimised environmental impact**		**Bio-based intermediates, materials and product groups**	
Innovation	27	Novel feedstock	30	Resource- and energy efficient bioprocesses	36	Smart drop-ins
	28	Using side and waste streams	31	Carbon-neutral bioprocesses	37	Dedicated bio-based chemicals
	29	Supply and pretreatment of novel feedstock	32	CO_2-based chemicals	38	Bio-based materials
			33	Climate-gas mitigation of microbial activities	39	Bio-functional materials
			34	Biodegradable plastics	40	Novel algae products
			35	Plastic degrading enzymes		

Subfield	**Contributions to sustainable agriculture**		**Health and well-being**	
Innovation	41	Crop improvement targeting genome and epigenome	47	Health-promoting ingredients
	42	de novo domestication	48	Novel antimicrobial agents
	43	Asexual reproduction of seeds	49	Probiotic sanitation strategies
	44	Increasing and maintaining soil fertility	50	Veterinary DNA vaccines
	45	Novel farming concepts		
	46	Novel protein sources		

The subfield *contributions to sustainable agriculture* comprises among others innovations based on genome editing (*crop improvement targeting genome and epigenome, de novo domestication, asexual reproduction of seeds*). They bear the potential to improve crop breeding significantly in terms of efficiency, time requirements and traits that can be modified. Moreover, conceptually new approaches in agricultural production are enabled by innovations driven by biological sciences and technologies: *Increasing and maintaining soil fertility* understands soil not as a mere substrate in which plants put their roots, but as a dynamic ecosystem. Soil innovations aim at complementing or substituting conventional fertilisers and pesticides, among others by stimulating soil microbiomes. *Novel farming concepts, e.*g. indoor farming, recirculating aquaculture and aquaponic systems, aim at sustainable, intensified food production systems with minimised land and resource requirements, especially for urban or extreme environments. Conventional livestock farming cannot provide a growing world population with valuable protein in a sustainable way, but this may be possible by exploiting *novel protein sources*, such as protein crops, aquacultured fish and non-vertebrates, algae, insects or cultured meat. Innovations in the subfield *health and well-being* aim at maintaining health and preventing diseases instead of treating diseases: this could be achieved by *health-promoting (food and feed) ingredients* which e.g. target the microbiome. Innovations also address the challenge of (multi-resistant) pathogens by providing *novel antimicrobial agents* and conceptually new types of vaccines (*DNA vaccines*), and preventing over-use of antimicrobial agents by *probiotic sanitation strategies*.

The top 50 bio-based innovations cannot only be structured by field and subfield, respectively, but also by applications areas, such as plant, marine, environmental and industrial applications. As an example, how the top 50 bio-based innovations can contribute to challenges in an application area, box 4 features their application fisheries, aquaculture and marine biotechnology.

Box 4: Contribution of selected top 50 bio-based innovations to challenges in the marine application area

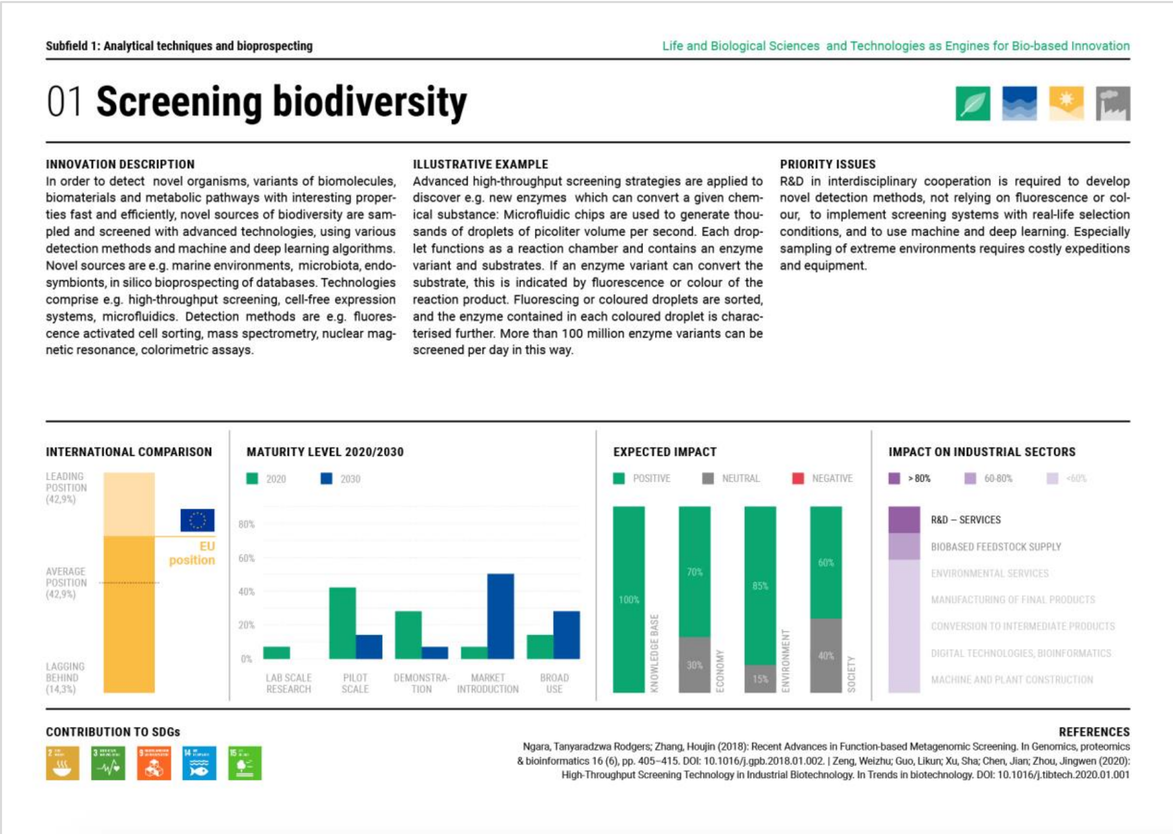
Resilient freshwater and marine ecosystems with a high biodiversity are the essential basis for sustainable primary production in fisheries and aquaculture and for ecosystem services. However, their integrity is severely challenged and damaged by e.g. overexploitation, pollution, land use change and climate change.

Life and biological sciences and technologies driven *analytical techniques* provide tools and approaches to probe and monitor the actual state of marine and freshwater ecosystems and biodiversity: use of *-omics technologies* (e.g. eDNA for identification of species in a habitat), the ability to *analyse microbial consortia (microbiomes)* and unculturable organisms, *labs-on-chip* and *biosensors* for rapid, sophisticated analyses even in remote areas without a fully equipped laboratory contribute to a better understanding of the status, pressures, impacts and responses of aquatic ecosystems.

This leads to approaches for the restoration of aquatic ecosystem services, e.g. by *engineering microbial consortia,* by *climate-gas mitigation of microbial activities* in waste and polluted water, by avoiding pollution of ground- and freshwater by *increasing and maintaining soil fertility* by establishing bio-based alternatives to the overuse of agrochemicals, or by attempts to reduce plastic discharge into oceans by *biodegradable plastics* and treatment of plastic waste with *plastic degrading enzymes*.

Sustainable and resilient freshwater and marine ecosystems with a high biodiversity are also a largely untapped resource for the bio-based sectors, pointing to the need of *screening their biodiversity* in order to replenish the development pipelines with *novel microbial cell factories* (e.g. algae, marine *microbiomes and biofilms*) and useful substances of marine and aquatic origin, ranging from *new enzymes*, *bio-based and bio-functional materials, novel algal products, health-promoting ingredients* to *novel antimicrobial agents.* Moreover, macro- und microalgae biomass as well as by-catch can provide *novel feedstocks* for bioprocessing in marine *biorefineries for new feedstock*, e.g. in coastal regions. These biorefineries, especially if they employ novel production organisms (such as macro- and microalgae, marine biofilms, but also shellfish and other non-vertebrates), will require specifically adapted *reactor designs and process monitoring.* Innovations in aquaculture can also contribute to sustainable agriculture, e.g. as part of *novel farming concepts* such as aquaponics, and by providing *novel protein sources* for human consumption from seafood or by using *novel protein sources* as feed in aquaculture. Bio-based innovations also provide solutions for disease control in seafood farming, e.g. by *probiotic sanitation strategies* and *veterinary DNA vaccines.*

More information on each innovation is provided by a factsheet. The factsheets can be found in Annex V, an example is shown in Figure 4: Each factsheet gives a description of the innovation and illustrates it with an example. Moreover, issues are pointed out which must be addressed with priority to overcome existing hurdles for this innovation. Infographics provide condensed information on the EU position in international comparison for this innovation, the presently achieved maturity level and the expected maturity level in 2030, which affect the innovation will have on the knowledge base, the economy, environment and on society, and which industrial sectors will benefit to a large extent from this innovation. Icons show to which SDGs the innovation will contribute and for which application areas (plant, marine, environment, industry) it is relevant. Finally yet importantly, references to scientific publications as source for further information are given.


Subfield 1: Analytical techniques and bioprospecting

Life and Biological Sciences and Technologies as Engines for Bio-based Innovation

01 **Screening biodiversity**

INNOVATION DESCRIPTION

In order to detect novel organisms, variants of biomolecules, biomaterials and metabolic pathways with interesting properties fast and efficiently, novel sources of biodiversity are sampled and screened with advanced technologies, using various detection methods and machine and deep learning algorithms. Novel sources are e.g. marine environments, microbiota, endosymbionts, in silico bioprospecting of databases. Technologies comprise e.g. high-throughput screening, cell-free expression systems, microfluidics. Detection methods are e.g. fluorescence activated cell sorting, mass spectrometry, nuclear magnetic resonance, colorimetric assays.

ILLUSTRATIVE EXAMPLE

Advanced high-throughput screening strategies are applied to discover e.g. new enzymes which can convert a given chemical substance: Microfluidic chips are used to generate thousands of droplets of picoliter volume per second. Each droplet functions as a reaction chamber and contains an enzyme variant and substrates. If an enzyme variant can convert the substrate, this is indicated by fluorescence or colour of the reaction product. Fluorescing or coloured droplets are sorted, and the enzyme contained in each coloured droplet is characterised further. More than 100 million enzyme variants can be screened per day in this way.

PRIORITY ISSUES

R&D in interdisciplinary cooperation is required to develop novel detection methods, not relying on fluorescence or colour, to implement screening systems with real-life selection conditions, and to use machine and deep learning. Especially sampling of extreme environments requires costly expeditions and equipment.

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Figure 4. Example of a factsheet

2.4 How can the portfolio of top 50 bio-based innovations be characterised?

In addition to detailed information for the individual innovations (available from the factsheets in Annex V), the overall top 50 bio-based innovations portfolio is now analysed with respect to the following questions:

- What is the actual and future maturity level of the innovations?
- What is the actual and future relevance of the innovations, and can different types of future relevance be distinguished?
- Which impacts on knowledge generation, economy, environment and society can be expected from the innovations?
- Which issues should be addressed with priority to overcome existing hurdles?

Additional analyses of the top 50 bio-based innovations on the European position in international comparison as well as their relevance for different industrial sectors will be presented in section 4. In section 3, the contribution of the top 50 bio-based innovations to achieving the SDGs will be discussed. An important information source for these analyses is the EU-wide online expert survey (Annex I), in which each of the top 50 bio-based innovations has been assessed by experts.

What is the actual and future maturity level of the innovations?

In order to gain understanding of the likely timeline of the top 50 bio-based innovations, participants in the EU-wide online expert survey assessed the actual and future maturity level of the innovations. They were asked to give the maturity level achieved globally on average, but not the level that was only achieved in single most advanced cases. In Table 6, the maturity levels are highlighted which received the highest share of responses by survey participants for the respective innovation.

Table 6 shows that the portfolio of top 50 bio-based innovations comprises

- 3 innovations which are, in 2020, on the level of mainly basic, lab scale research,
- 20 innovations on the level of application-oriented R&D up to pilot scale,
- 21 innovations on the level of scale-up and demonstration, and
- 6 innovations are fully implemented and ready for market introduction.

Survey participants expect that nearly all innovations will develop in a way that they will reach a higher maturity level by 2030. The only exceptions are c*rop improvement targeting genome and epigenome,* reflecting the actual restrictive regulatory situation for field testing and commercialisation of genome-edited crops, and *resource- and energy efficient bioprocesses* and *dedicated bio-based chemicals.* Experts seem to be sceptical that competitiveness of many *dedicated bio-based chemicals* for their broad use can be achieved by 2030 under current market conditions. Twenty of the top 50 bio-based innovations are expected to experience a highly dynamic development, i.e. leapfrogging over two maturity levels. Broad use in 2030 is expected mainly for innovations in the field of *cross-cutting technologies or approaches*, namely *precision genome editing, macromolecular design*, *multi-enzyme biocatalysis, synthesis and assembly of long DNA fragments, modular cloning systems, deep learning, computational protein design, reactor design and process monitoring, process models and -omics technologies. Smart drop-ins, bio-based materials and biodegradable plastics* are the only innovations from the field *Innovation areas or solutions to challenges* which are expected to reach broad use by 2030[2]. This points to a need to create markets and implement demand-side support measures for other bio-based product groups to enhance their broad use.

Table 6. Actual and future maturity level of the top 50 bio-based innovations

Innovation		Mainly basic, lab scale research	Application -oriented R&D, pilot scale	Scale-up & demonstration	Fully implemented, market introduction	Broad use
12	Minimal cells					
13	Expansion of the genetic code					
42	de novo domestication					
3	Analysing microbial consortia					
20	Engineering microbial consortia					

[2] Survey participants assessed the maturity level achieved globally on average for the respective innovation, but not the level that has only achieved in single most advanced cases.

21	Microbial Electrosynthesis					
25	Cell heterogeneity					
33	Climate-gas mitigation of microbial activities					
35	Plastic degrading enzymes					
39	Bio-functional materials					
43	Asexual reproduction of seeds					
1	Screening biodiversity					
4	Lab-on-a-chip					
5	Biosensing					
8	New enzymes					
14	FAIR principle for databases					
19	Novel microbial cell factories					
29	Supply and pretreatment of novel feedstock					
40	Novel algae products					
46	Novel protein sources					
49	Probiotic sanitation strategies					
50	Veterinary DNA vaccines					
9	Precision genome editing					
41	Crop improvement targeting genome and epigenome					
17	Computational cell factory engineering					
22	Optimising biorefineries					
23	Biorefineries for new feedstock					
26	Stress-tolerant production organisms					
27	Novel feedstock					
28	Using side and waste streams					
31	Carbon-neutral bioprocesses					
32	CO_2-based chemicals					
44	Increasing and maintaining soil fertility					
45	Novel farming concepts					
47	Health-promoting ingredients					
48	Novel antimicrobial agents					
6	Macromolecular design					
7	Multi-enzyme biocatalysis					
10	Synthesis and assembly of long DNA fragments					
11	Modular cloning systems					
15	Deep Learning					
16	Computational protein design					
24	Reactor design and process monitoring					
36	Smart drop-ins					
30	Resource- and energy efficient bioprocesses					

37	Dedicated bio-based chemicals					
2	-omics technologies					
18	Process models					
34	Biodegradable plastics					
38	Bio-based materials					

Legend: Maturity level 2020 **Maturity level 2030**

Source: EU-wide online expert survey; the maturity level is coloured which was chosen by most survey respondents

Actual and future relevance of the innovations

Most of the top 50 bio-based innovations fall into one of these three categories of relevance (Table 7):

- Innovations which are of high relevance in 2020, and will remain highly relevant also in the next decade (2030).
- Innovations which are of medium relevance in 2020, but will become highly relevant by 2030.
- Innovations which are of medium relevance in 2020 and remain so in 2030.

Eighteen of the top 50 bio-based innovations are considered as highly relevant today and also in the future. In the field *Cross-cutting technologies or approaches*, these are mainly technologies for expanding the range of available biocatalysts and their engineering for desired functions (*new enzymes, computational protein design, novel microbial cell factories*, *precision genome editing, synthesis and assembly of long DNA fragments*).

In the field *Innovation areas, solutions to challenges*, innovations for expanding the range of feedstock for the bio-based sectors in a sustainable way without competing for land use with food and feed production and environmental services are considered as highly relevant (*novel feedstock, using side and waste streams, supply and pretreatment of novel feedstock*). *Optimising biorefineries*, especially with respect to *resource- and energy efficient bioprocesses* and their *carbon-neutrality* is and will remain an important task to achieve competitiveness of bio-based industrial production. With respect to products, innovations in *bio-based materials* are of high relevance, be it in *smart drop-ins* or *dedicated bio-based chemicals*. Their high relevance is attributed to the potentially favourable environmental footprint, compared to fossil-based products. In primary production, innovations are considered most relevant which enable alternatives to the predominant agricultural practices, either by developing *novel farming concepts* such as indoor farming, aquaculture and aquaponics or by targeting *soil fertility* by developing more sustainable alternatives to conventional fertilizers and pesticides. This also contributes to reducing pollution and eutrophication of groundwater, freshwater and oceans. In health and well-being, innovations are highly relevant and will remain so in the next decade which target disease prevention and *health-promotion* instead of treating diseases, and innovations, which expand the range of available *antimicrobial agents* in times where multi-resistant pathogens are on the rise. This applies to human health as well as to animal health, e.g. in livestock farming and aquaculture.

Twenty of the top 50 bio-based innovations are considered to be of medium relevance today, but are expected to become highly relevant in the coming decade (Table 7). Most innovations in this relevance category are presently less mature than those in the first category, but will become more relevant with increasing maturity. Often, they are the follow-up development of related innovations in the first category.

Innovations in bioprospecting (*screening biodiversity*) are required to continuously fill the innovation pipeline with novel biocatalysts, functions and materials. Organisms living in marine and extreme environments are examples of still underexploited resources. Analytical techniques such as *-omics technologies* will develop their full potential especially when synergistically combined with innovations in bioinformatics and digital technologies (*computational protein design and cell factory engineering, deep learning*), thus enabling *macromolecular design* (beyond proteins) for desired functions on demand as well as engineering more complex biocatalytic systems (*multi-enzyme biocatalysis, analysing and engineering microbial consortia*). In addition, *-omics technologies* have promising applications in environmental and biodiversity monitoring and analyses. Building on biorefinery, feedstock and cell factory innovations from the first relevance category, the development of *biorefineries for new feedstocks*, *reactor designs for novel cell factories* as well as complementing process optimisation by *targeting stress tolerance of cell factories* will become highly relevant. This could, for example, be marine biorefineries which convert macroalgal biomass, use microalgae as novel cell factories which utilise CO_2 as carbon source, and which require novel photobioreactor concepts at industrial scale. While the present relevance of *bio-based intermediates, materials and product groups* is mainly based on the potentially more favourable environmental footprint compared to fossil-based products, in the coming decade the exploitation of *biofunctionality* on the one hand, and the (re-)use of CO_2 as feedstock in *CO_2-based chemicals* and closing material cycles (e.g. by *biodegradable plastics*) will become more relevant. In agriculture, application of genome editing technologies in crop breeding (*crop improvement targeting genome and epigenome, de novo domestication*) is expected to become highly relevant from a scientific-technological perspective. Novel agricultural practices and novel farming and aquaponic concepts aiming at delivering *novel protein sources* for food and feed for livestock farming and aquaculture are expected to mature to a stage in the coming decade where they will become more relevant beyond the niches in which they are at present. In health, the novel concept of *probiotic sanitation strategies* is expected to become more relevant, targeted at reducing the use of antimicrobial agents and preventing the emergence of multiresistant pathogens, both in human and animal health.

Nine of the top 50 bio-based innovations are in the third relevance category, being of medium actual and future relevance. Only in the case of *biosensing* and *microbial electrosynthesis*, the medium relevance in the future can be attributed to the early development stage and emerging character of these innovations in 2020. In the other cases, the medium actual and future relevance of the innovations in this category is due to the fact that they represent novel concepts and approaches, which are very relevant for a specific application, solution or development within a bio-based sector, but not for the bio-based sectors as a whole, and/or they represent only one solution within a comprehensive strategy to achieve a certain goal. For example, the *FAIR principle for data bases* is of major relevance (only) for the use of digital resources. Addressing *cell heterogeneity* in bioproduction processes is one of many approaches pursued to increase yield, productivity and stability of bioprocesses. *Climate-gas mitigation of microbial activities* is one of many elements in fighting climate change, *plastic degrading enzymes* are one of several approaches of recycling plastic waste and cover a specific segment within waste recycling and the circular economy.

Three of the top 50 bio-based innovations do not fit into the three relevance categories (Table 7): *Minimal cells* and *expansion of the genetic code* were considered as emerging cross-cutting approaches, which will only reach a level of maturity with medium relevance in the coming decade. By contrast, *process models* are considered to be of high relevance now, significantly contributing to the digitalisation of the bio-based process industry. However, this digitalisation is expected to become mainstream and usual business by 2030, so that the relevance of *process models* for the bio-based sectors declines from high in 2020 to medium in 2030.

Table 7. The top 50 bio-based innovations portfolio comprises innovations of three types of future relevance

High relevance 2020/2030		Medium relevance 2020 High relevance 2030		Medium relevance 2020/2030	
		1	Screening biodiversity		
		2	-omics technologies		
		3	Analysing microbial consortia		
		4	Lab-on-a-chip	5	Biosensing
		6	Macromolecular design		
8	New enzymes	7	Multi-enzyme biocatalysis		
9	Precision genome editing				
10	Synthesis and assembly of long DNA fragments	11	Modular cloning systems		
16	Computational protein design	15	Deep Learning	14	FAIR principle for databases
		17	Computational cell factory engineering		
19	Novel microbial cell factories	20	Engineering microbial consortia	21	Microbial Electrosynthesis
22	Optimising biorefineries	23	Biorefineries for new feedstock		
		24	Reactor design and process monitoring		
		26	Stress-tolerant production organisms	25	Cell heterogeneity
27	Novel feedstock				
28	Using side and waste streams				
29	Supply and pretreatment of novel feedstock				
30	Resource- and energy efficient bioprocesses	32	CO_2-based chemicals	33	Climate-gas mitigation of microbial activities
31	Carbon-neutral bioprocesses	34	Biodegradable plastics	35	Plastic degrading enzymes
36	Smart drop-ins				
37	Dedicated bio-based chemicals				
38	Bio-based materials	39	Bio-functional materials	40	Novel algae products
44	Increasing and maintaining soil fertility	41	Crop improvement targeting genome and epigenome	43	Asexual reproduction of seeds
45	Novel farming concepts	42	de novo domestication		
		46	Novel protein sources		
47	Health-promoting ingredients				
48	Novel antimicrobial agents	49	Probiotic sanitation strategies	50	Veterinary DNA vaccines

Source: EU-wide online expert survey; highest share of experts' assessment of relevance in 2020/2030 per innovation determines the relevance category

Expected impacts on knowledge generation, economy, environment and society by 2030

Life and biological sciences and technologies driven innovations are expected to deliver positive impacts. Table 8 presents data from the EU-wide online expert survey (Annex I): Experts were asked whether they expected positive, neutral or negative impacts on the knowledge base, the economy, the environment and the society from an innovation. In Table 8, impacts of innovations are marked in green if more than 75 % of the survey participants expected a positive impact and in orange if 50 - 75 % of participants expected a positive impact. Data for neutral or negative impacts are not shown here, but are available on the factsheets (Annex VI).

Table 8. Expected positive impacts of the top 50 bio-based innovations by 2030

Innovation		Positive impact expected on			
		Knowledge Base	Economy	Environ-ment	Society
1	Screening biodiversity				
2	-omics technologies				
3	Analysing microbial consortia				
4	Lab-on-a-chip				
5	Biosensing				
6	Macromolecular design				
7	Multi-enzyme biocatalysis				
8	New enzymes				
9	Precision genome editing				
10	Synthesis and assembly of long DNA fragments				
11	Modular cloning systems				
12	Minimal cells				
13	Expansion of the genetic code				
14	FAIR principle for databases				
15	Deep Learning				
16	Computational protein design				
17	Computational cell factory engineering				
18	Process models				
19	Novel microbial cell factories				
20	Engineering microbial consortia				
21	Microbial Electrosynthesis				
22	Optimising biorefineries				
23	Biorefineries for new feedstock				

Innovation		Positive impact expected on			
		Knowledge Base	Economy	Environ-ment	Society
24	Reactor design and process monitoring	●	●	○	
25	Cell heterogeneity	○	○		
26	Stress-tolerant production organisms	●	●	○	
27	Novel feedstock	●	●	●	○
28	Using side and waste streams	●	●	●	●
29	Supply and pretreatment of novel feedstock	●	●	○	
30	Resource- and energy efficient bioprocesses	●	●	●	○
31	Carbon-neutral bioprocesses	●	○	●	○
32	CO_2-based chemicals	●	○	●	○
33	Climate-gas mitigation of microbial activities	○		●	○
34	Biodegradable plastics	●	○	●	●
35	Plastic degrading enzymes	●	○	○	○
36	Smart drop-ins	●	○	○	○
37	Dedicated bio-based chemicals	●	●	●	○
38	Bio-based materials	●	●	●	●
39	Bio-functional materials	●	○	○	○
40	Novel algae products	●	○	○	○
41	Crop improvement targeting genome and epigenome	●	●	●	○
42	de novo domestication	●	●	●	○
43	Asexual reproduction of seeds	●	●		
44	Increasing and maintaining soil fertility	●	●	●	●
45	Novel farming concepts	●	●	●	○
46	Novel protein sources	●	●	○	●
47	Health-promoting ingredients	●	●		●
48	Novel antimicrobial agents	●	●	○	●
49	Probiotic sanitation strategies	●	●	○	○
50	Veterinary DNA vaccines	●	●	○	○

Legend: **more than 75 % of survey respondents** ● **50 % to 74 % of survey respondents** ○

Life and biological science and technologies driven innovations are knowledge-based and knowledge-intensive. Against this background, it is not surprising that more than 75 % of the experts expect positive impacts on the knowledge base from nearly all top 50 bio-based innovations, both in the field of *cross-cutting technologies or approaches* and in the field of *innovation areas, solutions to challenges*. The 10 innovations with the highest share of survey participants expecting positive impacts on the knowledge base are *screening biodiversity, analysing microbial consortia, macromolecular design, new enzymes, deep learning, computational protein design, engineering microbial consortia, stress-tolerant production organisms, supply and pretreatment of novel feedstock, crop improvement targeting genome and epigenome, health-promoting ingredients, novel antimicrobial agents* and *veterinary DNA vaccines*.

The top 50 bio-based innovations should enable or provide process, product or service innovations. This is reflected in Table 8: more than half of the survey respondents expect positive economic impacts for 49 of the top 50 bio-based innovations, the only exception is *climate-gas mitigation of microbial activities*. The 10 innovations with the highest share of survey participants expecting positive impacts on the economy are *new enzymes, deep learning, process models, novel microbial cell factories, engineering microbial consortia., novel feedstock, using side and waste streams, crop improvement targeting genome and epigenome, health-promoting ingredients* and *novel antimicrobial agents*.

A positive impact on the environment is expected by more than half of the survey respondents for 41 of the top 50 bio-based innovations, reflecting the fact that many biocatalysts and bioprocesses often operate with high selectivity and specificity under ambient conditions, in aqueous solutions, often avoid toxic or environmentally harmful substances and bear the potential of a more favourable environmental footprint than conventional processes. In addition, innovations in the subfield *analytical techniques* provide observation, mapping and monitoring tools for biodiversity in and for pollution of ecosystems on land and in water, thus delivering essential information on biodiversity and ecosystems status, pressures, impacts and responses. Most of the innovations for which only a minority of survey respondents expects a positive impact on the environment are tools and applications in synthetic biology (*synthesis and assembly of long DNA fragments, modular cloning systems, minimal cells, expansion of the genetic code*) and innovations in digital technologies, which do not directly serve the optimisation of biocatalysts or bioprocesses (*FAIR principle for databases, deep learning*). The latter, nevertheless, are important in data-intensive environmental and biodiversity observation, mapping and monitoring. The 10 innovations with the highest share of survey participants expecting positive impacts on the environment are *screening biodiversity, analysing microbial consortia, new enzymes, optimising biorefineries, biorefineries for new feedstock, using side and waste streams, resource- and energy efficient bioprocesses, carbon-neutral bioprocesses, bio-based materials, increasing and maintaining soil fertility* and *novel farming concepts*.

The majority of survey participants expect positive societal impacts from environmental, nutrition- or health-related innovations: the 10 innovations with the highest share of survey participants expecting positive impacts on the society are *analysing microbial consortia, using side and waste streams, biodegradable plastics, plastic degrading enzymes, bio-based materials, increasing and maintaining soil fertility, novel farming concepts, novel protein sources, health-promoting ingredients* and *novel antimicrobial agents.* It would, however, be a misinterpretation of the data presented in Table 8 to assume that the positive impacts of the top 50 bio-based innovations portfolio on society are lower than for economy and environment. Rather, Table 8 displays only *direct, short-term* positive impacts on society for innovations. These impacts are directly "visible", perceivable and explainable to citizens due to concrete applications, such as waste reduction and recycling or healthy food whereas more abstract, indirect or long-term positive impacts are not displayed. This can be illustrated with the examples of *plastic degrading enzymes* and *new enzymes* (Table 8): for the concrete enzyme application of plastic degradation, a majority of survey respondents mark a positive societal impact, whereas for the cross-cutting innovation *new enzymes* only few experts stress the (very likely) positive societal impact. Considering that innovations in the field *cross-cutting technologies or approaches* without concrete applications make up approximately 50 % of the top 50 bio-based innovations portfolio, it can be concluded that the positive societal impacts of the top 50 bio-based innovations are clearly underestimated in Table 8.

Most innovations are expected to have positive impacts in several impact categories simultaneously. For three of the top 50 bio-based innovations, more than 75 % of the survey participants expect positive impacts for knowledge base, economy, environment and society. These are *Using side and waste streams, Bio-based materials* and *Increasing and maintaining soil fertility* (Figure 5).

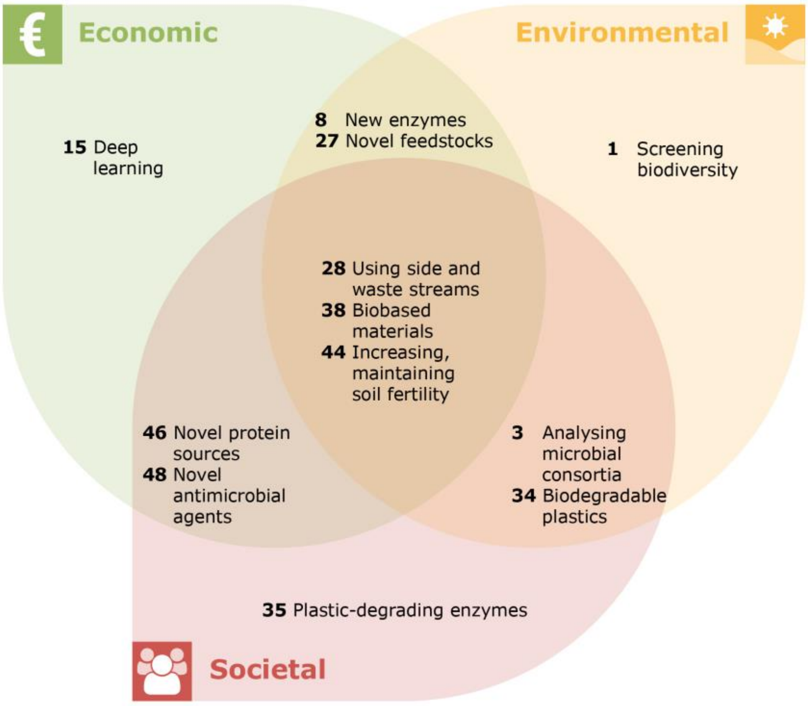

Figure 5. Expected impacts of selected top 50 bio-based innovations

Source: EU-wide online expert survey; selected innovations are displayed for which more than 75 % of survey respondents see a positive impact

Issues to be addressed to overcome existing hurdles

Participants in the EU-wide online expert survey were asked to choose three issues per innovation, which should be addressed with priority to overcome existing hurdles for the respective innovation. The results are shown in Table 9 and Table 10. In line with the different maturity levels of the top 50 bio-based innovations, different hurdles for the further development and exploitation of the innovations exist. For most of the top 50 bio-based innovations in the field *cross-cutting technologies and approaches*, R&D, cooperation and innovation financing are the major issues to be addressed, pointing to the need to include these cross-cutting technologies and approaches in publicly funded R&D programmes, which support interdisciplinary and academia-industry cooperation. R&D needs are a major issue especially for innovations of presently low maturity, but high future relevance (*microbial electrosynthesis*), and for innovations with a high, but currently underexploited potential (microbiome research and applications: *analysing and engineering microbial consortia, increasing and maintaining soil fertility, probiotic sanitation strategies*; *digital technologies, screening biodiversity, novel algae products*). Not surprisingly, standards are a key issue for innovations in synthetic biology (*synthesis and assembly of long DNA fragments, modular cloning systems, minimal cells, expansion of the genetic code*), because the bioengineering approaches of synthetic biology are built on the use of standardised parts („biobricks"). The *FAIR principle for databases* is a standard in itself. For *precision genome editing*, survey respondents chose regulation together with public perception, acceptance as key issues because the present regulation in the EU is perceived as a hindrance to exploiting the full potential of this technology.

Table 9. Issues to be addressed with priority to overcome existing innovation-specific hurdles

Field		Innovation	R&D	Cooperation	Innovation financing	Regulations, standards	Market creation	Public perception, acceptance
Cross-cutting technologies and approaches	1	Screening biodiversity						
	2	-omics technologies						
	3	Analysing microbial consortia			*		*	
	4	Lab-on-a-chip						
	5	Biosensing		*	*	*		
	6	Macromolecular design						
	7	Multi-enzyme biocatalysis						
	8	New enzymes						
	9	Precision genome editing	*	*	*			
	10	Synthesis and assembly of long DNA fragments						
	11	Modular cloning systems				*		
	12	Minimal cells						
	13	Expansion of the genetic code						
	14	FAIR principle for databases						
	15	Deep Learning						
	16	Computational protein design						
	17	Computational cell factory engineering			*	*		
	18	Process models						
	19	Novel microbial cell factories						
	20	Engineering microbial consortia						
	21	Microbial Electrosynthesis						
	22	Optimising biorefineries		*		*		
	23	Biorefineries for new feedstock		*		*	*	*
	24	Reactor design and process monitoring						
	25	Cell heterogeneity			*	*		
	26	Stress-tolerant production organisms						

Table 10. Issues to be addressed with priority to overcome existing innovation-specific hurdles

Field		Innovation	R&D	Cooperation	Innovation financing	Regulations, standards	Market creation	Public perception, acceptance
Innovation areas or solutions to challenges	27	Novel feedstock						
	28	Using side and waste streams						
	29	Supply and pretreatment of novel feedstock		*			*	
	30	Resource- and energy efficient bioprocesses						
	31	Carbon-neutral bioprocesses						
	32	CO_2-based chemicals						
	33	Climate-gas mitigation of microbial activities						
	34	Biodegradable plastics						
	35	Plastic degrading enzymes						
	36	Smart drop-ins						
	37	Dedicated bio-based chemicals						
	38	Bio-based materials						
	39	Bio-functional materials	*	*				
	40	Novel algae products						
	41	Crop improvement targeting genome and epigenome		*	*			
	42	de novo domestication	*	*	*			
	43	Asexual reproduction of seeds			*	*		*
	44	Increasing and maintaining soil fertility						
	45	Novel farming concepts						
	46	Novel protein sources		*	*			
	47	Health-promoting ingredients	*	*	*			
	48	Novel antimicrobial agents						
	49	Probiotic sanitation strategies						
	50	Veterinary DNA vaccines						

Source: EU-wide online expert survey; the three issues are coloured which were chosen by most respondents. If more than three issues were given the same number of votes, this is marked with an asterisk.

In the field *Innovation areas or solutions to challenges*, R&D is only a priority issue for 11 out of 24 innovations: In this field, striving for industrial implementation and commercialisation is more important than in the field *cross-cutting technologies and approaches.* As a consequence, cooperation between feedstock providers and converters, between partners along the value chain and between core bio-based sectors and more distant industrial sectors is required in addition to interdisciplinary and academia-industry cooperation. Moreover, many innovations in this field are on the scale-up and demonstration maturity level (Table 6). In order to reach full implementation and market introduction, it is required to make financial resources available for investments into production facilities, and to create markets for the envisioned products and services, e.g. by frame conditions and demand-side support measures which give unique selling propositions of bio-based products a competitive advantage. Public perception and acceptance is not only an issue for innovations, which are controversially debated (*precision genome editing* and its applications, especially in crop breeding: *crop improvement targeting genome and epigenome, asexual reproduction of seeds*). It is also an issue for bio-based products (e.g. *dedicated bio-based chemicals*) where it relates to business decision-makers (e.g. brand owners) to invest in such products and processes, and to consumers' willingness to buy bio-based products. The possibility of local resistance in the population to new bio-based production facilities (*biorefineries for new feedstock*) should also be anticipated and be addressed proactively.

All in all, the broad spectrum of issues to be addressed with priority to overcome existing hurdles points to the need to develop holistic, comprehensive R&D&I support programmes which comprise a broad tool box of instruments.

Conclusions

To sum up, the portfolio of top 50 bio-based innovations represents important developments and innovations in the life and biological science and technologies and covers their complexity and potential in a well-balanced way. The top 50 bio-based innovations are of high relevance for the advancement of the bio-based sectors and achieving impacts in SDGs and major policy goals. However, the portfolio is not a 1:1 blueprint for R&D&I support programmes. Rather, a prioritisation of the top 50 bio-based innovations is required according to specific strategic goals and application areas, pointing to the need to turn this portfolio into tailor-made action plans and roadmaps.

This study took advances in the life and biological science and technologies as engines for innovations in the bio-based sectors as starting point and thus viewed the area from a science and technology driven perspective. However, the policy analysis (section3) shows that there is a clear shift from biotech-oriented R&D&I programmes towards goal- and mission-oriented programmes, both on EU and Member States level. This shift presents several challenges to the support of the top50 bio-based innovations: although the top 50 bio-based innovations are taken into account in strategies, action plans and programmes, they are widely scattered and often difficult to identify. It is therefore important that researchers are given guidance to find suitable programmes and calls. Moreover, a good balance must be struck between actively supporting the integration of biological sciences and technologies expertise into application-oriented communities on the one hand, and maintaining a critical mass in (non-application-oriented) biological sciences and technologies expertise on the other hand. And finally yet importantly, a level playing field for all solutions in technology-open R&D&I programmes should be ensured.

3 Policy mapping and assessment

3.1 Introduction

Bio-based sectors[3] are a cross-cutting field that interconnects many economic sectors. It is Europe's response to current global challenges, such as global warming, food security and resource sustainability, which are directly linked to UN Sustainable Development Goals (SDGs). The transition towards sustainable bio-based sectors requires advances in life and biological sciences and the implementation of policies thereof.

Bio-based innovation can contribute to reach the UN Sustainable Development Goals (SDGs) and related goals as set in EU strategies and initiatives. The strategies and implementation programmes create the conditions enabling bio-based research and innovation. In this section, attention will be paid to these relations as illustrated in Figure 6.

Figure 6: Relations between SDGs, EU strategies, implementation programmes and life science and biotechnology for bio-based innovation, as explored in this section

Section 3.2 provides an assessment of relevant SDGs to which life science and biotechnology can contribute, with the top 50 bio-based innovations as starting point. The envisaged role of life science and biotechnology for bio-based innovation as foreseen in relevant EU strategies and initiatives is presented in section 3.3. Since Horizon 2020 and BBI JU are key funding initiatives supporting bioscience and technology driven bio-based innovation, main results of formal reviews and evaluations of these programmes are summarised and discussed in section 3.4. Moreover, the role of the different funding programmes under Horizon 2020 for the deployment of bio-based innovation is explored by a detailed analysis of 111 projects with a direct relation to the top 50 bio-based innovations. In section 3.5 an overview of national policies and regional approaches is provided with a focus on the role of life science and biotechnology in bioeconomy strategies and other policy documents. Details of each Member State and the United Kingdom are presented in country fiches which can be found in Annex V. The assessment of policies, interviews with stakeholders and a workshop held on 11 November 2020 has resulted in a selection of policy related topics that have been assessed in more detail in section 3.6, i.e.:

[3] As outlined in section 2 the study relates to bio-based sectors, which represents a part of the bioeconomy. But as most policy initiatives relate to the whole bioeconomy, mostly the later term is used in this section.

the role of industrial technology roadmaps, the transition to a circular bioeconomy, the role of Central and Eastern European countries, the role of regional bioeconomy clusters, and GMO legislation.

3.2 Contribution to UN Sustainable Development Goals

The international community has adopted the UN Sustainable Development Goals (SDGs) and the comprehensive Paris Agreement on climate change (COP21) back in 2015. The 17 SDGs provide a framework to develop and achieve a more sustainable future. These goals are interconnected and must be achieved by 2030. For each innovation it has been determined to which SDGs they contribute (See Annex VI). Figure 7 shows what percentage of the top 50 bio-based innovations contributes to specific SDG.

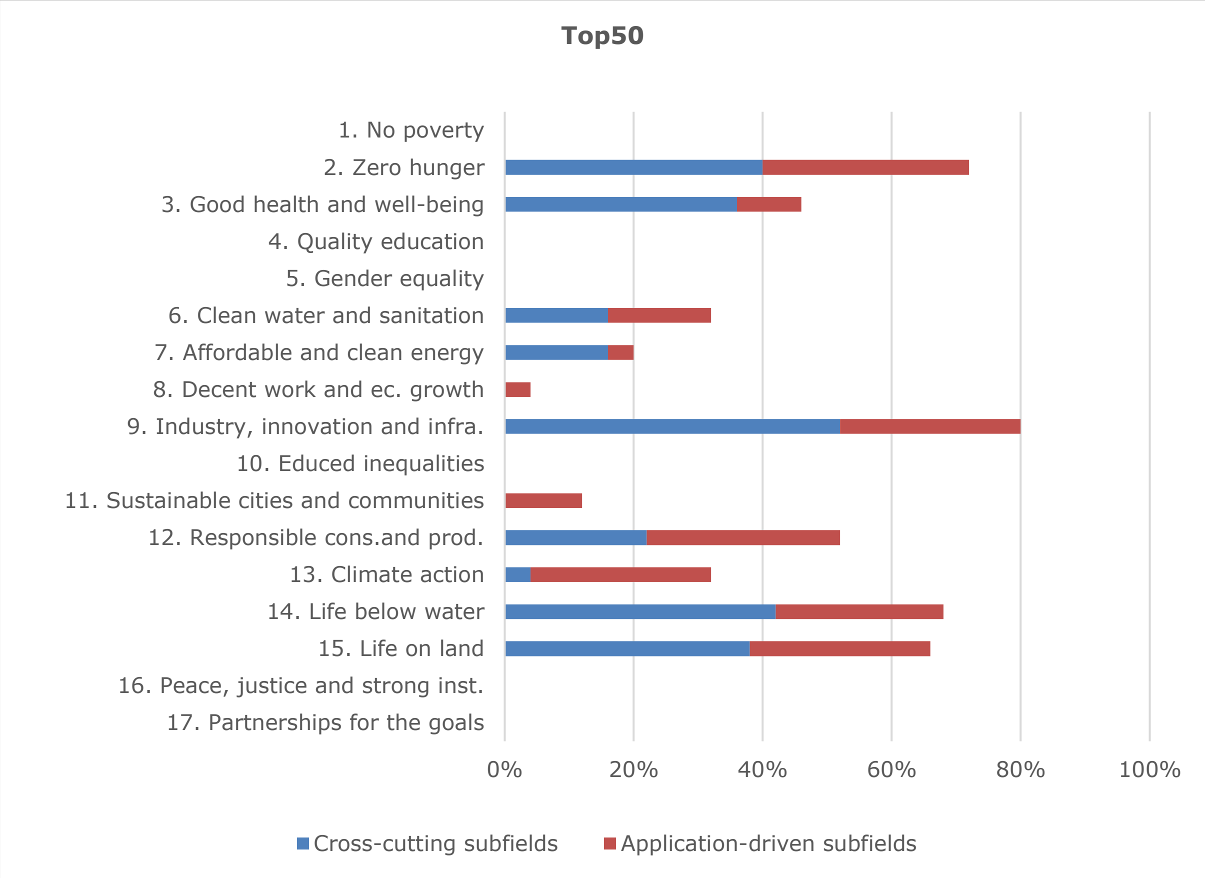

Figure 7: Percentage of top 50 bio-based innovations covering specific SDGs

With 80% of the top50 of bio-based innovations contributing to SDG 9 *Industry, innovation and infrastructure*, this is the most prominently targeted SDG. The contributions to SDGs 12, 14 and 15 are also strong. The direct link with climate action is strong in the application-driven innovations but less in the cross-cutting technologies resulting in a relative low score. The strong link with SDG 2 *zero hunger* exists because many innovations - although not the focus of our research - have multiple applications, including food.

Our assessment of the top 50 bio-based innovations shows large overlaps with the envisaged contribution of industrial biotechnology to delivering UN SDGs as assessed by EuropaBio (2018) as shown in Table 8. In addition, the table shows which SDGs are taken up by the Horizon Europe clusters *Digital and Industry*, and *Food and Natural Resources*, clusters for which a substantial role for life science and biotechnology is foreseen. The contributions to SDGs as found in our top 50 bio-based innovations are well in line with relevant policies. The contribution to SDG 12 *responsible consumption and production* and SDG 13 *climate action* are mentioned in all investigated documents as well as in our own assessment. Not coincidentally these are the main topics of the European Green Deal as overarching EU policy framework.

Table 11. Contribution of relevant Horizon Europe clusters and biotechnology to SDGs

#	SDG	Horizon Europe - Cluster Digital and Industry	Horizon Europe – cluster 6 "Food, Bioeconomy, Natural Resources, Agriculture and Environment	Industrial bio-techology (EuropeBio 2018)	top50 bio-based inno-vations
1	No poverty			✓	
2	Zero hunger		✓	✓	✓
3	Good health and well-being				✓
4	Quality education				
5	Gender equality				
6	Clean water and sanitation			✓	✓
7	Affordable and clean energy			✓	✓
8	Decent work and economic growth	✓	✓	✓	
9	Industry, innovation and infrastructure	✓		✓	✓
10	Reduced inequalities				
11	sustainable cities and communities		✓	✓	✓
12	Responsible consumption and production	✓	✓	✓	✓
13	Climate action	✓	✓	✓	✓
14	Life below water		✓	✓	✓
15	Life on land		✓		✓
16	Peace, justice and strong institutions				
17	Partnerships for the goals			✓	

Sources: Horizon Europe: COM(2018) 436; EuropaBio (2018) and this tender study

3.3 Mapping and assessment of EU strategies

Below the role of life sciences and biotechnology in relevant EU strategies is highlighted. Moreover, relevant information from formal evaluations supplemented with information obtained during the interviews and workshops is presented.

EU Bioeconomy Strategy - 2012

The European Commission implemented an EU Bioeconomy Strategy ('Innovating for sustainable Growth: A Bioeconomy for Europe) in 2012[4]. The European Commission (2017) has performed a mid-term review of the 2012 European Bioeconomy Strategy and Action Plan.[5] The main findings were that key actions proposed in the Action Plan were carried out and resulted in an over two-fold increase in dedicated EU funding for the bioeconomy under Horizon 2020 (4.52 billion Euro for 2014 – 2020) compared to FP7, its predecessor programme (1.9 billion Euro for 2007 – 2013). Also, the launch of the BBI JU was mentioned as a major deliverable. Further mobilisation of investments is still needed, which requires a stable regulatory environment. Moreover, the need for inclusion of circularity was addressed, and the need for better monitoring and assessment frameworks to assess progress. The review has been used as input to develop the updated Bioeconomy Strategy of 2018, as clearly pointed out in the Commission Staff Working Document (SWD/2018/431)attached to the Bioeconomy Strategy.[6]

Updated EU Bioeconomy Strategy - 2018

In 2018, the EU Bioeconomy Strategy has been updated (COM/2018/673) as a response to new European policy priorities and aims to accelerate the deployment of a sustainable European bioeconomy, thereby maximising its contribution towards the 2030 SDGs and COP21.[7] One major EU policy priority is *'strengthening European competitiveness and creating jobs'*. Here, the EU strives to capitalise on the advances in life sciences and biotechnologies, as well as innovations that merge the physical, digital, and biological worlds.

To support the existing five objectives laid out in the 2012 EU Bioeconomy Strategy, the updated strategy defined three main action areas:

1. Strengthening and scale-up the bio-based sectors, unlock investments and markets;

2. Deploy local bioeconomies rapidly across Europe;

3. Understand the ecological boundaries of the bioeconomy.

The first action area relies on its competitive industrial base that develops and deploys new bio-based value chains, based on the use of renewable resources including waste.

According to the strategy, maintaining and enhancing global leadership of the European industrial base requires the exploitation of advances in life sciences and biotechnologies and the promotion of technologies such as artificial intelligence. Therefore, the EU will intensify the mobilisation of public and private stakeholders, in research, demonstration and deployment of bio-based solutions (Action 1.1). In addition to research and innovation grants under Horizon 2020, the EU will deploy an additional financial instrument (European Circular Bioeconomy Find (ECBF) good for EUR 100 million (See section 3.3). It is expected that these actions result in the development of a tool box of solutions to process biomass into bio-based products, which will support the modernisation and the renewal of the EU industries.

It seems that the EU is fully aware of the potential of life sciences and biotechnology as advances in these disciplines are strongly linked to the generation of economic value and future revenue.

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[4] https://ec.europa.eu/research/bioeconomy/pdf/official-strategy_en.pdf
[5] https://ec.europa.eu/research/bioeconomy/pdf/review_of_2012_eu_bes.pdf
[6] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018SC0431
[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0673

The European Green Deal

The European Green Deal (COM(2019)640)[8] resets the Commission's commitment to tackling climate and environmental-related challenges, while maintaining sight on the SDGs of the UN. The European Green Deal is a response to challenges such as climate warming, the extinction of species, and the pollution of forests and oceans. The initiative aims to promote a modern, resource-efficient, and competitive economy having no net emissions of greenhouse gases in 2050, and where economic growth is decoupled from resource use.

The European Green Deal consists of eight action areas where digitalisation of many economic sectors is vital to achieve, for instance, climate objectives in 2030 and 2050. The European Green Deal does not show particular commitment towards the promotion of life science and biotechnologies, but is indirectly relying on these principles as it seeks to develop new innovative techniques to promote the sustainability of the food system (i.e. reduce use of chemical pesticides, fertilisers and antibiotics). Moreover, the European Green Deal refers to several strategies and initiatives relevant for biotechnology enabling bio-based innovation such as the Circular Economy Action Plan 2020, and the EU Industrial Strategy, as well as Horizon Europe– the new European research and innovation framework programme.

The Circular Economy Action Plan -2020

The EC has adopted the New Circular Economy Action Plan 2020[9] as key part of the European Green Deal to ensure a climate-neutral, resource-efficient and competitive economy. The EC is planning to review Directive 94/62/EC on packaging and packaging waste to reinforce the mandatory essential requirements for packaging, thereby driving the design for re-use and recyclability. Furthermore, the EC aims to address emerging sustainability challenges by developing a policy framework on the use of biodegradable or compostable plastics. The New Circular Economy Action Plan 2020 does not address life sciences and biotechnology directly but refers to the EU Bioeconomy Strategy and its Action Plan. Circular thinking is expected to become an integral part of the bioeconomy, leading to a circular bio-based sectors.

EU Industrial Strategy

The scope of the New EU Industrial Strategy (COM(2020)102)[10] is to help Europe's industry lead the twin transitions towards climate neutrality and digital leadership. The strategy states that the global race on the twin transitions will increasingly be based on frontier science and mastering deep technologies. Foresight suggests that the next era of industry will be one where the physical, digital, and biological worlds are connected. This calls for the development of individual roadmaps from the industrial sectors dedicated towards climate neutrality and digital leadership, which should be supported through public-private partnerships. Furthermore, the European Innovation Council (to be launched in 2021) will focus on identifying next generation technologies and thereafter accelerate their commercial application. Maintaining a competitive industry not only requires next generation technologies but also the recruitment of a qualified workforce. Therefore, Europe must increase investment in skills for which actions are required from industry and the Member States (European pact for skills) together with the European Education Area.

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[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN
[9] https://ec.europa.eu/jrc/communities/sites/jrccties/files/new_circular_economy_action_plan.pdf
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0102

EU Farm to Fork Strategy and CAP reform

The EU Farm to Fork Strategy (European Union 2020)[11] as part of the European Green Deal expects that new innovative techniques, including biotechnology and the development of bio-based products, may play a role in increasing sustainability, provided they are safe for consumers and the environment while bringing benefits for society as a whole. The Common Agricultural Policy (CAP) reform (COM(2018)392)[12] does not specifically address life sciences and biotechnology. Links can be found with the European Green Deal and the bioeconomy strategy, though. According to a recent analysis of links between CAP Reform and European Green Deal (SWD (2020)93)[13], *with one of the CAP specific objectives targeting the promotion of the bioeconomy, the future CAP Strategic Plans may include interventions aiming at unleashing a new potential for increasing farmers income and supporting the shift towards a carbon free economy. Using food and feed residues, farm waste or other bio-based resources to produce textiles, natural packaging (replacing plastic), construction materials (reducing the use of energy-intensive materials such as steel and cement) or to produce a clean and affordable energy (e.g. through biogas production) could also help the farmers to diversify their income while significantly contributing to the European Green Deal*.

Revised EU Waste Framework Directive - bio-waste

The Waste Framework Directive 2008/98/EC[14] as revised by Directive (EU) 2018/851[15] requires Member States to ensure that, by 31 December 2023, bio-waste is either separated and recycled at source, or is collected separately and is not mixed with other types of waste. Furthermore, Member States shall take measures to encourage the recycling, including composting and digestion, of bio-waste and to promote the use of materials produced from bio-waste. Bio-waste is an important resource for the full deployment of the bioeconomy. It does not require additional land and avoids associated environmental impacts. Several innovations in the subfield *sustainable exploitation of novel feedstock* are focused on the optimal usage of bio-waste.

3.4 Mapping and assessment of EU implementation programmes

The EU recognizes the importance of supporting research and innovation as it generates the scientific and technological breakthroughs needed to tackle the urgent challenges that society faces. Therefore, the EU launched framework programs for research and innovation, which supports the creation of innovative products and services with the aim to deliver on global challenges and industrial modernisation. The relevance for bioscience and biotechnology for bio-based innovation of the main programmes, e.g. Horizon 2020 and its successor Horizon Europe, as well as BBI JU and the new European Circular Bioeconomy Fund (ECBF) is discussed below. More detailed introductory descriptions of the programmes can be found in Annex I.

Horizon 2020

Horizon 2020[16] is the 8th framework programme funding research, technological development, and innovation. It is a seven-year program running from 2014 to 2020 having a total budget of 77 billion Euro, which is distributed over the following three distinct priorities: excellent science, industrial leadership and societal challenges. Within industrial leadership, biotechnology is acknowledged as Key Enabling Technology. By careful assessment of the CORDIS database, we have identified 111 Horizon 2020 projects

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[11] https://ec.europa.eu/food/sites/food/files/safety/docs/f2f_action-plan_2020_strategy-info_en.pdf
[12] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A392%3AFIN
[13] https://ec.europa.eu/transparency/regdoc/rep/10102/2020/EN/SWD-2020-93-F1-EN-MAIN-PART-1.PDF
[14] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF
[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L0851
[16] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32013D0743

(including BBI JU projects) that funded the identified top 50 bio-based innovations. The total EC contribution of these 111 selected projects was 544 million Euro (EU-27 + UK). Table 12 shows the distribution of this amount by Technical Readiness Level (TRL) and type of funding programme.

Table 12. Distribution of EU contribution of 111 selected Horizon 2020 projects that have a direct link with the top 50 bio-based innovations, between funding programmes (EU-27 + UK)

Group	Funding programme	Abbreviation	TRL		Amount (Mio. Euro)
1. Research and Development	European Research Council grants	ERC	1	2	256
	Marie Skłodowska-Curie actions	MSCA	1 - 5	19	
	BBI Research and Innovation Actions	BBI-RIA	3 - 5	90	
	H2020 Research and Innovation Action	RIA	3 - 5	145	
	SME instrument phase 1	SME1	4 - 5	0.5	
2. Demo-scale	H2020 Innovation Action	IA	6 - 7	64	182
	BBI Innovation Actions – Demonstration	BBI-IA-DEMO	6 - 7	108	
	SME instrument phase 2	SME2	6 - 7	10	
3. Large-scale	BBI Innovation Actions - Flagship	BBI-IA-FLAG	8	106	106

It becomes clear that not only research and development but also demonstration projects and flagships have received considerable amounts of EU funding. Figure 8 shows that the subfield '*enabling bio-based production at industrial scale*' has received the largest amount of EU funding by these 111 selected H2020 projects, thanks to large budgets for flagships and demo scale projects. Also, the subfields '*sustainable exploitation of novel feedstock*' and '*bio-based intermediates, materials and product groups*' have received substantial funding. The subfield *health and well-being* was not covered within the selection of projects, mainly because this subfield is at the boundary of the scope of this study, as red biotechnology is excluded (see section 2). Therefore, the figure should not lead to the conclusion that this subfield is not supported at all.

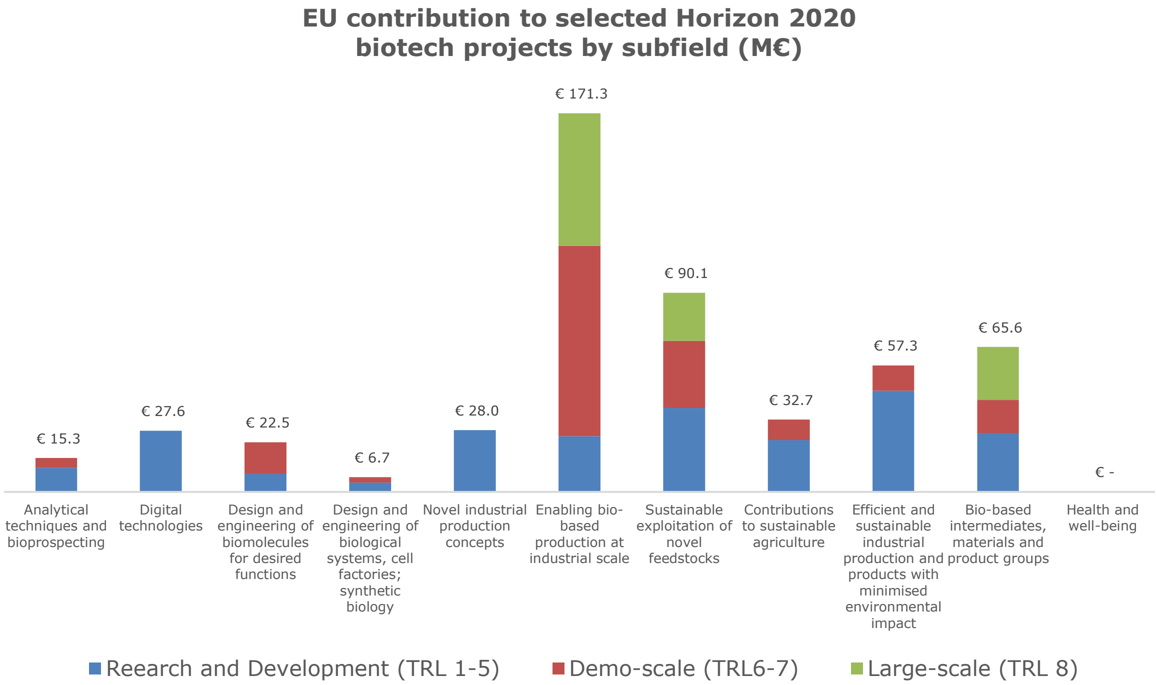

Figure 8: Distribution of EU contributions per subfield. Source: own assessment solely based information available in the CORDIS database.

More information, including top ten of recipients of EU funding, and distribution of funding among the top 50 bio-based innovations can be found in Annex III. The country fiches presented in Annex V provide more information on the budget allocation and the top-10 of most active actors per Member State.

Horizon Europe

The Commission's proposal for Horizon Europe[17] is an ambitious EU research and innovation framework programme to succeed Horizon 2020. Horizon Europe will be structured in three pillars: (1) open Science; (2) global challenges and European industrial competitiveness and (3) open innovation. Research and innovation under the second pillar is grouped into integrated clusters of activities, e.g. health; inclusive and secure society; digital and industry; climate, energy and mobility; and food, bioeconomy, natural resources, agriculture and environment.

Within the cluster *Digital and Industry*, great emphasis is placed on making the digitised, circular, low-carbon and low-emission economy a reality. The EU wants to ensure that all industrial players, and society at large, can benefit from advanced and clean technologies and digitisation. Within several areas of intervention of the cluster "*Food, Bioeconomy, Natural Resources, Agriculture and Environment"*, life sciences and biotechnology can play a pivotal role. The broad lines of „bio-based innovation" summarise well what society and Horizon Europe expects from bio-based innovation including the role of life science and biotechnology:

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A436%3AFIN

Box 5: Key points of the broad lines of bio-based innovation

- Sustainable biomass sourcing and production systems, focusing on high-value applications and uses, social and environmental sustainability, impact on climate and biodiversity reduction targets and overall resource efficiency.
- Life sciences and their convergence with digital technologies for prospecting, understanding and sustainable use of biological resources.
- Bio-based value chains, materials, including bio-inspired materials, products and processes with novel qualities, functionalities and improved sustainability (including sustainability), fostering the development of advanced biorefineries using a wider range of biomass.
- Biotechnology, including cross-sectoral cutting-edge biotechnology, for application in competitive, sustainable and novel industrial processes, environmental services and consumer products.
- Circularity of the bio-based economy through technological, systemic, social and business model innovation to radically increase the value generated per unit of biological resources, keeping the value of such resources in the economy for longer and supporting the principle of the cascading use of sustainable biomass through research and innovation;
- Inclusive bioeconomy patterns with different actors participating in the creation of value, maximising societal impact.
- Increased understanding of the boundaries of the bio-based economy and its synergies and trade-offs with a healthy environment.

The Bio-based Industries Initiative – BBI JU

The public-private partnership Bio-based Industries Joint Undertaking (BBI JU) is an integrated and fundamental tool under Horizon 2020 to realize the bio-based industry vision and potential. According to the 2017 mid-term evaluation (DG Research and Innovation 2017[18]), BBI JU was deemed essential for structuring and mobilising a sector that was extremely fragmented across geographies and industrial applications. Moreover, it has triggered additional investment by the industry in Europe, for example by flagship projects[19]. In June 2020, a draft proposal for a European Partnership for a Circular Bio-based Europe (CBE)[20]was published including lessons learned from BBI JU.

This positive overall impression was confirmed by interviews with involved stakeholders. The responsiveness of BBI JUto evolving fields e.g., marine biomass was appreciated in the mid-term evaluation of 2017 and during interviews. NGOs are sceptic about the high level of industry participation in setting the agenda[21], focusing mainly on production processes and low real attention paid to biodiversity impacts within BBI JU. It can be expected that an industry led consortium mainly focuses on new processes and value chains but understanding the ecological boundaries of the bioeconomy is key to the long-term success of the bioeconomy and therefore important action areas of the updated in 2018 EU Bioeconomy Strategy as well as Draft CBE proposal. In addition, circular thinking with its focus on resource efficiency and utilisation of waste streams would be integral part of the proposed European Partnership for a Circular Bio-based Europe (CBE).

[18] https://ec.europa.eu/research/bioeconomy/pdf/publications/bioeconomy_expert_group_report.pdf
[19] For a more detailed description see Annex III
[20] https://www.jointprogramming.nl/upload_mm/1/6/2/e1d0b695-37da-46b6-b03b-b31261dd0289_PP_HEU_Biobased.pdf
[21] For instance as expressed during the webinar „The State of Bioeconomy Policies in the EU" organised by Denkhaus Bremen on October 6th 2020.

European Circular Bioeconomy Fund (ECBF)

The ECBF is jointly developed by the European Investment Bank (EIB) and the European Commission with the aim to fill funding gaps faced by circular bioeconomy projects. With a target size of 250 million Euro, to which the European Investment Bank (EIB) has committed 100 million Euro, ECBF will be an important financial instrument in achieving the European Green Deal goals of making Europe climate neutral by 2050[22]. The BBI JU identified the ECBF as a financial synergy with EU policy initiatives (Bio-based Industries Consortium 2020). Investments are focused on companies or projects with Technology Readiness Level (TRL) of 6-9 and some first significant commercial traction with the aim to increase public and private capital investment to help scale-up innovations in the bioeconomy and circular bioeconomy. This means that the fund is an important addition to current available funds for the further market deployment of bio-based innovation.

3.5 Mapping and assessment of national policies

As can be observed from the „knowledge4policy" part of the EU website[23] many EU Member States have published a bioeconomy strategy and developed approaches to promote the bioeconomy in their respective countries. The available overviews have no special focus on the role of life sciences and biotechnology in these bioeconomy strategies. This information was obtained by screening national biosciences related policies and scrutinising the bioeconomy strategies.

Table 13. Overview of availability of bioeconomy strategy, action plan, bioscience related policy and national support measures in the EU-27 plus UK.

	Bioeconomy policies in place in EU27 + UK				EU contribution (111 selected H2020 projects)	
Country	Bioeconomy Strategy	Action plan	Bioscience related policy	National support measures	Mln. Euro	Euro/ capita
Austria	✓	✓	✓	✓	14.6	1.65
Belgium	✗	✗	✓	✓	29.4	2.54
Bulgaria	✗	✗	✓	✓	0.1	0.02
Croatia	✓	✗	✓	✓	2.0	0.50
Cyprus	✗	✗	✓	✓	0.6	0.67
Czech Republic	✗	✗	✓	✓	2.1	0.20
Denmark	✗	✗	✓	✓	21.4	3.67
Estonia	✗	✗	✓	✓	0.7	0.56
Finland	✓	✓	✓	✓	15.5	2.81

[22] See https://www.ecbf.vc/team
[23] https://ec.europa.eu/knowledge4policy/visualisation/bioeconomy-different-countries_en

France	✓	✓	(✓)	✓	61.4	0.92
Germany	✓	(✓)	✓	✓	75.0	0.90
Greece	✗	✗	✗	✓	8.2	0.76
Hungary	✗	✗	✗	(✓)	0.1	0.01
Ireland	✓	✓	(✓)	✓	25.9	5.22
Italy	✓	✓	(✓)	✓	62.7	1.04
Latvia	✓	✗	(✓)	(✓)	0.3	0.17
Lithuania	(✓)	✗	(✓)	✓	1.7	0.63
Luxembourg	✗	✗	(✓)	(✓)	0.6	1.01
Malta	✗	✗	✗	(✓)	0.0	0.00
Netherlands	✓	✗	(✓)	✓	73.9	4.25
Poland	(✓)	✗	(✓)	(✓)	2.9	0.08
Portugal	(✓)	✗	(✓)	✓	11.7	1.14
Romania	✗	✗	(✓)	(✓)	21.3	1.10
Slovakia	(✓)	✗	(✓)	(✓)	0.6	0.11
Slovenia	✗	✗	(✓)	✓	3.4	1.63
Spain	✓	✓	(✓)	✓	63.2	1.33
Sweden	✓	✗	✓	✓	17.4	1.69
United Kingdom	✓	(✓)	✓	✓	26.9	0.40
Total					**543.7**	**1.06**
Yes	11	6	5	20		
Partly	5	2	20	8		
No	12	20	3	0		

Note: please refer to Annex III for an explanatory note of the indicators

Table 13 shows that about 11 countries have a bioeconomy strategy, but only 6 have also an action plan with concrete measures, even though action plans are regarded as the key resource for effective strategy execution. Five countries have a separate bioscience related policy. Many countries have bioscience related policies integrated in for instance their bioeconomy strategy or another policy. In only a few cases we could not find a bioscience related policy at all. There is high thematic variety with regard to bioeconomy in different strategies and policy documents. The term bioeconomy is sometimes also used as a buzzword that includes all renewable resources processed into bio-based products, food, feed and bioenergy. Moreover, there is still a lack of coherent, detailed and realistic bioeconomy strategies, especially in the CEE countries, where bioeconomy as a topic is often fragmented between different policies and these policies lack coordination between themselves (e.g. policies on bio-waste management in different Member States).

In order to get insight in the level of activity of the Member States as well as the UK, the distribution of EU contribution funding of the 111 selected Horizon 2020 projects with a direct link with the top 50 bio-based innovations between Member States was assessed as well. The results of the assessment are summarised in the right two columns of Table 13 and Table 14 More details at Member State level can be found in the country fiches in Annex V. The regional distribution of EU biotech funding of 111 selected projects by main region is presented in Figure 9.

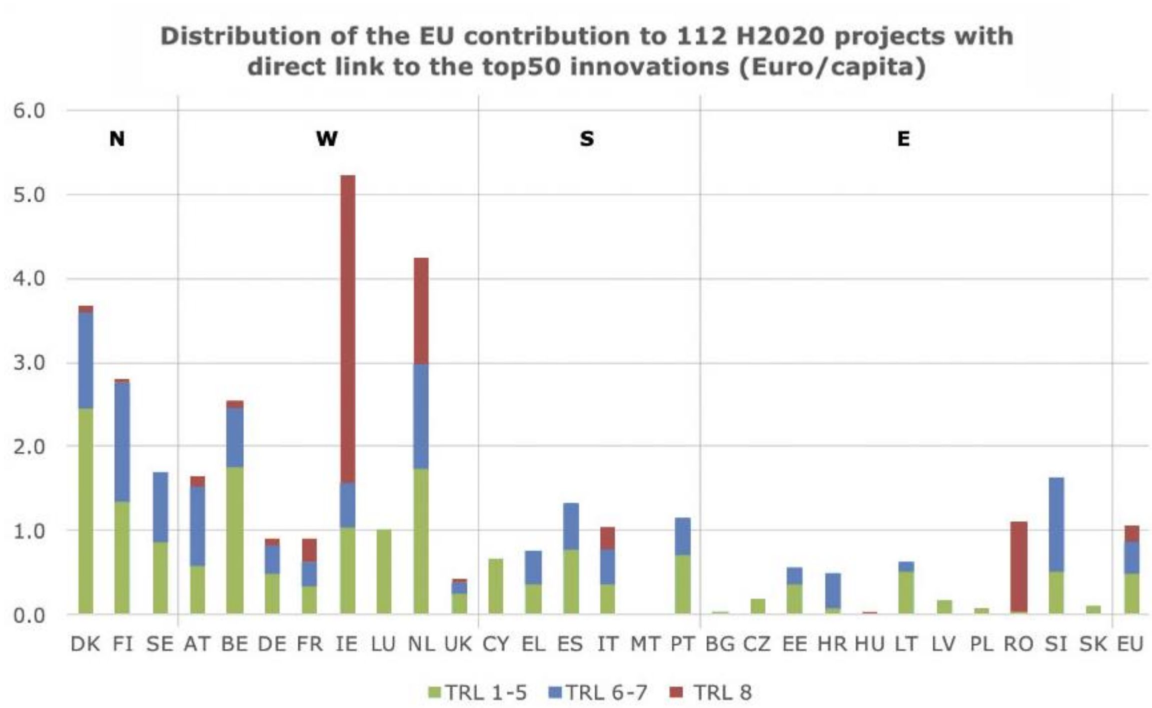

Figure 9: Distribution of the EU contribution to 112 H2020 projects with direct link to the top 50 bio-based innovations (Euro/capita). Source: own assessment solely based information available in the CORDIS database.

Countries with a high level of EU biotech funding per capita have a bioeconomy strategy (Ireland, Netherlands) or a separate bioscience related policy (Denmark) in place. Countries that receive a low level of EU biotech funding (many Central and Eastern European countries), often have no bioeconomy strategy in place.

Concerning the differences between regions, Western European countries dominate the EU budget allocation at all TRL levels, and that the Central and Eastern Countries only receive 7% of the available budget (35 million Euro), of which 59% is part of a few big Flagship projects. Flagships are big TRL-8 projects which have quite some impact on the regional distribution. Their share is relatively high in Central and Eastern and low in the Nordic countries.

Table 14. Distribution of the EU contribution to 111 H2020 projects with direct link to the top 50 bio-based innovations (Euro/capita). Source: own assessment solely based information available in the CORDIS database. Million Euro.

Region	Million Euro TRL 1-5	Million Euro TRL 6-7	Million Euro TRL 8	Total	%
Northern European countries a)	31	23	1	54	11%
Western European countries	126	87	68	280	54%
Southern European countries	71	59	16	146	28%
Eastern European countries	10	5	21	35	7%
EU-27	238	173	105	516	100%
Northern European countries a)	56%	42%	1%	100%	
Western European countries	45%	31%	24%	100%	
Southern European countries	49%	40%	11%	100%	
Eastern European countries	28%	13%	59%	100%	
EU-27	46%	34%	20%	100%	

[a] See Figure 6 for the classification of Northern, western Southern and Eastern European countries

3.6 Assessment of policy approaches by topic

During the interviews and assessment of strategies and funding programmes, a number of topics appeared to be particularly relevant. The following topics are discussed in more depth in this section:

- The role of industrial technology roadmaps
- The transition to a circular bioeconomy
- The role of Central and Eastern European countries
- The role of regional bioeconomy clusters
- The role of GMO legislation

3.6.1 The role of industrial technology roadmaps

Introduction

The overview of policy approaches and implementation programmes (see section 3.3 and 3.4) shows that an overarching challenge-based approach has been established combating climate change and developing a circular economy. Within the Horizon Europe cluster *Digital and Industry* the broad lines of bio-based innovation are described. The Bioeconomy Action plan and the SIRA of BBI JU include biotechnology as part of bio-based innovation. However, currently no high-level industry technology roadmaps covering life science and biotechnology are in place. On the one hand, this is in line with the currently dominant challenge-based approach, which is ideally speaking technology neutral. On the other hand, industrial technology roadmaps could play a role in the development of concrete measures to support relevant innovations, i.e. action plans, which are still lacking in many Member States as shown in the assessment of national policies (section 3.5). Moreover, industrial technology roadmaps can help to highlight relevant innovations with potential impact further in the future, which may not be the focus of the more short-term challenge-oriented strategies.

What is an industrial technology roadmap?

An industrial technology roadmap is a flexible planning technique to support strategic and long-range planning, by matching short-term and long-term goals with specific technology solutions (European Bioeconomy Library 2020). It is a plan that applies to a new product or process and may include using technology forecasting/technology scouting to identify suitable emerging technologies. Developing an industrial roadmap has three major uses (European Bioeconomy Library 2020): (1) It helps reach a consensus about a set of needs and the technologies required to satisfy those needs, (2) it provides a mechanism to help forecast technology developments, and (3) it provides a framework to help plan and coordinate technology developments. It may also be used as an analysis tool to map the development and emergence of new industries.

Existing life science and biotechnology roadmaps

In 2009, the European Commission (COM (2009)512)[24] identified among others industrial biotechnology as one of the Key Enabling Technologies (KETs) for their potential impact in strengthening Europe's industrial and innovation capacity. A Working Group analysed the status and challenges for industrial biotechnology in Europe (Sherpa Group 2011) and results were merged with findings on other KETS in a high-level final report (See European Commission 2011). Throughout the Horizon 2020 programme reference is made to the KETs.

The most recent roadmap that was fully focused on biotechnology was „A roadmap to a thriving industrial biotechnology sector in Europe" (BIO-TIC 2015)[25] that is a main deliverable of the FP7 funded BIO-TIC project. Although this roadmap has no formal status, it has proven to be useful in policy-making. In both the Updated Bioeconomy Strategy and SIRA of BBI JU reference is made to the BIO-TIC roadmap.

Conclusion

The development of such an in-depth industrial technology roadmaps at EU and regional level appears useful, which addresses properly the complexity and wide variety of challenges (related to feedstock, technologies, value chains etc.), in a way coherent with the main EU Bioeconomy Strategy and Circular Economy Action Plan, taking into account innovations at both low and higher stage of development. This is supported by the European Commission proposal for a new Industrial Strategy for Europe (COM (2020)102)[26], which states that *„Industrial sectors should be invited and incentivised to define their own roadmaps for climate neutrality or digital leadership. These should be enabled by high quality research and skills and supported by the EU. A number of sectors have already taken this approach since the launch of the European Green Deal. In the co-design and entrepreneurial spirit of this strategy, this should be supported through Public Private Partnerships to help industry develop the technologies to meet their goals, as has successfully been done in industrial alliances".* In line with the New Industrial Strategy for Europe, a biotechnology roadmap could be developed under the flag of the proposed European Partnership for a Circular Bio-based Europe (CBE).

3.6.2 The transition to a circular bioeconomy

Introduction

According to the Circular Economy Action Plan 2020, circularity is an essential part of a wider transformation of industry towards climate-neutrality and long-term competitiveness. It can deliver substantial material savings throughout value chains and production processes, generate extra value and unlock economic opportunities. The EU

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[24] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0512:FIN:EN:PDF
[25] http://www.industrialbiotech-europe.eu/wp-content/uploads/2015/08/BIO-TIC-roadmap.pdf
[26] COM/2020/102 final

Bioeconomy Strategy and its Action Plan emphasise on the circular character of the bioeconomy. In this section, we investigate the potential contribution of bio-based innovation to the circular economy and bioeconomy, and what circularity means to the way bio-based innovation should take place.

At present, no legal binding EU definition of circular bioeconomy is in place. Stegmann et al. (2020) investigated define the term "circular bioeconomy" via a literature review and analysed the concept's role in north-west European bioeconomy clusters through interviews, resulting in the following definition: the circular bioeconomy focuses on the sustainable, resource-efficient valorisation of biomass in integrated, multi-output production chains (e.g. biorefineries) while also making use of residues and wastes and optimising the value of biomass over time via cascading. Such an optimisation can focus on economic environmental or social aspects and ideally considers all three pillars of sustainability. The cascading steps aim at retaining the resource quality by adhering to the bio-based value pyramid and the waste hierarchy where possible and adequate.

Potential contribution of bio-based innovation to the circular economy

According to the Draft CBE proposal[27], the bioeconomy is the „green motor" of the circular economy. The bioeconomy is the supplier of bio-based carbon, which is renewable carbon from all types of biomass. Other suppliers of renewable carbon are direct CO_2-utilisation and carbon from recycling of already existing plastics and other materials. As assessed in Annex III many bio-based innovations of the top 50 bio-based innovations contribute to using natural resources, including sustainably sourced bio-based and other raw materials. The subfield #8 *„efficient and sustainable industrial production and products with minimised environmental impact"*[28] contributes to several circular economy targets. Part of the cross-cutting technologies[29] that are further from the market may not have impacts directly attributable to circular targets. They could, however, bring up new possibilities which are currently not foreseeable. Moreover, they can be important enablers of many other innovations that have a direct link with circular economy aspects. In addition, it is observed that the subfields of the top 50 bio-based innovations have less an obvious contribution to circularity aspects that are related to the usage phase of products such as: prolonging the use of products, prevention or reduction of waste, avoiding and reduction of litter.

Potential contribution of circular thinking to bio-based innovation

In the EU we are exceeding at least three safe planetary boundaries: climate, biodiversity, biogeochemical flows of nutrients[20]. Giving the land use and associated biodiversity impacts of growing crops for bio-based products, sustainable biomass sourcing is next to efficient processing and innovative products a major challenge, which should be considered carefully when designing new bio-based solutions. Optimal use of waste biomass is a key priority. Separate bio-waste collection as proposed in the European Green Deal will support this. Moreover, the use of green carbon in the production of bio-based products could be integrated with use of CO_2 based carbon and recycled carbon, for instance by utilising CO_2 from emissions from bio-based processing.

3.6.3 The role of Central and Eastern European countries

Even though the CEE countries have made massive progress in their economic development over the past decade, they are still lagging behind compared to the Western Europe in terms of bioeconomy uptake and are often integrated in the bio-based value chain only as biomass providers. Eastern Europe has dominance of biomass providing sectors agriculture, the forest-based industry, pulp and paper. Indeed, an important share

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[27] https://www.jointprogramming.nl/upload_mm/1/6/2/e1d0b695-37da-46b6-b03b-b31261dd0289_PP_HEU_Biobased.pdf

[28] Subfield #8 contains the following innovations: resource and energy efficient bioprocesses, carbon-neutral bioprocesses, CO_2-based chemicals, climate gas mitigation of microbial activities, and biodegradable plastics and plastic degrading enzymes.

[29] e.g. subfields #1 analytical techniques; and #3 design and engineering of biological systems, cell factories and synthetic biology

of European biomass is provided by CEE countries (for instance Poland, Romania), due to dominance of large biomass providing sectors (i.e. agriculture, forest-based industry) that also provide high employment but have low added value. At the same time, majority of biorefineries, where value added production takes place, are located in Western Europe (especially Belgium and the Netherlands). In parallel, on EU level R&D projects, CEE countries have a significantly lower involvement compared to the Western European countries, partly because of lower R&D capacity and already well established and well-functioning research consortiums within Western European academic institutions that have no incentives to take newcomers on board.

Increased effort from policy-makers is needed into bridging the geographical division in bioeconomy (both academia and private sector) and to increase the opportunities for stakeholders from the countries with currently lower level of participation.

Role of regional bioeconomy clusters

Introduction

Cluster development is a key in pursuing specific bioeconomy policy targets, such as linking academia with private sector for further value creation and increase R&D capacity. Also, clusters would enable to bridge local feedstock supply from traditional sectors with existing industrial infrastructure, knowledge base and public support mechanisms. The strategic bioeconomy cluster development, which brings together different regions, their stakeholders and financial support instruments has already proven to be efficient in a number of national and international level examples. Important examples are BIOEAST cluster with 11 CEE countries and 3BI European intercluster that builds on the complementary strengths of four regional clusters: Bio-based Delta (NL), BioEconomy (DE), BioVale (UK) and Industries & Agro Ressources (FR). Annex III provides an overview of relevant bioeconomy clusters.

Role of regional bioeconomy clusters

Regional clusters perform many tasks and stimulate innovations using different tools, depending on the maturity of the innovation (Overbeek et al. 2015). In the early developmental stage, regional clusters aid in entrepreneurial activities and knowledge development, such as experiments, demonstrations and business ventures. Next, formation of partnerships and knowledge diffusion is stimulated by providing a network and in meetings, workshops, and conferences. At a later stage in development, regional clusters can help in market formation and resource mobilisation, by creating niche markets and allocating financial, material, and human capital to the emerging innovation. Finally, clusters perform a role in lobbying and support as advocacy coalition, by uniting stakeholders under a common voice (Overbeek et al. 2015).

Regional focus and strengths

The focus of bioeconomy clusters is partially determined by national bioeconomy strategies. However, the stakeholders at a regional level will push for markets that support local economic activities for stakeholders at a regional level, such as the regional government, businesses and universities. (Bezama et al. 2019). Overall, a trend is observed among the clusters, where the research and innovation programs shift away from energy applications towards material and chemical applications of biomass (Stegmann et al. 2020).

Gaps in regional clusters

According to Stegmann et al. (2020), who analysed the interaction between circular and bioeconomy in seven bioeconomy clusters in North-West Europe, often only few feedstock suppliers are active in bioeconomy clusters. Moreover, the LIFT project identified real collaboration with primary producers, as well as consumers, as one of the gaps to be addressed (LIFT 2020). A positive public perception and public involvement in decision making for a transition towards a bioeconomy will help the acceptance of new technologies. Activities to open a two-way communication with citizens are required to prevent a negative neighbourhood symptom ('not in my back yard') (Bezama et al. 2019). Where many regional clusters are active in dissemination and informing citizens, these activities are mostly one-way and aimed at increasing the public awareness. An active involvement of citizens is still in its infancy.

3.6.4 Role of GMO legislation

Introduction

In about 12 innovations of the top50 (24%), especially in the subfield *„design and engineering of biological systems, cell factories; synthetic biology"*, gene editing plays an important role. The EU legislation on GMOs is comprehensive as it addresses the development of GMOs, the stepwise release into the environment, the general cultivation and seed production, marketing, labelling, enforcement and the whole agro-food chain, up to the consumption by humans and animals. See Annex III for a brief overview of current legislation. Since the European GMO legislation is among the strictest and most prohibitive in the world, other regions have more opportunity to exploit innovations involving gene editing than the EU (See Annex III). Despite this situation, the current EU strategies as analysed in section 3.3 pay hardly - if any - attention to this topic, probably due to its controversial nature. This section gives an overview of key developments.

New Genomic Editing Techniques (NGTs) & GMO legislation

After the implementation of the GMO Directive (2001/18/EC)[30] in 2001, new genomic editing techniques (NGTs) such as CRISPR/Cas, TALENs, Zinc-Finger Nucleases, Meganucleases, Oligonucleotide-Directed Mutagenesis and base editing have been developed enabling a precise modification of DNA sequences. These NGTs are mutagenesis techniques, which are unlike transgenesis, a set of techniques which make it possible to alter the genome of a living species without the insertion of foreign DNA. Annex I B of the GMO Directive, excludes mutagenesis from the Directive. However, in Case C-258/16 of the Court of Justice of the European Union, Confédération paysanne and the other associations argue that mutagenesis techniques have evolved over time (See Annex0). The Court of Justice has decided that organisms obtained by mutagenesis are GMOs within the meaning of the GMO Directive, in so far as the techniques and methods of mutagenesis alter the genetic material of an organism in a way that does not occur naturally.

The Court Decision was welcomed by NGOs[31] and by involved sectors seen as a missed opportunity.[32] Especially GMO crops are perceived as a highly controversial issue, and hardly grown in the EU, while gene editing for contained industrial use or medical purposes is possible within the strict regulatory framework. For the purpose of balanced policy-making, especially on the NGTs, it would be beneficial if an informed discussion on the benefits and drawbacks of gene editing takes place. In this light the study regarding the status of novel genomic techniques under Union law[33] (see Annex III) as requested by the Council in light of the Court of Justice's judgment in Case C-528/16, should be welcomed.

[30] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32001L0018

[31] See for instance: https://www.eurovia.org/decision-of-the-european-court-of-justice-on-new-gmos-a-historic-victory-for-peasants-and-citizens-of-the-eu/

[32] See for instance: https://www.europabio.org/cross-sector/publications/court-ruling-could-lock-out-benefits-genome-editing-europe

[33] COUNCIL DECISION (EU) 2019/1904.

4 Innovation Ecosystem

4.1 Introduction

For successful innovation and commercialisation in life and biological science and technologies a well-functioning innovation ecosystem is needed. Such one is characterised by strong and well-connected actors and enabling framework conditions (e.g. regulation, investment climate, financing possibilities).

This section reviews first the current actor landscape and the EU-27 competitiveness in international comparison. Second, it summarizes the current and future outlook of key innovation and commercialisation factors in the EU-27 for bio-based innovations in a SWOT analysis The analysis builds upon stakeholder interviews, patent analysis, survey, policy analysis and workshop discussions (see Annex I).

Bio-based innovations targeted at novel products, which differ highly from each other in several aspects. Bio-based products differ significantly

- in their maturity
- between those segments that contain high volume, low price products and und low volume, high price products
- in market conditions and relevant actors, e.g. regarding the dominance of large incumbent firms, the importance of dynamic SMEs, business-to-business vs. business-to-consumer relationship, in competition to fossil-based products, regulations etc.

Hence, the competitiveness of EU-27 and key drivers and barriers may differ between the innovations or sectors. The current section takes a holistic view for bio-based innovation and products, but differentiating where more detailed information is available.

4.2 EU Competitiveness

According to the expert assessments, the EU-27 is highly competitive in enabling bio-based innovations. In particular, for those bio-based innovations that are expected to contribute highly to sustainability, such as the use of waste or environmental biotechnological methods and processes (example for innovation) a high EU-expertise was assessed. This positive assessment related to innovation capabilities is rather confirmed in the top 50 bio-based innovations survey, where the present EU position was asked differentiated between the top 50 bio-based innovations. For 2/3 of the innovations, the respondents claim that the position of the EU-27 is above the average. The EU is leading in environmentally beneficial or sustainable solutions such as novel feedstock and bioprocess engineering or more generally bio-based products. However, the EU is rather lagging behind in innovations related to digital technologies, genome editing and synthetic biology.

Moreover, the expert interviews point out that regarding commercialisation of-bio-based innovation the framework conditions in EU-27 (e.g. in relation to financing, consistent and incentive setting regulation) and the competiveness of the European actors is less given.

Patents are another key indicator, which can be interpreted with respect to technological competitiveness. In order to complement and triangulate the expert survey results, a patent analysis was conducted for each of the top 50 bio-based innovations (see Annex IV) and the EU-27 shares of worldwide patents for two 4-year time periods (2004-2007, 2014-2017) were calculated.

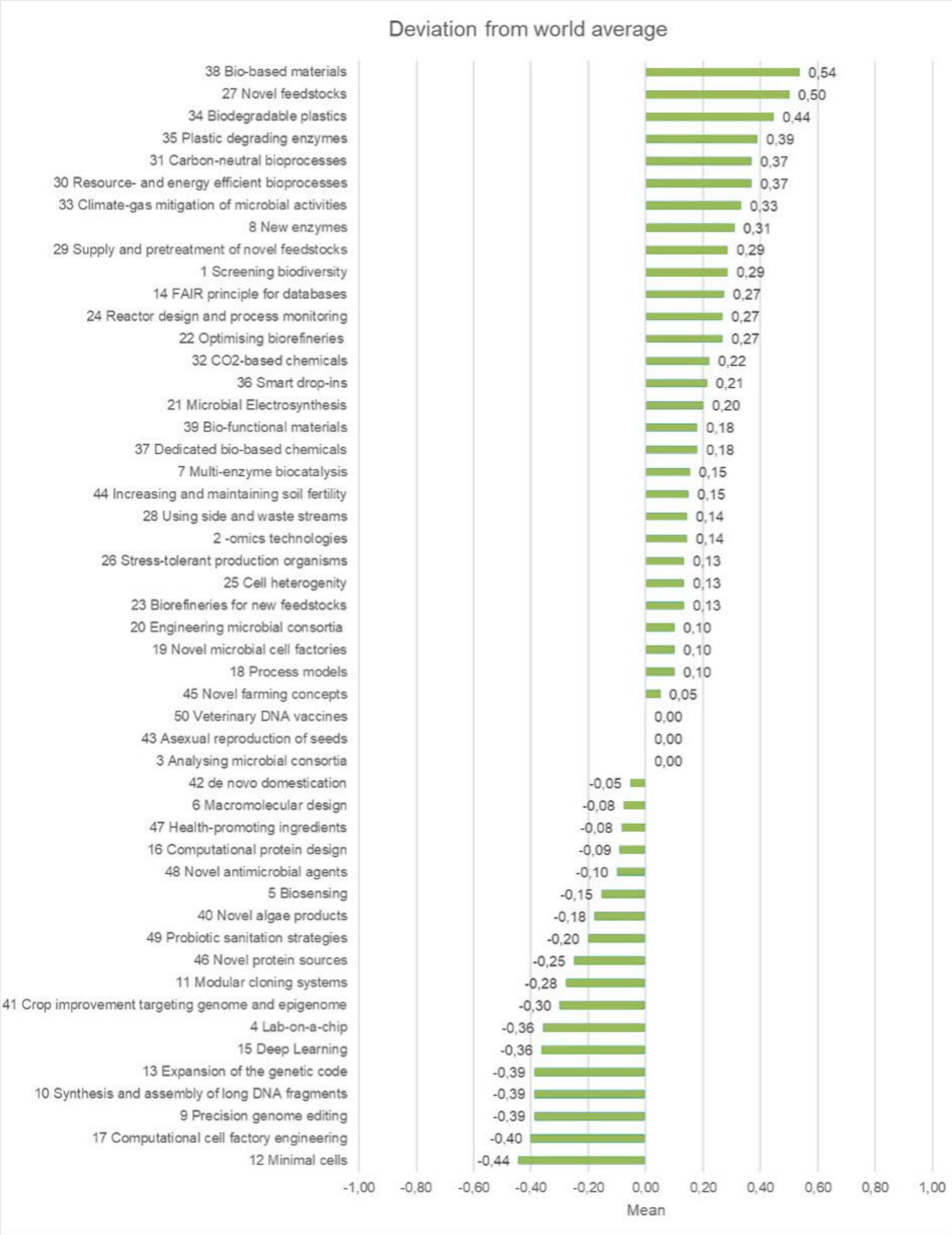


Figure 10. EU-27 position for the top 50 bio-based innovations (positive value means a EU-27 position above world average (1=leading position), negative value means a EU-27 position below world average (=-1 lagging behind other world regions)

Source: EU-wide online expert survey

Taking the median of EU-27 share across those top 50 bio-based innovations with reliable patent data, the EU-27 possesses around 22% of the patents worldwide. Unsurprisingly, the EU-27 shares decrease over time whereas Asian countries generally catch up in patenting. But for some innovations, EU-27 shares have remained stable or even increased over time: The EU-27 developed rather strongly in innovations with an expected strong impact on environmental sustainability, such as carbon-neutral bioprocesses, Novel feedstock and biodegradable plastics and increased its shares. Unsurprisingly, drastic declines can be observed for agricultural biotechnologies, with strong declines in seed reproduction (from 22% to 3% between 2004-2007 to 2014-2017) and crop improvement (from 50% to 13% between 2004-2007 to 2014-2017). Rather weak shares can be attributed for some digital technologies (e.g. deep learning or genome editing). Moreover, EU-27 shows strengths in some product groups with special functionalities, such as novel algae products or veterinary vaccines.

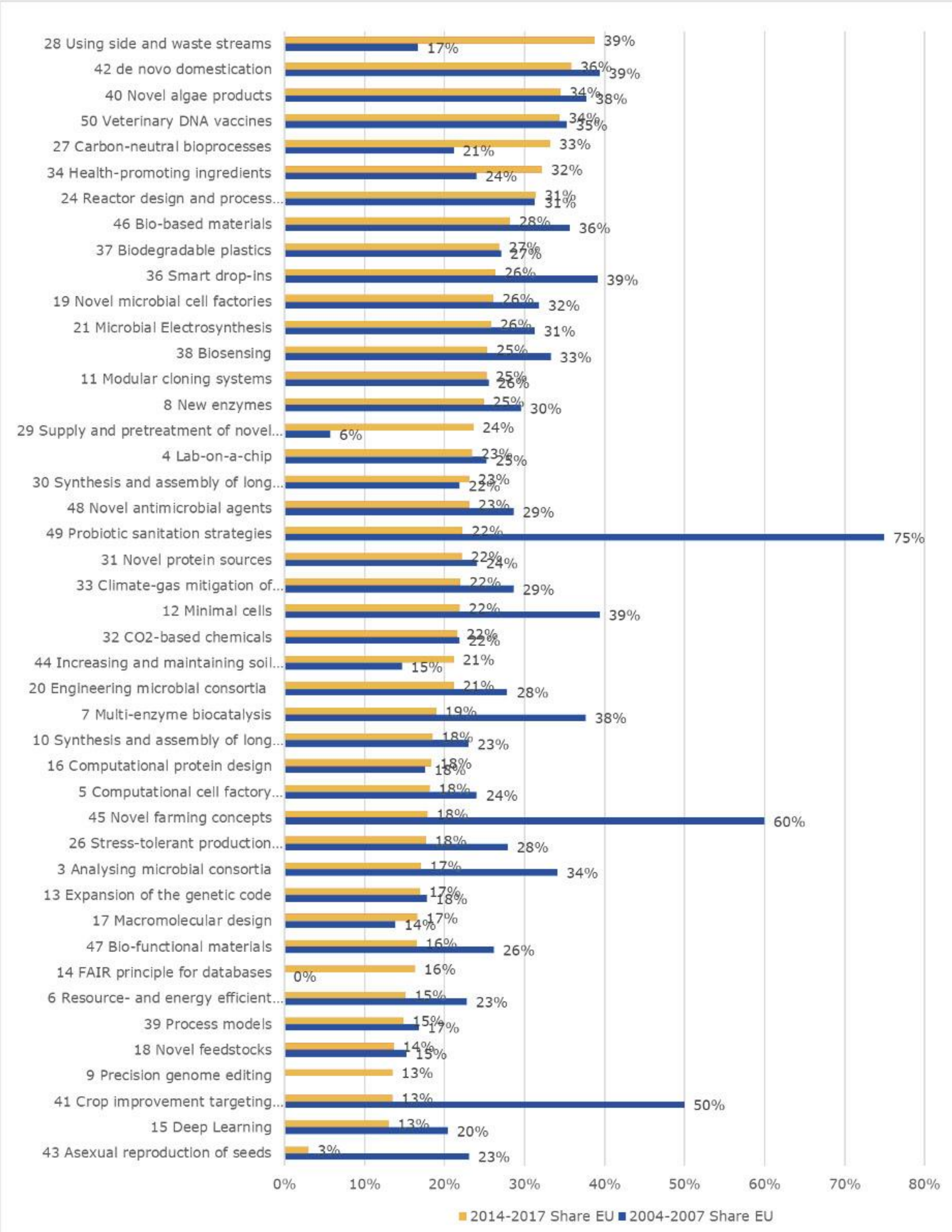


Figure 11: Share of EU-27 of worldwide patents in the period 2014-2017 compared to 2004-2007

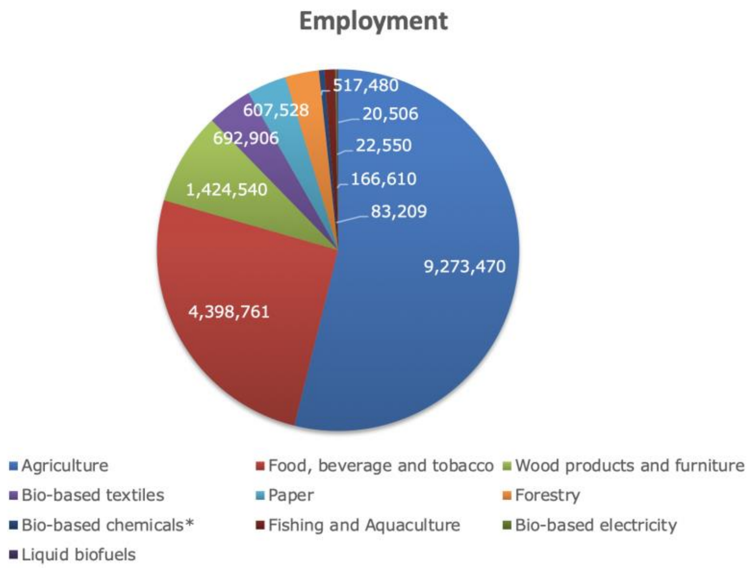
Source: Fraunhofer ISI calculation based on World Patents Index (WPINDEX)

4.3 Activities in Europe: Actors and structures

Sectoral perspective of bio-based innovations

As bio-based innovations cover a lot different potential products, processes, and applications in a variety of sectors, the amount of relevant actors for enabling bio-based innovations and their use in production and services is very large. This is shown by the employment in bioeconomy-relevant sectors in 2017, as well as the value added (Figure 12).

In 2017, the employment in the bioeconomy amounts to around 17 million persons across the EU-27 Ronzon et al. 2020) However, the majority is employed in the agricultural sector and another quarter in the food industry, and thus in „traditional" bio-based sectors. Regarding value added, the chemical or paper industry gain importance, but still agriculture and food industry dominate. Due to the overall trend of increasing productivity in these traditional industries, the employment in the bioeconomy is shrinking almost every year (Ronzon et al. 2020).



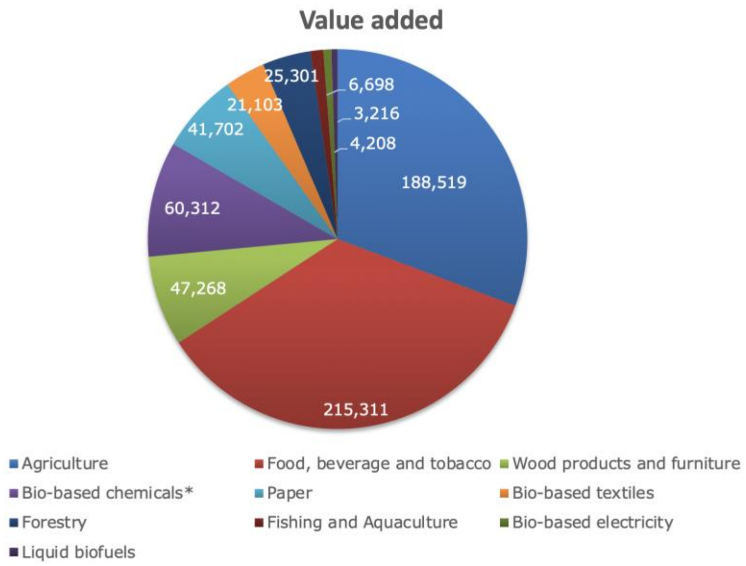


Figure 12: Employment and value added of the EU-27 in the bioeconomy in 2017.

Source: https://datam.jrc.ec.europa.eu/datam/area/BIOECONOMY

However, the sectoral distribution of employment and value added may look differently when focusing on innovations and taking a forward-looking perspective. The innovations emerge more in dynamic sectors or niches and may be in contrast to the overall picture that the employment in bioeconomy is declining.

However, specific information about innovation activities on sectoral or also on actor level is hard to elaborate.[34] Some insights on industrial sectors may be gleaned from the top 50 bio-based innovations survey: It included the question, which industrial sectors - in a value chain perspective - would benefit to a large extent from the respective innovation by 2030. The answer categories did not cover a sectoral classification („NACE" codes) as in Figure 12, but coming from a value chain perspective. The results underline that bio-based innovations usually effect several sectors in the value chain. The reason is that it is not sufficient that one actor in a value chain changes the technology, but other stages before and later in the value chain have to be modified as well. This implies that a bio-based value chain usually has to be built up from scratch or the previous value chain has to be largely reconfigured. This can be shown for biorefinery innovations: they do not only use a new (bio-based instead of fossil) feedstock, but a whole new system of integrated new conversion and downstream processes, process equipment and control have to be implemented, together with new logistics and distribution concepts. Moreover, new markets have to be established. Hence, the whole value chain has to be taken into account.

Looking at individual sectors, unsurprisingly, R&D services are very important for the cross-cutting technologies, but also to some extent for the applied ones. This implies that even in 10 years in a higher maturity stage those innovations and value chains remain R&D intensive. Vice versa, manufacturing of final products and supply of bio-based feedstock sector is more affected by applied technologies. For only few innovations significant impact for machinery (*biorefinery* or *bioreactor innovations*), digital technologies (e.g. *deep learning, fair principle, macromolecular design*) or environmental services is expected. These results are interesting, in particular considering the expected high potential of digital technologies for the bio-based sectors and whole industry.

To summarize, while it is not directly quantifiable, bio-based innovations have the potential to affect many value chains. Consequently, innovations in life and biological sciences have a key role in the bio-based sectors, which is in tend rather declining e.g. regarding employment. However, at the same time the generation and uptake of innovation is dependent on the willingness and competencies of the various actors to take these value chains forward and that markets are created. Hence, the interaction between feedstock providers, converters and manufacturers across many industries is of high importance (see section 4.4).

[34] Important reasons for that are the high heterogeneity of value chains and larger companies are only partly active in bio-based value chains, but do not disclosure all bio and life sciences activities

Table 15. Industrial sector(s) that will benefit from this innovation to a large extent by 2030 (green=high agreement; yellow = medium agreement; white=low agreement

No.	Short title Innovation	Supply of bio-based feedstock	Conversion to intermediate products	Manufacturing of final products	R&D-Services	Machine and plant construction	Digital technologies, bioinformatics	Environmental services
1	Screening biodiversity							
2	-omics technologies							
3	Analysing microbial consortia							
4	Lab-on-a-chip							
5	Biosensing							
6	Macromolecular design							
7	Multi-enzyme biocatalysis							
9	Precision genome editing							
10	Synthesis and assembly of long DNA fragments							
11	Modular cloning systems							
12	Minimal cells							
13	Expansion of the genetic code							
14	FAIR principle for databases							
15	Deep Learning							
16	Computational protein design							
17	Computational cell factory engineering							
18	Process models							
19	Novel microbial cell factories							
20	Engineering microbial consortia							
21	Microbial Electrosynthesis							
22	Optimising biorefineries							
23	Biorefineries for new feedstock							
24	Reactor design and process monitoring							
25	Cell heterogeneity							
26	Stress-tolerant production organisms							
27	Novel feedstock							

No.	Short title Innovation	Supply of bio-based feedstock	Conversion to intermediate products	Manufacturing of final products	R&D-Services	Machine and plant construction	Digital technologies, bioinformatics	Environmental services
28	Using side and waste streams	>75 %	50–74 %	50–74 %	50–74 %	50–74 %		50–74 %
29	Supply and pretreatment of novel feedstock	>75 %	50–74 %	50–74 %	50–74 %	50–74 %		
30	Resource- and energy efficient bioprocesses	50–74 %	>75 %	>75 %	50–74 %			
31	Carbon-neutral bioprocesses		50–74 %	>75 %		50–74 %		50–74 %
32	CO2-based chemicals	50–74 %	>75 %	>75 %	50–74 %	50–74 %		
33	Climate-gas mitigation of microbial activities				50–74 %	50–74 %		>75 %
34	Biodegradable plastics	50–74 %	50–74 %	>75 %	50–74 %	50–74 %		>75 %
35	Plastic degrading enzymes		50–74 %	50–74 %	50–74 %			>75 %
36	Smart drop-ins	>75 %	>75 %	50–74 %				
37	Dedicated bio-based chemicals	50–74 %	>75 %	>75 %				
38	Bio-based materials	>75 %	50–74 %	>75 %		50–74 %		50–74 %
39	Bio-functional materials	50–74 %	50–74 %	>75 %	50–74 %			
40	Novel algae products	50–74 %	50–74 %	>75 %	50–74 %			50–74 %
41	Crop improvement targeting genome and epigenome	50–74 %	50–74 %	50–74 %	50–74 %		50–74 %	50–74 %
42	de novo domestication	50–74 %			50–74 %			
43	Asexual reproduction of seeds	50–74 %			50–74 %			
44	Increasing and maintaining soil fertility	50–74 %		50–74 %	50–74 %		50–74 %	>75 %
45	Novel farming concepts	50–74 %		50–74 %	50–74 %	50–74 %	50–74 %	50–74 %
46	Novel protein sources	50–74 %	50–74 %	50–74 %	50–74 %			
47	Health-promoting ingredients	50–74 %	50–74 %	>75 %	>75 %			
48	Novel antimicrobial agents		50–74 %	>75 %	50–74 %			
49	Probiotic sanitation strategies	50–74 %		>75 %	50–74 %			>75 %
50	Veterinary DNA vaccines			50–74 %	50–74 %		50–74 %	

Legend: more than 75 % of survey respondents — 50 % to 74 % of survey respondents

Source: EU-wide online expert survey

Actors in bio-based Innovation

The bio-based innovation landscape consists of diverse relevant actors, with universities, R&D institutions, SMEs, large companies engaged in innovation, brand-owners as users, politicians and ministries as well as NGOs, consumers and the wider public.

We analysed the beneficiaries in Horizon-2020 projects related to the Top 50 bio-based innovations in order to obtain data on the actors who are innovation enablers and users. The analysis shows that a broad range of actors regarding type, size and countries are involved. A distribution of the EU funding regarding type of actors shows that the majority of funding is to provide companies – with many different small, but also larger companies – as well as universities and R&D institutions.

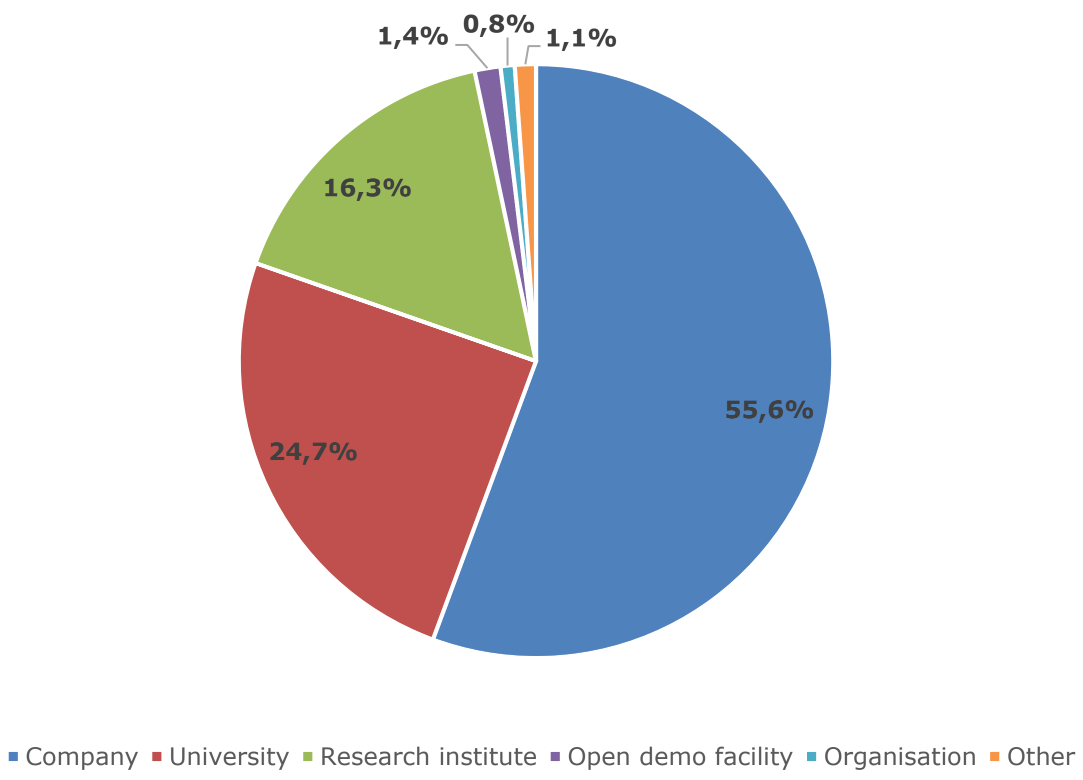


Figure 13: Share of EU contributions for 111 selected HORIZON 2020 projects by actor type

Source: Own calculation based on CORDIS data

While meaningful data is missing, the interviews reveal a mixed picture regarding the assessment of the SME landscape in the EU-27. SMEs have an important role in the value chain as they often provide biotechnological R&D services or test cutting-edge innovative approaches in early R&D and pilot stage levels, which are later often taken over by larger firms and developed to production maturity. For products with lower production volume SME may even produce and market these themselves (Wydra et al. 2017). While there are different opinions about whether the number of dedicated SME is sufficient to fill the pipeline of bio-based innovations of bio-based innovation, there is consensus that growth of these firms is likely to stay behind the dynamics in the U.S. As main reasons shortages in financing are considered. Regarding large companies, the EU-27 possesses rather high capabilities to remain competitive in bio-based innovations. Overall, EU-27 has a diversified industrial landscape with strong existing industrial players. A key question is to which extent those companies, usually called incumbents, take risks and invest heavily in emerging innovations that may cannibalize to some extent own existing markets. Here, the interviewed experts see some indications that incumbent actors e.g. from the chemical industry are in-trend increase their activities in bio-based innovations.

Another aspect is the distribution of activities and collaboration across the EU-27 countries. Prior assessment e.g. regarding patents or distribution of biorefineries show a rather strong dominance of Western Europe, some significant specialised activities in the other countries, but a lagging behind in East and Central Europe. Similar patterns can be found for the Horizon funding related to the top 50 bio-based innovations as indicated in section 3.5, with less than 7 % of EU-27 contributions towards actors from those countries. Potential reasons for this low participation the following factors low tradition are public-partnerships, low concentration on high-tech fields, rather low awareness of the potential of bio-based innovations in these countries are considered.

The impact of COVID-19 on industrial landscape is still uncertain.[35] While a few interviewed experts stated that the negative experiences in the pandemic to be dependent on global supply chains, as it is the case for bio-based innovations, could lead to increasing activities to build up more supply chains in the EU-27. However, no clear indications could be found in the total set of interviews or other sources, where there are significant activities and opportunities arising from Covid-19 experiences.

4.4 SWOT for EU-27

The strengths and weaknesses of the SWOT analysis present internal characteristics of European bio-based life and biological sciences, where the EU-27 has corporate advantages and disadvantages. The opportunities and threats whereas present external factors that favour our hinder bio-based innovation and commercialisation in the EU-27.

STRENGTHS

Relevant knowledge base and skills

Strong actor orientation towards sustainability

Strong clustering (both on national and international level)

WEAKNESSES

Trans- and interdisciplinarity of research

Financing start-up initiation and growth of SMEs

Inclusion of the entire value chain

Scattered demand-side measures for market creation

Lack of integration of Central and Eastern European countries in innovation activities and networks

OPPORTUNITIES

Positioning within circular economy

Availability of diverse feedstock streams

Explosive growth of digitalisation, automation, and AI

Increased involvement of distant industries into new VCs

THREATS

Restricting regulations

Low public perception

Figure 14: SWOT analysis for the EU-27 bio-based innovation

[35] Potential long-term impacts on policy, consumer behavior are discussed in the scenarios section 5

Strengths

Relevant knowledge base and skills

A key strength is the high and diversified knowledge base in the EU-27. The interviews as well as the online survey state an overall rather positive competitive position for many innovations (section2).

It is important for the development of life and biological sciences that the EU maintains their leading position. Therefore, the development of knowledge base and skills should keep pace with key developments in the respective fields. For example, skills required for the explosive growth of digitalisation, automation, and AI require a bottom-up approach, where new courses and curricula may be needed to keep pace with rapid changes brought forth by digitalisation. Besides new courses and curricula, existing curricula may also need to change and adapt to meet new needs. Another issue is that large and complex problems such as the environmental challenges cannot be solved from the sphere of individual disciplines, and therefore, problem-solving skills on a trans- and interdisciplinary level become increasingly important.

Strong actor orientation towards sustainability

A significant amount of bio-based innovations provide high potential to address environmental challenges, e.g. by reducing waste, contributing to biodiversity (e.g. *increasing and maintaining soil fertility*) or lowering greenhouse gas emissions (e.g. *CO_2 based chemicals*). As pointed out above, the EU-27 possesses rather competitive advantages in particular regarding environmental technologies (see section 4.2). Those competitive advantages can be transferred in marketable products and processes, because of a strong perceived sustainability orientation of the actors including science, industry and policy.

EU policy initiatives such as European Green Deal and Circular Economy Package (see section 3.2) provide strategic orientation for the actors, which is largely missing in other world regions. An open question for market uptake is still to which extent demand-side measures such as RED+ or ETS encompass material use of bio-based feedstock or products that can be produced by bio and life sciences.

Strong clustering

National and international level clustering has been proven to be a successful tool in pursuing specific bioeconomy policy targets, such as international collaboration, link academia with private sector for further value creation and increase R&D capacity in the EU-27. Clusters also serve as useful tools international collaboration and knowledge diffusion among stakeholders. Some of the largest clusters with key importance in the EU-27 include BIOEAST cluster with 11 CEE countries and 3BI European intercluster that builds on the complementary strengths of four regional sub-clusters: Bio-based Delta (NL), BioEconomy (DE), BioVale (UK) and Industries & Agro Ressources (FR), to name a few. (see more examples and elaboration in section 2).

Weaknesses

Trans- and interdisciplinarity of research

Majority of the environmental problems are large and complex in their nature. These problems cannot be solved from the sphere of individual disciplines, and therefore, problem-solving skills on a trans- and interdisciplinary level become increasingly important (Devaney und Henchion 2018). Hence, at the heart of the bio-based sector's future is the need for a different kind of workforce with trans- and interdisciplinary skills.

Collaboration allows researchers to address complex problems that are unable to be solved by an individual researcher or a single discipline. Furthermore, interdisciplinary research can accelerate the translation of knowledge from laboratory scale to demonstration scale and to commercial scale.

The transdisciplinary approach to innovation differs from inter-disciplinary approaches, as it is not solely based on operating towards a shared goal or having separate disciplines interact with and enrich each other. Instead, transdisciplinary innovation engages in these interactions in an integrated system with a social purpose, resulting in a continuously evolving and adapting practice. More recently, transdisciplinarity is increasingly relevant to innovators whose technologies or solutions aimed at addressing complex societal issues. This larger-scale emphasis moves innovation beyond „customer-centred" to a „society-centred" perspective, which requires active collaboration with public and private sector organisations.

Trans- and interdisciplinary research is already being encouraged within EU funded projects and have gained increased importance in education (Tripp und Shortlidge 2019; Tan-Wilson et al. 2020) and is not a unique phenomenon for bio and life sciences. However, it remains a key issue in further exploiting the potential of bio-based innovations. Financing start-up initiation and growth of SMEs.

Developing new and innovative products requires scale-up from the lab to a commercial product. Essentially, this is required to examine whether the technology is scalable and reproducible outside the laboratory environment. Access to finance is a major barrier to the commercialisation of new and innovative products. Already now, several funding frameworks are available for the bio-based industries, such as Horizon 2020 and BBI JU at the European level, and ERA-NET and EUREKA at the transnational level. Currently, the European Public-Private Partnership BBI JU is bridging some of the funding gaps with the flagship projects. Nevertheless, it cannot support all commercial scale projects and thus access to funding remains an issue. Similar challenges arise for firm funding, in particular for SMEs. Financing shortages compared to other world regions, such as the U.S., is a main hurdle for SME growth in the EU-27. Measures, such as the launch of European Circular Bioeconomy Fund can be regarded as promising, but still magnitude and flexibility for fast actions remain an issue.

Funding gaps can be specifically identified for projects that show a high disruptive potential. These projects are most likely to result in new development and innovations and, at the same time, are most challenging to fund from the private sector due to their inherent high risks.

Inclusion of the entire value chain

The inclusion of the entire value chain refers to the integration of production and processes throughout the supply chain (i.e. supply chain integration). Supply chain integration (SCI) is defined overall as a process of redefining and connecting entities through coordinating or sharing information and resources (Katunzi 2011).For supply integration, integration back down to the suppliers represents a change in attitude away from conflict to cooperation, starting from product development, the supply of high-quality products, processes and specification change information, technology exchange and design support.

Another relevant type of integration is the cooperation between the biomass supply sector and all downstream industries. Currently, there is a lack of cooperation and knowledge exchange between different actors in the value chain. Support is required for actors to cooperate across-sectorial borders to overcome the barriers between processing and feedstock supply.

While existing initiatives, such as the BBI JU have enabled advances in the creation of new value chains and cooperations (Bio-based Industries Joint Undertaking 2020). Still cross-sectoral cooperation, especially between the primary feedstock and converting sector remains a hurdle for the future (Bio-based Industries Consortium 2020).

Scattered demand-side measures for market creation

Despite substantial scientific-technological progress, achieving cost-competitiveness for bio-based innovation will remain difficult for many IB products in times of low prices for fossil resources. Moreover, .path dependencies towards fossil-based products such as existing infrastructure and long-time experiences of users with existing products. Hence, market creation measures to support bio-based products have a crucial role to create demand-pull. However, still demand-side measures such as public procurement, bans of fossil-based products, are very scattered across the EU-27 (International Advisory Council on Global Bioeconomy).

Lack of integration of Central and Eastern European countries in innovation activities and networks

There is still a geographical isolation of the central and eastern European countries in terms of integration in bio-based life sciences and technology. For example, Western European countries dominate the EU budget allocation at all TRL levels, and that the Central and Eastern Countries only receive 7% of the available budget (35 million Euro). Moreover, these countries often have no bioeconomy strategy in place. The role of the Eastern European countries in bio-based innovation is further explored in section3.

Opportunities

Positioning within circular economy

As outlined in section 3.6, circularity becomes increasingly important for bio-based innovation (Fritsche et al. 2020). Bio-based innovation can contribute to certain dimensions of circular economy according to the planned EU legal definition, such as „… the efficient use of raw materials, reducing waste generation; increasing preparing for re-use and recycling of waste or using natural energy resources efficiently". Hence, bio-based innovations are considered as an important key technology for achieving circular economy goals and there is an increasingly strong link between Horizon Europe – the new EU research and innovation framework programme for bio-based innovations and the circular economy.

However, it will depend on a certain extent on a concrete policy design of circular economy, how they can contribute and benefit from higher circularity orientation. E.g. to which extent bio-based value chain will be in the explicit focus, or whether higher incentives will be provided to recycle fossil based plastic instead of enabling circular-oriented bio-based value chains.

Availability of diverse feedstock streams

The availability of sustainably produced biomass that can be directly converted presents a key bottleneck for the bio-based sector. The commercialisation of bio-based innovations may increase the demand, which could contribute to an increased sustainable feedstock production. However, many innovations aim to increase the efficiency in which the biomass feedstock is utilised. Moreover, a number of identified relevant innovation in this report aim at the exploitation of feedstock (i.e. novel algae products, using side and waste streams) or in some cases their „sustainable" supply (e.g. supply and pre-treatment of novel feedstock", novel farming concepts, novel protein sources etc.).

Europe possesses a wide variety of feedstock across the EU (Hamelin et al. 2019; Camia et al. 2018; Elbersen et al. 2016).[36] The EU has a comparable large potential availability of biomass residuals and therefore the potential to include an important producer in those

[36] E.g. XX the importance of residual biomass as a key feedstock for the European bioeconomy point that 8500 PJ y−1 are available for residual biomass, which corresponds to the whole annual (2015) primary energy consumption of Italy and Belgium combined.

value chains while keeping land use to a minimum. Making this feedstock available would result in an important opportunity to diversify the European sustainable feedstock input and the marketable products thereof.

Explosive growth of digitalisation, automation, and AI

The digital transformation is multidimensional that is impacting innovation in all sectors of the economy. Breakthroughs come into view across innovation processes, from research (e.g. large-scale computerised experiments, big data analytics), to development (e.g. new techniques of simulation and prototyping) and commercialisation (e.g. use of marketplace platforms). In this rapid development, there are large opportunities for life science and technology, e.g. for *Deep Learning, Computational Protein Design, and Process Models*. In order to take full advantage of these opportunities, a focus on common data formats and standardisation is required.

For an innovation to thrive, an optimal climate needs to be created, where multiple parties can contribute to the innovation for it to mature. This type of collaboration, where parties can build on each other's work and collaborate to the same goals can only be achieved when the same language is used. This is especially important in machine learning, where multiple data formats exist.

Standards come in various aspects throughout the innovation pipeline. Besides standard biological parts to enhance reproducibility and comparability, standards exist for protocols and computational frameworks. Nowadays, computational biologists face significant standardisation challenges due to the incompatibility of computational tools and inconsistent nomenclature. For example, the analysis of omics data to inform subsequent designs can be complicated by the plethora of databases and tools that are not always compatible with each other. Using standard computational tools and nomenclature would facilitate efficient electronically exchange of designs and enhance scientific reproducibility.

Increased involvement of distant industries into new VCs.

The potential benefits of new value chains in bio-based innovations in involved sectors are not yet widespread to more distant industrial sectors such as between primary biomass production and refining industry. More efficient knowledge diffusion when novel supply chains are developed, is important to inform different stakeholder groups on potential benefits and already existing innovations of bio-based sectors. Furthermore, information on available funds, initiatives and tools available to enable the uptake of bio-based innovations is also as important.

Threats

Restricting regulations

Bio-based innovation mostly takes place in a highly regulated environment. Potential different kind of regulations are relevant for the innovation and commercialisation process, depending on technology, resources, market segments, etc. These include:

- Regulation for technologies: of high importance are the GMO-regulation and the regulatory treatment of genome editing techniques. Eleven of the identified top 50 bio-based innovations relate to genome editing and regulatory hurdles are often identified as key priority for further development (see section 2).

- Regulation for resources: e.g. compliance with the legal requirements of access and benefit sharing (ABS), which have been adopted in the Nagoya Protocol (see Annex III)

- Product-market regulation and standards, such as use of waste as resource or environmental benefit of products/processes

- Market policy regulation (e.g. ETS, bans, public procurement rules) to support bio-based innovations
- Market-entry regulations, e.g. via patenting system

The relationship between innovation and regulation is a priori open. Regulation may restrict innovation by setting low incentives or forbidding certain activities, but it may also enhance creativity for new solutions. A clear and transparent regulation may provide important strategic orientations for actors. There is a clear demand from society for restricting regulations, however, from an actor perspective, these lead to unnecessary administrative burdens and low incentives for bio-based innovations, which hinders innovation and commercialisation in bio-based innovation.

Low public perception

The public perception and awareness on bioscience and bio-based products derived thereof is at a relatively low level. This lack of awareness arises from the fact that bioscience is used as a technology or a tool. It is not an end product itself. This is difficult to explain and thoroughly comprehend for lay people from the outside, despite that bio-based methods are commonly used to produce food (e.g. beer, cheese, bread) and not only medicines (e.g. vaccines, biopharmaceuticals). In addition to the complexity of bioscience, the challenge also touches upon people's general lack of awareness of the origins of everyday products that originate from fossil carbon.

The lack of awareness of the existence of bio-based products that are produced using bioscience, together with the lack of understanding their benefits, presents a significant threat to technology uptake and the creation of new markets. An under informed or misinformed audience can draw wrong conclusions that are not necessarily fact-based, resulting in an aversion against a product or technology (Fritsche et al. 2020).

5 Bio-based Innovation scenarios for 2030

5.1 Elaboration of bio-based innovation scenarios

In the prior sections, we analysed the status quo and outlook to 2030 in the field of life and biological sciences and technologies for the top innovations, innovation actor landscape and ecosystem as well as policy. But, how will these developments interact? What are the wider implications? How will bio-based innovations emerge and be used? Which impact will they have on economic and societal goals? For these forward-looking reflections, we present here four different scenarios. Each scenario provides a consistent picture, how the innovation and commercialisation in bio and life sciences and technologies may develop in the EU by 2030. We will use these scenarios to reflect on the needed actions to achieve the intended impacts and to minimize unintended impacts.

How were the scenarios elaborated?

Five factors are - in the context of this study objective - most important and were used for developing the scenarios:

- Policy
- Cooperation
- Societal attitude towards sustainability
- The role of actors
- Technological developments

For each of the factors, potential developments were delineated and combined to four scenarios, which were identified and discussed and modified in an expert workshop. For more details on the methodology, please refer to the annex.

Please note that the scenarios,

- do not reflect necessarily desirable visions for the future, but aim to grasp plausible and consistent potential developments,
- the existing EU strategies and initiatives (e.g. Bioeconomy Strategy, European Green Deal) are the common strategic frame for all 4 scenarios. Within this common strategic frame, scenarios differ in the emphasis to specific strategic goals (e.g. climate change mitigation, economic development, international competitiveness).

5.2 Four bio-based innovation scenarios for 2030

The resulting scenario can be characterised as following and are presented in more detail in Table 13 with presentation of the five factors and summarisation of the innovations that are favoured or hindered as well as the impact and key hurdles in each scenario.

Scenario 1 „**Technology Push**" is characterised by a high national focus on high-tech fields in order to be competitive on an international level. Centres of excellence (academia, SMEs) would generate knowledge base and innovations, while the Member States would concentrate autarchic on their relative strengths. On the consumer side, sustainability of bio-based innovations is taken as given and controversial technologies are tolerated as they offer benefits (e.g. sustainable consumption without life style change). In such scenario, the economic potential of bio-based innovations and a greater variety of products and services to the customer may be realised, if the gap between R&D and commercialisation is not increasing too much.

In scenario 2, „**Sustainability first**" citizens' movements call for and support stringent sustainability policies and actions. This pushes policy to develop and implement additional ambitious actions plans to promote sustainability targets. Bio-based innovations contribute to make industrial production more sustainable, reduce emission of greenhouse gases and to recycle plastic and other wastes. However, as bio-based innovations present one of many solutions available to tackle sustainability issues, they have to prove advantageousness over other alternatives. Global division in international supply chains increases in some value chains, so that the world regions can focus on their strengths to enable efficient and sustainable production. Such scenario would have great potential to reach societal, sustainable and economic goals. However, while those results are desirable, realisation may rely on a strong global economy, as otherwise economic considerations sustain.

In scenario 3, „**Economic recovery from pandemic**" the focus is on economic growth and recovery from pandemic. Policy supports existing traditional industries and actors to save jobs, and other stakeholders act accordingly to economic incentives. Such conditions would enable incumbent large companies to stay ahead. Bio-based innovations gain only in those countries and sectors significant importance, where this fits to such policy. While such activities may be economic successful from a Member State perspectives in the short term, for a more long-term and sustainable access behavioural change of consumers, which could be a possible development in light of the Covid-19 crisis, would be a key. Here, an important role of NGOs to push for balance the targets and actions arises.

In scenario 4, „**Push of bioeconomy markets**" a policy induced market pull with specific measures to support commercialisation and market development for bio-based processes, products (e.g. materials) and services supports its uptake. Moreover, there are efforts to reduce dependency of global trade, which leads to establishment of EU value chains in the bioeconomy. The actor landscape along the value chain is very diverse. The consumers are guided via the introduction and modification of relevant regulations and standards towards more sustainable behaviour.

These scenarios can be illustrated in their scope by two key factors, which reflect more general developments that are rather independent from developments from the bio-based innovations itself. This shows that the scenarios differ significantly in terms of cooperation between countries and world regions as well as in social attitude towards sustainability.

Figure 15. Four scenarios illustrate four different paths how the bioeconomy might develop in the coming 10 years in the EU.

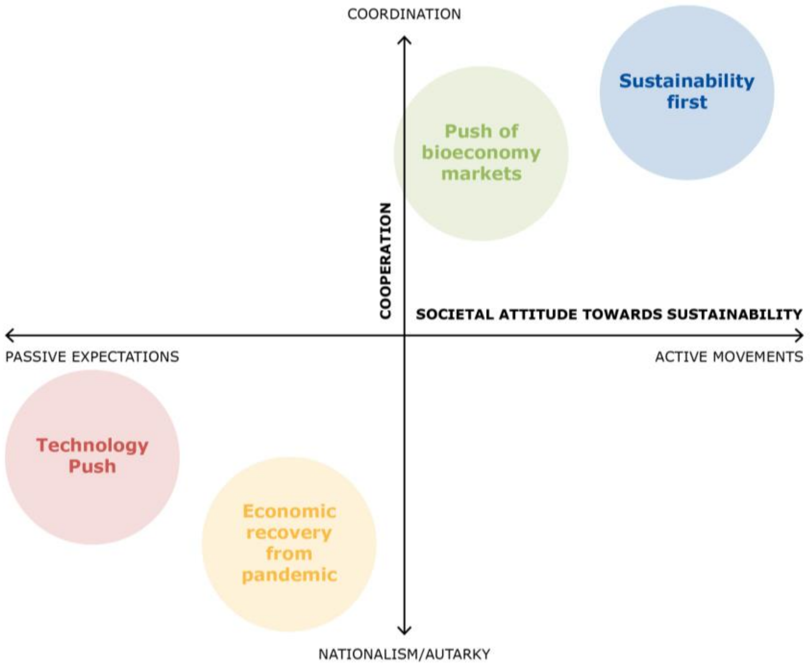


Table 16. Characteristics of four scenarios and their impact and implications

Key factor	Status-Quo	Scenario 1: Technology Push	Scenario 2: Sustainability first	Scenario 3: Economic recovery from pandemic	Scenario 4: Push of bioeconomy markets
CHARACTERISTICS					
Politics	• MS differ significantly how the EU bioeconomy strategy is implemented into action plans • Policy set rather little incentive for disruptive bio-based solutions • bio-based products contribute to Circular Economy and European Green Deal	**Focus on R&D&I support** • Policy has focus on knowledge generation, R&D&I support and high-tech solutions • EU aims to become competitive in technologies where it currently lags behind • R&D&I capacities in some MS insufficient for high-tech focus	**Focus on sustainability transformation** • EU-wide implementation of sustainability-oriented policies • Enforcement of more harmonised actions plans to achieve ambitious sustainability goals in most Member States	**Focus on economic growth** • Focus on short term goals in industry support, economic recovery/growth and reduction of unemployment • Focus of support on established industries, bio-based industries and R&D&I of lower priority, specific bio-based innovation policies on EU level limited	**Focus on market uptake of bio-based products** • Specific measures to support commercialisation and market development for bio-based processes, products and services • Goal to reduce dependency of global trade leads to establishment of EU value chains in the bioeconomy
Cooperation	• In the EU focus on R&D&I, bio-based production sites more often in Asia, North and South America • Relatively weak R&D&I cooperation and coordination between feedstock providers and converters	**Focus on global competition** • EU joins MS forces to take the lead over USA and China • Division of work within the EU: MS with focus on R&D&I; MS with focus on feedstock production	**Global supply chains** • EU imports bulk products from agricultural commodities • Circular economy favours use of waste, side streams and CO2 as feedstock for bioproduction in the EU • Circular economy requires close R&D&I cooperation and coordination between feedstock providers and converters	**Domestic focus** • Trend towards nationalism continues; national benefit is prioritised over cooperation and collaboration on EU level • MS already strong in bioeconomy and life sciences become stronger, Member States with fewer bioeconomy-related R&D&I resources are left behind	**Focus on the EU production** • Eastern European countries are actively supported as providers of feedstock and platform chemicals • This requires close R&D&I cooperation and coordination between feedstock providing and – converting Member States

Societal attitude towards sustain-ability	• Rather positive overall public attitude towards the bioeconomy • Limited willingness to pay more for bio-based products • Biomass supply is critically discussed	**Technology will fix it** • Innovative solutions offer sustainable consumption without major life style changes • Society tolerates controversial technologies if they offer clear benefits	**Citizens' movements towards sustainability** • Citizens have intrinsic motivation to change towards more sustainable behaviour • Citizens accept restrictions	**Nudging by money** • Lifestyle changes and changes of consumption patterns towards sustainability must be induced by financial incentives and economic advantages	**Regulation will fix it - Nudging by standards and quotas** • Obligations for sectors that favour bio-based products and processes over fossil-based ones • Consumers assume sustainability of bio-based products
The role of actors	• Financing and market conditions for SMEs more favourable in Northern America than in the EU • cooperation between academia and industry is rather difficult • NGOs with weak strategic focus on bioeconomy	**Focus on filling the innovation pipeline** • Academia, research organisations and SMEs drive knowledge generation and innovation • Favourable innovation financing conditions through VC • Knowledge transfer to existing industries (incumbents) by cooperation with academia, or by joint ventures or buying SMEs	**Actor landscape enriched by new actors, novel market segments** • Brand owners and novel (regional) actors establish bio-based „green" brands and innovative product groups • NGOs promote (regional) bioeconomy	**Domination by large firms** • In the bioeconomy, large established companies and brand owners (incumbents) have a prominent role • NGOs promote future-oriented investments	**Diverse actor landscape** • large firms and new actors exploit market opportunities
Technolo-gical develop-ments	• Broad range of innovations currently developed, both cross-cutting methods and application-oriented innovations • EU overall competitive with other world regions • EU leading in innovations with high potential for sustainability, lagging behind: genome editing, synthetic biology • Potential for controversies, e.g. for genome editing, synthetic biology, negative local impact of biorefineries	**Basic research and high tech solutions** • Sustainability as „built-in" feature of industrial processes, products and services, technological innovations in agriculture • GMO/gene editing possible under certain restrictions	**Sustainability as the main driver for technological developments** • EU focuses on its technological strengths • Technologically mature innovations and those with high environmental/ societal impact flourish	**Moderate technological development** • Innovations that support (member-state specific) business as usual prevail	**Technology supports commercialisation of innovations** • Policy focuses on debottlenecking market creation issues → advantage for rather mature innovations • Focus is on innovations that expand and convert the EU feedstock resources

IMPACT AND IMPLICATIONS					
Innovations benefiting		Cross-cutting technologies and competencies, e.g. digital technologies, synthetic biology, innovations contributing to sustainable agriculture (use of genome-editing tools in crop breeding, de novo domestication)	Resource- and energy efficient bioprocesses, CO2-based chemicals, bio-based materials	Multi-enzyme biocatalysis, new enzymes, smart drop-ins, biodegradable plastics	Biorefineries, new enzymes, bio-based intermediates, materials and end-products, exploitation of novel feedstock (non-food feedstock, side/waste streams, marine resources)
Innovations hindered		Industrial conversion technologies and bio-based intermediates and products	Analytical techniques and bioprocessing, Design and engineering of biological systems, synthetic biology, digital technologies, gene editing or GMO for agriculture	Novel industrial production concepts; Analytical techniques and bioprospecting	Design and engineering of biological systems, synthetic biology, digital technologies
Impact (+)/ Hurdles (-) /		+ Society will have a broader choice in products and services + Improvement in EU competitiveness toward US and China - Gap between R&D and commercialisation could hinder realising bio-based potential -conflicts around sustainability will increase and create new division in society -benefits of bio-based innovations will be distributed unequally between countries	+ Overall, high potential to achieve ecologic goals. Unclear whether positive impacts results from bio-based innovations. Those must prove its value here, because bio-based solutions are only one of many solutions available to tackle sustainability issues -Required orientation towards sustainability only plausible, in uneventful/quiescent times. Hence Covid-19 pandemic has to be overcome	+High potential for economic impact in short-term - role of bio and life sciences here will differ between countries, but rather modest importance of bio-based innovations as emphasis on traditional business -For long-term success and sustainability behavioural changes beyond economic focus unavoidable	+new type of businesses would emerge, important role of brand owners - instruments needed that companies really move away from conventional feedstock towards bio-based -greater alignment of procedures and regulations for bio-based products across-sectors and countries needed

5.3 Implications of the bio-based innovation scenarios

From the scenario analysis different implications for bio-based innovations in the future as well as potential stakeholder actions can be drawn:

Wide variety of potential developments for bio-based innovations in the EU

A great variety of potential developments in bio-based innovation in the EU is plausible in the next decade, as important conditions may take various paths. E.g. the level of cooperation and competition between the EU Member States and between the EU and other world regions could evolve each very differently. There may evolve more integrated approaches of labour division in the bio-based sectors, but increasing competition with limited cooperation is possible as well. Similarly, the consumer perspective and behaviour regarding sustainability and bio-based products may range from a continuation of rather passive and neutral attitude towards active movements. Those framework conditions may lead to very different dynamics and EU landscape in bio-based innovation as the distinctive four scenarios show.

Bio-based innovations with significant impact, but tension between policy goals arise

Bio-based innovations will have a significant impact on the economy and society. In almost all scenarios significant effects arise, with the exception of a sole economic focus on traditional industries (scenario „Economic recovery from pandemic"). Such focus would not lead to a full exploitation of the bio-based innovations potential. But, more important than the magnitude of impact, ecological and societal goals differ between the scenarios and tension between goals and actors arise. E.g. while a high focus on economic goals to recover from the pandemics and/or high-tech focus are plausible in short- and mid-term, such strategies do not lead to sustainable production and consumption patterns and enable the full potential of bio-based innovations. But at the same time, in the „sustainability first" the questions arises whether such positive scenario is realizable, at least under the current economic conditions with the COVID-19, a strong shift to sustainability appears challenging.[37]

The innovation focus depends on the framework conditions

There is no a-prio list of innovations that is more favourable to foster for exploitation and commercialisation than other. Instead, it depends on the context and importance of certain policy goals. E.g. a high focus on national competitiveness would enable in particular advances in innovations with cross-cutting technologies and competencies, e.g. digital technologies, synthetic biology or innovations contributing to sustainable agriculture. Instead, the „Sustainability first" scenario would favour resource- and energy efficient bioprocesses, CO_2-based chemicals, bio-based materials. At the same time, the potential role and competitiveness of certain Member States may differ, e.g. potential boost for the front-runners countries with a sound knowledge base in the „Technology Push" scenario, to a highly differentiated and rather scattered specific activities of countries in line of existing specialisation in the economies.

Actions to maximize benefits and lower burdens needed

To fully exploit the potential of bio-based innovations, a coherent policy-mix is needed. In all scenarios, additional action - next to the general policy setting described in line 1 in table 1– to overcome hurdles would be useful to maximize the impact or avoid unintended negative impacts. Important examples are:

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[37] However, workshop participants also saw opportunities for behavioral change especially on the consumer side towards sustainability as a response to lessons-learned from Covid-19 that behavior has to change.

- The issue of sharing benefits or other ways of balancing between Member States is an important topic in the „Technology Push" scenario as the gap between Member States may widen, if no countermeasures are taken.

- Support of behavioural change of consumers towards sustainability and bio-based products is an issue in several scenarios ("Sustainability first","Economic recovery from pandemic"), key issues are higher awareness, support to strengthen the self-responsibility and transparency and clarity of characteristic and benefits of bio-based solutions.

- In all scenarios, it is a challenge to get the innovations from idea to market and to achieve their wide adoption. While in the „Technology Push" scenario the gaps between R&D and commercialisation may increase, the „sustainability scenario" calls for more international collaboration and the „Push of bioeconomy markets" for more favourable market conditions for bio-based innovations.

Conclusion

In a nutshell, the scenarios underline the importance of policy-mix and that it is context specific. To realize the potential of bio-based innovations and avoid negative effects, policy has to deploy a coherent mix of measures, to engage stakeholder involvement and to anticipate unintended impacts and disfavoured actors.

6 Recommendations

For a successful transition away from a fossil-based economy towards a sustainable bioeconomy, innovations are of major importance. Life and biological sciences and technologies are among the key drivers and enablers for such urgently required bio-based innovations. Their important role has been pointed out and acknowledged in bioeconomy strategies and action plans, on both EU and Member State level.

Many factors on different geographical levels affect innovation and commercialisation for bio-based innovations and the realisation of their potential. In Table 17 the main relevant conclusions for policy and stakeholders are summarised and recommendations are derived. The conclusions and recommendations are structured by action focus. However, they are closely interrelated and it has to emphasised that a coherent policy approach is needed, which takes into accounts the different aspects.

Table 17. Recommendations

Strategic approach to bioeconomy	Bio-based innovations as starting point	Areas of specific innovation focus	Clusters, knowledge transfer and collaboration	Commercialisation and market uptake of bio-based innovations	Striving for higher European coherence and cooperation
Take a strategic approach to bioeconomy	Transform the „default" portfolio of top50 bio-based innovations into tailor-made actions plans and roadmaps	Maintain the leading position in sustainability and a circular bioeconomy	Foster cross-industry collaborations	Finance growth of SMEs and other actors	Continue and intensify actions to achieve higher European coherence and reduce geographical imbalances
	Balance technology-focused and mission-oriented programmes	Promote digitalisation, automation, and AI	Foster transdisciplinarity and co-creation/co-innovation processes	Implement demand-side incentives for market creation	Ensure international coordination of strategies, actions and framework conditions in the bioeconomy
		Elaborate a strategy on use of New Genomic Techniques	Foster bioeconomy clusters on regional, national and supranational levels		

6.1 Strategic approach to bioeconomy

The role of life science and biotechnology for bio-based innovation is recognised in relevant EU strategies and implementation programmes, in particular the EU Bioeconomy Strategy, the proposed CBE and the broad lines of „bio-based innovation" in Horizon Europe's cluster "Food, Natural Resources, Agriculture and Environment". Over the past years, substantial funding was made available for bio-based innovation represented by the top 50 bio-based innovations.

Bioeconomy has been included in various EU strategies, Member States (MS) and regions have developed their own strategies, tailored to their specific strengths, capacities, sector focus and goals. Diversity in strategies in principle is good, as there is no one size fits all strategy. However, not all Member States have a strategy, bioeconomy is often scattered over different policies and action plans are still lacking in many Member States.

Recommendation: Take a strategic approach to bioeconomy

Decision-makers in the EU, Member States and regional policy, in companies, associations and in research institutions are encouraged to further develop strategic approaches to science, technology and innovation to address societal goals. They should carry out strategic dialogues with relevant stakeholders, and should use the information presented in this report - among other - as information base for these activities. Member States with bioeconomy strategies are encouraged to develop action plans to accompany their national strategies on bioeconomy. Member States without strategies are encouraged to develop strategies specifically tailored to their capacities.

6.2 Bio- based innovations are of high importance

This study presents top 50 bio-based innovations, enabled by advances in life and biological sciences and technologies. This portfolio of top 50 bio-based innovations represents important developments and innovation needs for a successful transition towards a sustainable bioeconomy and for achieving impacts in SDGs. It covers the complexity and potential of this field in a well-balanced way. However, this portfolio is a „default portfolio". It cannot be used directly as a 1:1 blueprint for R&D&I policy: as shown in the policy analysis and the innovation ecosystem analysis, Member States and regions differ to a large extent in their specific strengths and weaknesses, their R&D&I capacities, the economic sector focus etc. This also requires a tailored choice of innovations from the portfolio, which fit best to the capacities and goals of the Member State and region, respectively. It was spelled out in the scenarios, which specific subsets of the „default" innovation portfolio may become more relevant than others, depending on the actual situation and the prioritised policy goals.

EU policy as well as Member State policies have made a clear shift away from technology-focused R&D&I programmes towards fostering solutions to grand challenges and mission-oriented support measures. The resulting strategies, action plans and programmes are, as a logic consequence, targeted at specific goals, being often technology-open and solution-oriented. This poses several challenges to life and biological science and technologies driven innovations.

Recommendation: Transform the „default" portfolio of top 50 bio-based innovations into tailor-made actions plans and roadmaps

Decision-makers in EU, Member States and regions, in companies, associations and in research institutions should transform the „default" portfolio of top 50 bio-based innovations into tailor-made actions plans and roadmaps, using - among others - the analyses in this report and the innovation fact sheets as information base. In-depth industrial technology roadmaps at EU and regional level should be elaborated which address the complexity of bio-based innovations and wide variety of challenges (related to feedstock, technologies, value chains etc.), in a way coherent with the main EU bioeconomy and circular economy strategies. Technology roadmaps can support orientation towards coherent long-term technology developments. They can help to avoid that mission-oriented policies focus too much on solutions that may be achievable in the short-term, but are an inferior solution in the long-term. Moreover, strategy and roadmap processes significantly contribute to knowledge sharing and to developing shared goals. Experts see these issues as important for advancing the bio-based sectors further.

In line with the Industrial Strategy for Europe 2020, a biotechnology roadmap could be developed on EU level under the flag of the proposed European Partnership for a Circular Bio-based Europe (CBE). Regions and Member States could develop tailored variants of this EU biotechnology roadmap.

Recommendation: Balance technology-focused and mission-oriented programmes

The specific challenges that technology-open and solution-oriented R&D&I programmes pose to life and biological science and technologies should be addressed: Specific attention should be paid to finding a good balance between actively supporting the integration of biological sciences and technological expertise into application-oriented communities on the one hand, and maintaining critical mass in (non-application-oriented) biological sciences and technologies expertise on the other hand. A level playing field for all solutions in technology-open missions should be ensured. Moreover, researchers and innovators should be given guidance to find suitable calls, which may be widely scattered and difficult to identify.

6.3 Areas of specific innovation focus

This study identified three areas, which pose extraordinary opportunities, or challenges for the EU-27, and which significantly depend on life and biological science and technology driven innovations. These areas are transitions towards a more sustainable industry and a circular bioeconomy, the convergence of life and biological science and technologies with digital technologies, and New Genomic Techniques (NGT).

With the European Green Deal, the EU has a strategic focus on rejuvenating industry in a sustainable way and aims at orienting the actor landscape towards this goal. Key areas are transitions towards environmental sustainability and sustainability supporting innovations. This is also reflected in the top 50 bio-based innovations portfolio, which comprises many innovations, which are relevant for sustainability shifts and a circular bioeconomy. It was shown in this study that the EU-27 is among the world leaders in most of these bio-based innovations.

By contrast, the EU-27 is lagging behind other world regions in innovations which support the digitalisation of the bio-based industry and which exploit bioinformatics, artificial intelligence and deep learning in the life and biological science and technologies. Automation and digitalisation of the bio-based industries bear significant potentials in efficiency and productivity gains. They could also support the linking of various industrial sectors, e.g. feedstock providers and converters. This cross-linking is a prerequisite for establishing new value chains and for advancing a circular bioeconomy. Starting with the Human Genome Project in the 1990s, the EU has invested heavily in the development and exploitation of -omics technologies. They yield vast amount of data, which can only be analysed and interpreted with bioinformatics and artificial intelligence, machine and deep learning approaches, making biological sciences and technologies a data-driven science. Other world regions, especially the U.S.A. and China, have taken the technological lead here. However, their data protection and privacy rules differ significantly from the EU regulations.

About 12 of the top 50 bio-based innovations involve the use of New Genome Techniques (NGT). The use of genome editing is controversially discussed, which limits their application in the EU. Since the European GMO legislation is among the strictest and most prohibitive in the world, other regions have more opportunity to exploit innovations involving genome editing than the EU. Despite this situation, the current EU strategies pay hardly - if any - attention to this topic, due to its controversial nature.

Recommendation: Maintain the leading position in sustainability and a circular bioeconomy

In order to maintain its leading position in the transition to a more sustainable industry, specific strategic emphasis and support should be given to the development and exploitation of the top 50 bio-based innovations, which contribute to this transition. These are innovations, which aim at sustainably using natural resources, including sustainably sourced bio-based and other raw materials, enabling the bioeconomy to be the supplier of bio-based carbon in the circular economy. Bio-based innovations that enable bio-waste utilisation have a large market potential, and the integrated use of carbon from the air (CO_2 based carbon), waste (recycled carbon) and from biological sources (green carbon) should be promoted (e.g., by utilising CO_2 captured from industrial processes). Although the top 50 bio-based innovations in the field of cross-cutting technologies and approaches may not have impacts directly attributable to circular targets, they could, however, bring up new possibilities, which are currently not foreseeable. Therefore, also these cross-cutting technologies and approaches should be an integral part of R&D programmes aiming at sustainability transitions. Moreover, in the concept of circular bioeconomy also the usage phase of products such as prolonging the use of products, valorisation of waste and side streams, and prevention or reduction of waste.

Recommendation: Promote digitalisation, automation, and AI

It is recommended that the EU should strive for a stronger position and more technological independence from other world regions regarding digital technologies and especially the use of artificial intelligence approaches. Synergies between the EU strategy and coordinated plan on artificial intelligence[38] and the bioeconomy strategy should be exploited in the strategy and roadmap processes, recommended above. Moreover, innovations enabled by the convergence of life and biological science and technologies with digital technologies should be explicitly supported. This also requires the active integration of digital industries into the bio-based sectors. Clusters may be one of several suitable instruments. Moreover, the lack of qualified staff, able to productively work at the interface of biological and digital science and technologies should be addressed, e.g. by new educational courses and curricula, designed to integrate these disciplines.

Recommendation: Elaborate a strategy on use of New Genomic Techniques

It is recommended that New Genomic Techniques are strategically addressed in the EU. For the purpose of balanced policy-making on the NGTs, it would be desirable if an informed and participatory discussion on the benefits and drawbacks of genome editing takes place, closely interlinked with policy processes. The study regarding the status of novel genomic techniques under Union law as requested by the Council in light of the Court of Justice's judgment in Case C-528/16, should be welcomed. In line with the mandate for the study, legal proposals should be prepared as follow up to the findings of the study and the participatory discussion.

6.4 Clusters, knowledge transfer and collaboration

The analysis of issues to be addressed revealed that cooperation is of major importance for nearly all top 50 bio-based innovations. Given the interdisciplinary character of biotechnology, cooperation and interdisciplinary research has already been in the focus of R&D&I policy for many years: research consortia usually comprise different scientific disciplines and exploit academia-industry cooperation as well as cooperation of actors along value chains. However, technology-driven developments (e.g. convergence of life and biological science and technologies with digital technologies) as well as new challenges in the bioeconomy (e.g. transition to a circular bioeconomy, use of CO_2 and waste as feedstock) require the active initiation and continuous support of new types of cooperation

[38] COM (2018) 237 (4/2018), COM(2018) 795 final (12/2018)

and knowledge transfer. The latter is currently often confined to research consortia whereas outreach beyond these consortia is still relatively weak.

Across Europe, cluster development is key instrument for specific bioeconomy policy targets, for example, linking academia with the private sector for further value creation and expansion of R&D capacity. Also, clusters connect actors in the value chains of local feedstock supply from traditional sectors with existing industrial infrastructure, knowledge base and public support mechanisms. The strategic bioeconomy cluster development, which brings together different regions, their stakeholders and financial support instruments, has already proven to be efficient in a number of national and international level examples.

Within geographical proximity, companies often have similar resources, are specialised on the same topic and compete for the same market niche. Clusters are an excellent opportunity even for these competing companies to build mutual trust and to cooperate e.g. by jointly entering into collaboration with other actors with complementary resources (e.g. different biomass resources, technical competences or infrastructural opportunities). Clusters as trust-building entities would enable cooperation and knowledge transfer opportunities with added value for all the partners involved.

Recommendation: Foster cross-industry collaborations

In order to develop innovations to industrial maturity, market introduction and broad use, collaborative R&D&I along the whole value chain is required, especially, if new value chains and markets have to be created or if existing value chains must be interlinked in new ways. Specific attention should be paid to intensify the interaction between feedstock providers and converters and the collaboration between core bioeconomy and more distant sectors (e.g. community waste treatment). Knowledge diffusion channels need to be mobilised to disseminate the knowledge to both, core and more distant bio-based sectors. Clusters could be a useful tool for reaching relevant stakeholder groups and providing them with necessary information. In addition, action plans and roadmaps should spell out concrete quantitative targets, e.g. concerning costs, profits, emission targets. This also attracts actors from more distant industries (e.g. waste processing), who are not interested in bio-based innovations in the first place, but in implementing promising solutions.

Recommendation: Foster transdisciplinarity and co-creation/co-innovation processes

Ambitious frameworks including Horizon Europe and the BBI JU aim at solving complex societal challenges, such as global warming, loss of biodiversity, transition to a circular bioeconomy. While the requirement of interdisciplinary research is widely acknowledged, transdisciplinary approaches should be strengthened further, especially in co-designing, testing, and scaling innovative, science-based, intervention strategies to breakthrough outcomes.

Recommendation: Foster bioeconomy clusters on regional, national and supranational levels

Further regional, national and supranational clustering should be promoted to support bioeconomy development. Member States and regional governments should commit themselves to support clusters in different sectors. It should be ensured that further inclusion of all stakeholders, especially primary producers or digital industries, is realised in such clusters. Moreover, transdisciplinary approaches should be promoted, e.g. active citizen involvement with clusters.

6.5 Commercialisation and market uptake of bio-based innovations

The analysis of priority issues to be addressed revealed that for more mature innovations, standards and regulations as well as measures for market creation become most important. The past years substantial funding was made through recent programmes, such as Horizon

2020, for higher TRL innovations such as demonstration projects and flagships linked to bio-based production. With the proposed European Partnership for a Circular Bio-based Europe (CBE) as a potential successor of BBI JU and the European Circular Bioeconomy Fund (ECBF), efforts are continued to bridge the gap from research to market. Nevertheless, it cannot support all commercial scale projects and thus - next to rather low flexibility for fast actions - access to funding remains an issue. In particular for SMEs, early innovation phases financing shortages remain a main hurdle for growth. However, they play an essential role in knowledge generation. Moreover, the lack of up-to-date pilot facilities in the EU is recognised as important gap according to experts.

At the same time, market conditions do not guarantee a successful market uptake of bio-based products, which are often more expensive than fossil-based products in mature markets. The latter benefit substantially from low oil prices and not all environmental externalities are included in their price. Specific challenges arise for dedicated and functional bio-based products, as new markets have to be created and entered.

Recommendation: Financing growth of SMEs and other actors

Access to finance should be improved to further increase commercialisation of innovations. Mainly the magnitude of financing should be enlarged in order to fund a larger number of promising projects (partly with substantial in-kind contribution of the beneficiaries). Moreover, additional different features may be optimised, such as

- administrative procedures to set up funds or individual financing,
- high emphasis on projects that appear risky, but may have high disruptive potential,
- support pilot facilities to upgrade to state-of-the-art infrastructure, as these may enable industry players to bring products successfully to the market.

Recommendation: Implement demand-side incentives for market creation

It is recommended that demand-side incentives will be implemented, like carbon taxes on fossil carbon, public procurement and/or obligatory targets for bio-based products etc. in order to create stable markets for circular bio-based products. Measures should be closely connected to sustainability goals and derived environmental standards. This requires that producers provide information on the sustainability profile of their products and processes. Support should be provided to them to carry out the required assessments. The latter approach, if communicated through e.g. labels, may also increase consumers' awareness and willingness-to-pay.

6.6 Striving for higher European coherence and cooperation

Although the Central and Eastern European (CEE) countries have made massive progress in the development of their bio-based sectors over the past decade, they are still lagging behind compared to the Western Europe in terms of bioeconomy uptake and contribution to and benefiting from bio-based innovations. On EU level R&D projects, CEE countries have a significantly lower involvement compared to the Western European countries, partly because of lower R&D capacity, partly because of weak incentives for well-established and well-functioning Western European consortia to take newcomers on board.

CEE are often integrated in the bioeconomy value chains only as biomass providers. Indeed, an important share of European biomass is mostly provided by CEE countries (for instance Poland, Romania), due to their large biomass providing sectors (i.e. agriculture, forest-based industry). This implies high employment, but only low added value in CEE countries. Some production facilities have been built, but expectation that these facilities form the seed and core of a developing innovation cluster has hardly been fulfilled. Instead, the majority of biorefineries, where value added production takes place, are located in Western Europe (especially Belgium and the Netherlands).

In comparison to other policies, bioeconomy policies and strategies are less integrated and harmonised across the EU. For instance, in renewable energy policies, European renewable energy targets are set in the (recast of the) Renewable Energy Directive. Member States were obliged to submit national Renewable Energy Action Plans (nREAPs) showing how to meet renewable energy targets. Thereby the fact was addressed that Member States have different available resources and their own unique energy markets. In the future, a similar situation may arise in e.g. waste policies, as Member States have obligations to separate collection of bio-waste by 2023. Organic waste fraction are considered a valuable feedstock for the bioeconomy.

In order to increase cooperation on bioeconomy policy, a new dedicated forum for Member States was launched in late 2020 (The European Bioeconomy Policy Forum (EBPF)), to support the strategic advancement of a circular and sustainable bioeconomy by bringing together Member States and EU institutions. The forum will facilitate sharing of best practices and coordinated approaches in developing bioeconomy policy solutions in different Member States. It could therefore contribute to increase inclusion of CEE countries, to reduce geographical imbalances and to strive to better coordination and harmonisation of strategies, actions and framework conditions within the bioeconomy and between bioeconomy and other policies.

Recommendation: Continue and intensify actions to achieve higher European coherence and reduce geographical imbalances

Urgently required and promising steps have already been taken to increase inclusiveness and to reduce geographical imbalances. These efforts need to be at least maintained, increasing them should be considered.

- R&D&I project level: Continue or increase the obligatory share of involvement of CEE partners in project consortia.
- Policies should prioritise measures to move the CEE countries towards value added positions within EU value chains, e.g. by establishing upgrading technologies and infrastructures in CEE countries, or by building-up value chains at local or national level for valorising of locally produced biomass.
- Bioeconomy policies in CEE countries should be better linked with other policies, e.g. waste management, energy, food.
- Establish clusters as focal points for developing value chains with higher value-added for CEE countries.

Recommendation: Ensure international coordination of strategies, actions and framework conditions in the bioeconomy

While specific national and regional approaches for exploiting bio-based innovations is useful, it has to be ensured that at the same time there is an international coordination of bioeconomy strategies and action plans on the one hand, and a better integration of bioeconomy policies with other related policies.

It is recommended that initiatives such as the recently launched European Bioeconomy Policy Forum (EBPF) are continued.

Member States are encouraged to proactively link their bioeconomy strategies and actions plans with the waste management and recycling plans they are obliged to develop by 2023.

7 Abbreviations

AI	Artificial intelligence
BBI JU	Bio-based Industries Joint Undertaking
CBE	European Partnership for a Circular Bio-based Europe
CEE countries	Central and Eastern European countries
CO_2	Carbon dioxide
e. g.	for example
EBPF	The European Bioeconomy Policy Forum
EC	European Commission
ECBF	European Circular Bioeconomy Fund
etc.	et cetera
ETS	Emissions Trading System
EU	European Union
H2020	Horizon 2020
i. e.	id est, that means
MS	Member States
NGT	New Genomic Techniques
nREAPs	National Renewable Energy Action Plans
R&D	Research & Development
R&D&I	Research & Development & Innovation
SDGs	UN Sustainable Development Goals
SMEs	Small and medium-sized enterprises
TRL	Technology Readiness Level
UN	United Nations

8 References

The following reference list contains three parts. First, the literature that is used in the main text or in the Annex sections below. Second, the references for the country fiches are presented. Third, the references for the innovation factsheets are presented; they are additionally given on the respective factsheet.

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Annex I: Methodology

Top 50-bio-based innovation selection

For the identification, selection and characterisation of the top 50 bio-based innovations a multi-method approach was followed. It comprised the steps

- Scanning of relevant sources and elaboration of a long list of innovations
- Consolidation of the long list of innovations
- Experts' validation of the consolidated list, reduction to top 50 bio-based innovations
- Experts' assessment of the top 50 bio-based innovations in an EU-wide online expert survey

In order to identify candidates for relevant innovations, the following sources were used or scanned by members of the project team:

- Science and technology foresight studies, roadmaps, strategic documents, project reports: Bio-Based Industries Consortium (2020); Engineering Biology Research Consortium (2019); Engineering Biology Research Consortium (2020); Fabbri et al. (2018); Ganz et al. (2019); Gheorghiu et al. (2017); Hurst et al. (2016); Warnke et al. (2016); Warnke et al. (2019); Weber et al. (2018); Wydra et al. (2017).
- Scientific literature: the tables of content of the years 2018-2020 of the following journals were scanned manually: Nature, Nature methods, Nature Biotechnology, Trends in Biotechnology, Current Opinion in Biotechnology.
- CORDIS (Community Research and Development Information Service) database of relevant FP7 and H2020 projects: The result packs[39] in the application domains Fundamental Research, Industrial Technologies, Digital Economy, Food and Natural Resources, Climate Change and Environment, Society as well as database of EU research projects[40] under Horizon 2020 were scanned.

The results were entered in an ACCESS database, resulting in a long list of potentially relevant innovations. In order to ensure an adequate coverage of the scope of the study and to avoid gaps and biases further desk research on individual innovations and discussion of the long list were carried out by the project team. These discussions resulted in deletions of some innovations from the database, in merging of several separate innovation descriptions into fewer new ones, or in different framing of innovations. A balanced, consolidated list of 87 innovations, organised into 20 subfields, resulted.

This consolidated list was validated and commented by 15 experts from seven EU countries in the online workshop "Top 50 bio-based innovations for the EU" on April 30, 2020. Based on experts' comments regarding the categorization in subfields and the aggregation level of some innovations, the subfields were restructured and rather a general level of aggregation for the innovations were taken, to avoid that the innovation list appears to be too fragmented. A portfolio of top 50 bio-based innovations resulted. They were further characterised by analysing relevant scientific publications, by patent and publication analyses and by an EU-wide online expert survey.

[39] https://cordis.europa.eu/results-packs/en
[40] https://data.europa.eu/euodp/de/data/dataset/cordisH2020projects

EU-wide online expert survey

An anonymous EU-wide online expert survey was conducted for the assessment of the top 50 bio-based innovations.

A total of appr. 1,500 expert email addresses were compiled from internal data bases and publicly available sources, such as websites. In addition, a snowballing approach was followed: appr. 30 associations and cluster organisations were asked to forward the invitation for participation in the survey in their networks. Care was taken that experts from all EU member states were invited to the survey.

Invitations were sent out on July 6, 2020 and July 13, 2020, with reminders on July 27, 2020 and July 29, 2020. After checking the response rates for individual subfields, targeted invitations were sent out to experts with specific expertise in the respective subfields on August 2, 2020. The survey was closed on August 18, 2020.

As the survey was an anonymous survey and a snowballing approach was conducted, it is not possible to give the exact number of invited experts and the response rate. During the active field phase of the survey from July 6 to August 18, 2020, the survey was opened a total of 948 times. The actual number of experts entering the survey is probably lower, because opening the survey from different devices by the same expert would be counted several times. 92 fully completed questionnaires were obtained with 188 subfield assessments.

The survey was structured in a way that experts were presented the 11 subfields and could choose which subfield they wanted to assess. They were then directed to ten questions (Table 18) which they were asked to answer for all innovations in the chosen subfield. After completion of answering the questions to this subfield, experts could either continue with answering the 10 questions for another subfield, or finish the questionnaire. On average, each survey participant assessed innovations in appr. 1.35 subfields. All in all, 11 to 33 valid answers per innovation were obtained, with an average of 18.8 respondents per subfield.

Raw survey data were transferred to SPSS and analysed with descriptive statistics.

Table 18. Questionnaire of the EU-wide online expert survey

No.	**Question**	**Answer options**
1	How do you rate your expertise regarding these innovations?	high/medium/low/no
2	How relevant is this innovation for the further development of the bioeconomy in the EU today (in 2020)?	high/medium/emerging/no
3	How relevant is this innovation for the further development of the bioeconomy in the EU in 10 years (in 2030)?	high/medium/emerging/no
4	What is the present maturity level of this innovation globally (year 2020)?	mainly basic, lab scale research/ application-oriented R&D, pilot scale/ Scale-up and demonstration/ fully implemented market introduction/ broad use
5	Which maturity level will most likely be achieved in 10 years (2030) globally?	mainly basic, lab scale research/ application-oriented R&D, pilot scale/ Scale-up and demonstration/ fully implemented market introduction/ broad use

No.	Question	Answer options
6	What is the present position of the EU in international comparison, regarding the maturity level of this innovation (year 2020) ?	Leading position/Average position/Lagging behind other world regions
7	Which issues must be addressed with priority to overcome existing hurdles and to raise the maturity level of this innovation in the EU?	R&D/Cooperation (e.g. academia-industry, PPPs, cross-sectoral)/Innovation financing/Regulations, standards/Market creation/Public perception, acceptance
8	Which impact on the following dimensions do you expect of this innovation in the EU by 2030?	Knowledge base/Economy/Environment/Society
9	Which industrial sector(s) will benefit to a large extent from this innovation in 10 years (2030)?	Supply of bio-based feedstocks/Conversion to intermediate products/Manufacturing of final products/R&D-Services/Machine and plant construction/Digital technologies, bioinformatics/Environmental services
10	According to your estimation, how large is the potential of this innovation to evoke socio-political controversies?	Low Potential/Medium Potential/Large Potential

Patent and Publications Analysis

In order to measure research and technological competitiveness of the EU-27 and respective dynamics different patent and publication indicators have been calculated.

In the beginning of the project, patent indicators were calculated in order to aim to detect highly dynamic fields for identification of top 50 bio-based innovations and make a first general assessment of the EU-27. As these presented only interim results as a basis for further analysis, these results were only included in the Progress report, but are not presented in this Final Report.

After the identification of the top 50 bio-based innovations, for each innovation a search strategy based on keywords and/or patent classification codes (IPCs/CPCs) for patents as well as for publications has been developed and refined in several steps after screening first results. The elaboration of sound search strategies turned out to be highly challenging, as at least some innovations were expressed on a level that does not match to expression used in patent analysis. E.g. the term biorefinery is not used for patent applications, but single technologies that may be used in a biorefinery are patented. However, it was out of scope this study to include all potential technologies that may be used in a biorefinery. Moreover, some of the Top 50 bio-based innovations are rather concepts instead of technical inventions and are therefore not well represented by patent literature.

With these search strategies transnational patent applications were calculated in Derwent World Patents Index (WPINDEX), a value-add database which allows for high-quality and complex key-word-based searches. Similarly, publications (scientific articles, excluding reviews or other scientific literature like editorials or conference proceedings) were calculated in the SciSearch (Science Citation Index) database by using the respective search strategies.

The following indicators were calculated

- Absolute numbers worldwide and for the EU-27 in 2004-2007 and 2014-2017
- Dynamics in EU by comparing growth rate between 2004-2007 and 2014-2017
- EU Shares of patents and publication in 2004-2007 and 2014-2017

The following limitations have to be taken into account. Despite several iteration rounds to refine search strategy for a few innovations (e.g. biorefinery) less than 5 patent applications per year worldwide could be identified. Those innovations, for which in both time periods this average yearly number was below 5, were excluded from further analysis.

Policy mapping of EU, & Member State level and regional policy approaches

As the project's topic is life and biological sciences and technologies as engines for bio-based innovation, bioeconomy strategies and associated actions will be analysed with specific focus on the foreseen role of life sciences and biotechnology. The policy mapping will provide an in-depth overview of the landscape of the relevant policies for life and biological sciences and technologies in the EU, different EU Member States and their regions.

Mapping of EU policy approaches

Since high-level EU policies are oriented towards the achievement of the UN Sustainable Development Goals, these will be presented and linked to opportunities to contribute to them via life science and biotechnology. Secondly, an overview of EU policies related to bioeconomy and bio-based innovations will be presented, including the role of life science and biotechnology in these policies. These policies include the EU Bioeconomy Strategy, European New , EU Industrial Strategy, and the Circular Economy Action Plan 2020. One of the main tools to promote life science and biotechnology as engines for bio-based innovation is the allocation of RTD budget and financing of pilots, demo's and flagship. Therefore, the main EU funding programmes such as Horizon 2020, (which also includes the Bio-based Industries initiative) and forthcoming Horizon Europe programme will be briefly described including their priorities toward life science and biotechnology. Moreover, an analysis of 111 selected projects from the CORDIS database will provide insight in budgets spent in the past years on the top 50 bio-based innovations and the clusters they belong to (see the section on assessment of EU funding below). Finally, the main EU legislative framework, relevant for life sciences and biotechnology will be described, as these have large impact on the implementation perspective of the different innovations.

Mapping of country level policy approaches

A number of EU Member States have published a bioeconomy strategy and developed approaches to promote the bioeconomy in the respective countries. The main strategies of each country can be obtained from „knowledge4policy" part of the EU website[41] resulting from the „Joint Survey on bioeconomy policy developments in different countries" by JRC, BBI JU and IEA Bioenergy (JRC 2018). The bioeconomy strategies have been summarised and analysed in the report „Bioeconomy and biorefining strategies in the EU Member States and beyond" (IEA Bioenergy 2018)[42]. Other relevant literature includes BioStep (2016)[43] and the BBI Country Fact Sheets[44]. The existing literature supports the identification of relevant bioeconomy strategies and their main properties. However, in general the literature does not highlight the specific role of life sciences and biotechnology in these

[41] https://ec.europa.eu/knowledge4policy/visualisation/bioeconomy-different-countries_en
[42] IEA Bioenergy (2018) Bioeconomy and biorefining strategies in the EU Member States and beyond, reference Year 2018. https://www.ieabioenergy.com/publications/bioeconomy-and-biorefining-strategies-in-the-eu-member-states-and-beyond/
[43] BioSTEP (2016) „Review of bioeconomy strategies at regional and national levels" (2016), http://www.bio-step.eu/fileadmin/BioSTEP/Bio_documents/BioSTEP_D2.3_Review_of_strategies.pdf
[44] https://www.bbi-europe.eu/news/new-bbi-ju-country-fact-sheets

bioeconomy strategies. This information was obtained by scrutinising the bioeconomy strategies in detail. Information on national support measures was additionally collected by the project team from different sources.

Assessment of EU funding spent on life science and biotechnology projects

Within the given time and because of large data gaps it is not possible to analyse national funding programmes in detail. We believe that organisations active in life science and biotechnology on national level generally will take the opportunity to apply for H2020 and BBI projects whenever possible. Therefore, the analysis of EU projects, available in CORDIS, is assumed to be a good indicator of the degree of activity and the role of life science and biotechnology for bio-based innovation at country level. In total 111 H2020 projects from CORDIS database were selected that were directed to the top 50 bio-based innovations and their clusters. We analysed the budget and country of origin of each of the 702 project partners that received support within these 112 projects and put this in the software tool „Power BI". This way it is possible to assess EU budgets spent on each cluster in each Member State. Also, the project type was noted, providing insight whether it concerned basic research, research and innovation actions, demonstration activities or flagships. The investigated project types and their TRL levels are presented and grouped in three categories as shown in Table 19

Table 19: Assessed EU funding programmes, their TRL range, classified in three groups

Funding programme	Abbreviation	TRL	Group
European Research Council grants	ERC	1	1. Research and Development
Marie Skłodowska-Curie actions	MSCA	1 - 5	
BBI Research and Innovation Actions	BBI-RIA	3 - 5	
H2020 Research and Innovation Action	RIA	3 - 5	
SME instrument phase 1	SME1	4 - 5	
H2020 Innovation Action	IA	6 - 7	2. Demo-scale
BBI Innovation Actions – Demonstration	BBI-IA-DEMO	6 - 7	
SME instrument phase 2	SME2	6 - 7	
BBI Innovation Actions – Flagship	BBI-IA-FLAG	8	3. Large-scale

Outline of country fiches

The collected county data has been visualised in „country fiches" of two pages containing:

- An indication whether a bioeconomy strategy, related action plan, and/or a bioscience related strategy is available at county level;
- An indication of addressed challenges and support measures;
- A brief description of the bioeconomy strategy;
- An overview of targeted economic sectors with their corresponding priorities;
- A description how life science and biotechnology are addressed in the strategies;
- An overview of main support measures;

- Amount of EU biotechnology budget received at country level, by the top 10 of most receiving countries, and distributed by thematic cluster. Additionally, the type of project (research and development, demo-scale or large-scale) is indicated.

All fiches are written in English, in a user-friendly way, including graphs and charts. Linguistic checks have been performed to ensure publishable quality. The country fiches are presented in Annex V.

Stakeholder mapping and assessment

One aim of the project was to provide a stakeholder mapping of innovation actors in a database. As outlined in the Inception Report and the Progress Report, the compilation of an exhaustive list of all relevant EU actors in the field of life and biological sciences and technologies bio-based innovation is not feasible. Hence, the work will focus on the identification of the most relevant companies and institutions.

After considering different options and sources (e.g. patent statistics), it was decided that CORDIS was used to identify relevant H2020 projects. Therefore, different keywords were used to extract around 350 potentially relevant projects for biology and life sciences and technologies. Then, this list was condensed in several steps by the project team to extract those projects with the most direct links to the top 50 bio-based innovations of this study (meaning e.g. that also those BBI JU projects were excluded, where biotechnology only plays a minor role). For those remaining 111 projects all relevant actors where identified and characteristics such as

- Name
- Type of Organisation
- Country
- Relevant top 50 bio-based innovation
- Relevant subfield
- Budget
- Funding scheme

assessed.

The data collected in Excel and will be attached to this Report. Moreover, the details of the project are also available through Power BI tool developed within the project and is available on demand.

The most important results are presented in section 3, 4 and Annex III.

This focus enabled us to have consistent selection criteria for actors and enabled us to provide similar characteristics for each actors. As shown in the main report and country fiches, we used this database to further analyse the EU funding per country, per innovation and subfields, per TRL and per type of actors.

It has to be remarked that any kind of database will have its limitation regarding to assess the innovation landscape in the EU. Irrespectively of the precise number of entries, it is hardly possible to derive clear implications from a snapshot assessment. A main problem is that appropriate identification is only possible to a limited extend. Especially on the user side, many actors are not only active in this field, but have other activities (e.g. in traditional chemistry) as well and the importance of bio-based innovations for those actors is not always clear. Moreover, the scene may be very dynamic and there are many actors especially on the user side, who may take up activities, process, and products. However, those actors are hard to identify ex-ante.

Hence, it was decided not to put to large emphasis on the database and to interpret the results too far. But to receive a fuller picture, a review of current literature / studies regarding the actor landscape in EU-27 were made as well as the patent analysis and the survey designed in such way that we received additional information about the EU position.

Stakeholder Engagement Summary

In the project stakeholder engagement was carried out via three Online Workshops, interviews for WP 2-4 and a Public Online Survey.

Online Workshop „Top 50 bio-based innovations for the EU"

This first workshop "Top 50 bio-based innovations for the EU" (Task 1.1.) was held on April 30th, 2020 with 13 external experts (see the Agenda and participant list below). The aim of this workshop was to validate and reduce the list of 87 innovations to 50 most relevant innovations.

Participants

Affiliation	Country
Aarhus University	Denmark
BASF SE	Germany
Bio-Based Industries Consortium	Belgium
Bio-Based Industries Consortium	Belgium
BioDeutschland	Germany
European Commission	Belgium
Evonik Industries AG	Germany
French National Institute for Agricultural, Food and Environmental Research	France
ICONS	Italy
Novozymes A/S	Denmark
SilicoLife	Portugal
Technical University of Denmark (DTU)	Denmark
University of Bologna (UNIBO)	Italy
University of Kiel - Bioeconomy on marine sites (BAMS)	Germany
University of Natural Resources and Life Sciences	Austria
Wageningen Food & Bio-based Research	Netherlands

Agenda

30 April 2020, 08.30-09.00	Time for Dial-In and technical preparation
09:00-09:30	Welcome and Introduction • Introduction round of participants • Presentation of goals of the project and aims of the workshop • Agenda of the workshop, instructions regarding communication
09:30-10:20	Presentation and overall discussion of top innovations • Presentation of preliminary sorting: included, unclear and not included innovations • Comprehension questions and answers • 2 rounds of voting: 1. Which innovations in the category "included" should be removed from this category? Choose up to 5 innovations 2. 2. Which innovations in the category „not included" should be removed from this category? Choose up to 5 innovations
10.20-10.30	*Short break*
10.30-12.30	Detailed discussion of innovations from the category unclear in thematic subgroups • Example for modus of discussion in whole group (~15min) • Discussion in 4 moderated subgroups about pros and cons for those innovation, where it has to be decided, whether they should be selected for the top 50 list
12:30-12:40	*Short Break*
12:40-13.00	Presentation of insights from subgroup discussions Next steps End of workshop
May 7, 10.00-11.00	Follow-up, for those who are interested: Presentation of the final results online on May 7, 10.00 -11.00 with possibility for questions, comments and discussion

Online Workshop „Scenarios for Bio-based Innovations in the EU"

The second workshop "Scenarios for Bio-based Innovations in the EU" was held on 15th of October 2020 with 8 external experts, while 15 were initially registered for the workshop (see the Agenda and participant list below). In the workshop, four scenarios were presented how innovations driven by life and biological sciences may develop in the EU in the coming 10 to 15 years, and which different pathways for their uptake and implementation may be anticipated. Workshop participants discussed these scenarios regarding plausibility and elaborated implications for policy, industrial actors and academia which may be derived from these scenarios.

Agenda

15 October 2020, 08:30-09:00	Time for Dial-In and technical preparation
09:00-09:20	Welcome and Introduction • Introduction round of participants • Presentation of goals of the project and aims of the workshop • Workshop aims and purpose of the scenarios
09:20-09:40	Presentation of the scenarios Presentation of preliminary scenarios Comprehension questions and answers
09:40- 10:45	Discussion of Scenarios, Round 1
10:45-11:00	*Short break*
11:00-11:45	Discussion of Scenarios, Round 2 • Science and technology • Translation from science to industry • Regulation and market creation • EU Member State policies • Circular bio-based economy
11:45-12:30	Presentation of insights from sub-group discussions Concluding remarks & next steps

Participants

Affiliation	**Country**
BEC Bioeconomy Cluster	Slovakia
CLIB2021	Germany
Delegation of the Government of Navarra	Spain
Innovhub SSI	Italy
JRC, European Commission	Belgium
NIFU	Norway
Novamont SpA	Italy
Teagasc	Ireland

Online Workshop „Policies for Bio-based Innovations in the EU", agenda and list of participants

The third workshop „Policies for Bio-based Innovations in the EU was held on 11th of November 2020, with 32 external experts (see participant list and Agenda below). At the workshop, the assessment regarding the Top 50 bio-based innovations for biology and life sciences in the EU were presented, as well actor capabilities for innovation and policies. On this basis, key recommendations and lessons learnt for policy-makers and other stakeholders were discussed with the participants.

Agenda

11 November 2020, 08.30-09.00	Time for Dial-In and technical preparation
09:00-09:30	Welcome and Introduction • Introduction round of participants • Presentation of goals of the project and aims of the workshop • Agenda of the workshop, instructions regarding communication
09:30-10:15	Presentation of the main results • Policy analysis • TOP 50 bio-based innovations
10.15-10.30	*Short break*
10.30-12.15	Policy conclusions and discussion of recommendations • Science and technology • Translation from science to industry • Regulation and market creation • EU Member State policies • Circular bio-based economy
12:15-12:30	Presentation of insights from sub-group discussions Concluding remarks & next steps

Participants

Affiliation	Country
APRE	Italy
Asebio- Spanish Bioindustry Association	Spain
Bio Base Europe Pilot Plant	Belgium
Bio Base Europe Pilot Plant	Belgium
BIOEAST	Hungary
CLIB2021 and KADIB	Germany
Czech Academy of Sciences	Czechia
Department of Agriculture, Food and Marine, Ireland	Ireland
DTU BIOSUSTAIN	Denmark
Novo Nordisk Foundation Center for Biosustainability	Denmark
ECBF- European Circular Bioeconomy Fund	Belgium
Flemish Institute for Technological Research (VITO)	The Netherlands
Forschungszentrum Jülich GmbH	Germany
Foundation for Science and Technology	Portugal
German Association for Synthetic Biology	Germany
INIAV National Institute of Agricultural and Veterinary Research	Portugal
LAB University of Apllied Science	Finland
Latvian State Institute of Wood Chemistry	Latvia
Lithuanian agency for science, innovation and technology	Lithuania
National Institute for Agriculture and Food Research and Technology (INIA)	Spain
NORDEN Nordic Bioeconomy Strategy-Nordic Council of Ministers	Sweden
NORDEN Nordic Bioeconomy Strategy-Nordic Council of Ministers	Estonia
Praxi network	Greece
Technical University of Denmark (DTU)	Denmark
The Center of Plant Systems Biology and Biotechnology (CPSBB)	Bulgaria
The Center of Plant Systems Biology and Biotechnology (CPSBB)	Bulgaria
The National Authority for Scientific Research	Romania
The National Authority for Scientific Research	Romania
The National Authority for Scientific Research	Greece
The University of Natural Resources and Life Sciences (BOKU)	Austria
TU Berlin	Germany
Wageningen University & Research	The Netherlands

Expert Interviews

Throughout different work packages, we have also carried out 18 semi-structured expert interviews that has served as expert consultations in order to fine tune and validate the project findings. Most of the experts were asked for several tasks. Hence, the initial planned interviews per task have been fulfilled (see the overview of interviewed experts in table below)

Affiliation	Country	Expert for tech maturity (Task 2.2)	Expert for innovation ecosystem (Task3.2)	Expert for policy (Task 4.2)
BASF SE	Germany	X		
BIOEAST Initiative	Hungary		X	X
Capricorn	Belgium		X	
CEFIC (2 experts)				X
Corbion	The Netherlands	X		
Czech Bio	Czech Republic		X	X
EuropaBio	Belgium	X	X	X
Evonik Industries AG	Germany	X		
Global Industrial Partnerships Development, Abolis Biotechnologies	France		X	
Iris Technology Group	Ireland	X		
KeyGene	The Netherlands	X		
Lanza Tech	Belgium		X	
Max-Planck Institute	Germany	X	X	
Novamont SpA	Italy	X		
Tolouse White Biotechnology	France		X	
University of Groningen	The Netherlands	X		
VITO Flemish Institute of Technology	The Netherlands	X	X	X
BASF SE	Germany	X		
BIOEAST Initiative	Hungary		X	X
Capricorn	Belgium		X	
CEFIC (2 experts)				X
Corbion	The Netherlands	X		
Czech Bio	Czech Republic		X	X

Annex II: Maturity and development opportunities

The following text summarizes the work of WP 2. Main messages are taken up in the main report text in the SWOT as well as the recommendations

Goal of the assessment

In this assessment, the development opportunities within the field of bio-based life science and technology are identified. Before being able to identify the development opportunities, it is required to understand the maturity of the field. The concept of maturity is not formalised, and no standard methodology to determine the maturity of a research field or subfield exists. However, several methods have been developed and tested by various authors. An overview is presented by (Keathley et al. 2013).

In this assessment, a systematic approach to estimate the maturity of the subfields within bio-based life science and technology is developed. This methodology is then applied to these subfields, as well as a comparable scientific field outside of life and biological science, in order to get a clear view on the maturity level. The systematic approach developed in this study aims to get a clear picture of the maturity without spending a large amount of resources. For this reason, laborious exercises such as an authorship analysis (Keathley 2013) or defining research cycles (Keathley 2013) are omitted. To compensate for omitting these exercises, the results are discussed during expert interviews to improve the obtained information. This information will then be used to identify the development opportunities and how the maturity can be further advanced.

Approach and Methodology

Approach

Due to the intangible nature of the concept of maturity, several methods will be utilised to get an assessment of the overall maturity. Three methods will be used to get quantitative data on the maturity level:

1. TRL analysis on the top 50 bio-based innovations
2. Patent to publication ratio analysis
3. Method analysis

The conclusions from these quantitative data will be combined with qualitative data from experts in the field. Where each of these methods have shortcomings, the combination of these methods provides a clear picture of the current status of bio-based life sciences and technology.

The entire field of life and biological science will be investigated by dividing the different topics in subfields. These subfields will help to analyse the differences in the different topics within life science and technology. Moreover, the subfields allow for a comparison with a well-developed discipline. This discipline should adhere to several criteria:

- High research intensity
- Intensive use of digital technologies
- Closely interlinked with a high number of other economic sectors
- Expected to have or to have overcome similar development hurdles as the field of life and biological sciences
- Face the challenge of contributing to comparable UN Sustainable Development Goals

The field of chemistry is chosen in order to compare the maturity of the subfields of life and biological sciences. Chemistry is a scientific field with a high research intensity. Moreover, the fields are similar of nature, dealing with small-scale natural sciences and large-scale processes. Finally, the field of chemistry has developed many digital technologies and is facing the same sustainability issues as the field of life and biological sciences. For the assessment of development opportunities best practice examples from other fields are included as well.

The final preparative step is the definition of biological and life science subfields. This division in subfields is required in order to perform the three quantitative analysis methods. Each of the three methods brings their own demands on the division in subfields. Therefore, the selected subfields for the use in this assessment needs to adhere to several demands.

First, the TRL assessment is based on the top 50 bio-based innovations and therefore, it is required that all top 50 bio-based innovations can be divided among the defined subfields. Moreover, the subfields should be defined in such a way that each subfield has 10 to 20 innovations assigned in order to have a significant sample size for the assessment.

Second, the patent to publication ratio, as well as the method analysis, require well-defined subfields. These subfields should be known or close to scientific disciplines in order to attribute papers and patents to the subfields.

After the subfield selection, the analyses can be performed. The overall analysis exists of three quantitative methods, combined with results from expert's interviews and an online survey. This input will be used to evaluate the three quantitative methods and to reach a conclusion on the overall maturity of life and biological sciences.

Methodology

The analysis of the maturity is performed using three quantitative methods. These methods are described in more detail in this section.

The first method is a TRL assessment. In this assessment, the TRL of each of the top 50 bio-based innovations will be gathered. Since each of the innovations can be assigned to subfield, a dataset of several TRLs can be obtained for each subfield. Due to the scope of the project, the TRLs of the innovations are fixed between TRL 3 and 7. Therefore, an average TRL or TRL range will not give a meaningful result. However, the pattern or division of the TRL levels in each subfield might show differences, which can be used to get an understanding of the maturity of the subfield.

The second method is a patent to publication ratio analysis. As scientific publications can be seen as indicators for research activities, and patents as indicators for innovation activities aiming at commercialisation, the ratio of publication to patent numbers can give an indication of the maturity of the respective subfield. A rule of thumb is: the larger the number of patents related to the number of publications, the higher the maturity level of the subfield. For each of the subfields, suitable patent and publication statistical analyses were performed.

The third analysis is a method analysis. This analysis is based on the idea that no quantitative analyses exist for new discoveries. New discoveries are first proven to be existing and qualitative analysis techniques are used to show these new discoveries. When a new discovery matures, more quantitative analysis techniques are developed and more results will be quantified. In a method analysis, the number of quantitative and qualitative analysis methods are counted. Any observed difference between the subfields, and between the subfield and the reference field of chemistry, will give an indication on the maturity of the subfields.

Identified subfields for the maturity assessment

For the maturity assessment, a separate division into four subfields was required. These four subfields are as follows:

1. Plant and marine biotechnology

Plant and marine biotechnology focuses on the exploitation of plant and marine resources. Plant biotechnology is a science that relies on next generation breeding techniques to make, for instance, precise genetic changes to place beneficial traits. Embracing such technology could reduce the agriculture's environmental footprint. Marine biotechnology, also referred to as blue biotechnology, is a knowledge generation and conversion process. It exploits the diversity found in marine environments, which enables access to biological compounds that provide novel applications.

2. Environmental and health biotechnology

Environmental biotechnology in particular is the application of processes or biological resources for the protection and restoration of the quality of the environment. Health biotechnology refers to a medicinal[45] or diagnostic product or a vaccine that has been produced by, for instance, microorganisms.

3. Applied, industrial, and process engineering

The scope of this subfield is to scale-up and employ biotechnological science to improve industrial processes. Most of these improvements address the process yields, process economics and environmental footprint.

4. On-demand design, engineering and analysis

This subfield focuses on efficient microbial cell engineering and improving analysis methods to minimise time and resources. This could be achieved by using synthetic biology tools, high throughput technology and bioinformatics.

Maturity

TRL analysis

With the approach finalised and the subfields identified, the quantitative analysis work can be performed. In preparation for the TRL analysis, the top 50 bio-based innovations were assigned to each subfield. It should be noted that the selection of the top 50 bio-based innovations did not account for a fair spread of TRL levels across each subfield. Therefore, the TRL analysis may not give an exact representation of the spread of TRL levels within each subfield. However, it is a useful indicator for differences between the subfields. The results of the TRL analysis is shown in Figure 16. In order to allow for comparisons of the spread of TRL levels, the number of innovations is given in percentages of the total number of innovations assigned to each subgroup.

[45] Only biotechnology for health applications prior the clinical phase are part of the scope of this study.

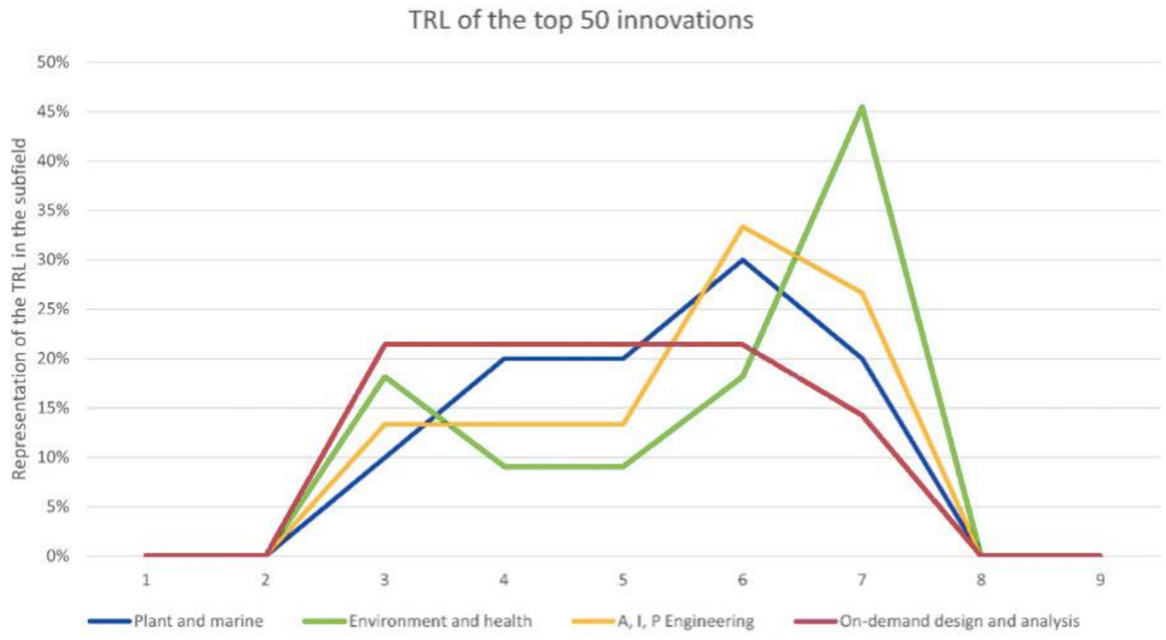

Figure 16. Number of innovations assigned to each TRL level per subfield, expressed in percentage of the total number of bio-based innovations per subfield.

In Figure 10, the TRL representation of each subfield is present as a percentage of the total innovations per subfield. Each subfield is represented by at least 10 bio-based innovations and at most 15 bio-based innovations.

No large differences can be observed from the TRL analysis. There is a small peak at TRL 7, which would suggest that environmental and health biotechnology could be more mature than the other subfields. However, this seems to be an artefact, where slightly more innovations at TRL 7, rather than TRL 6 were selected in this subfield. Note that this subfield has less innovations at TRL 5 and 6, which contradicts the hypothesis that this subfield would be more mature.

When the number of innovations at TRL 6 and 7 are both taken into account, environmental and health biotechnology has an equal share as other subfields with 64% for environmental and health, 60% for applied, industrial and process engineering, 50% for plant and marine biotechnology and 36% for on-demand design, engineering and analysis. From this data, it appears from this data that on-demand design, engineering and analysis is less mature than the other subfields.

From this analysis, it is not possible to draw any hard conclusions. The selection procedure of the top 50 bio-based innovations creates a nearly equal spread for each subfields, since the innovations are cherry-picked rather than selected at random. However, it can be said that on-demand design, engineering and analysis appears to be less mature than the other subfields.

Patent to publication ratios

Another exploratory approach to measure maturity for the top 50 bio-based innovations and the subfields is to measure the patent to publication ratios. The idea behind is that the more mature innovations are, the higher the ratio of patents to publications. Examples may be well established fields such as enzymes, which have the highest patent to publication ratio among the top 50 bio-based innovations, while more the emerging innovation *computational cell factory engineering* has the lowest score among those innovations, for which sufficient patent and publication data was available (see Annex IV).

However, it has to be noted that the operationalization for a cross-analysis of top 50 bio-based innovations is highly challenging. Next to some limitations of the patent and publication indicators described in Annex IV the boundaries across the top 50 bio-based innovations has to be similar in that way that all innovations are covered in a similar broadness for both indicators. However, e.g. there are hardly patents for biorefineries, as mostly processes, which may be used in biorefineries but also in other settings, hardly refer to biorefineries in the patent application itself. In contrast, enzymes are a well established field in patent statistics with own IPC-classification codes and patents can be attributed easily to the related innovations. As consequence, the following results should be interpreted carefully. The subfields are compared by the mean and the median of the attributed top 50 bio-based innovations for world-wide patents and publications in the period 2014-2017 (see table Table 20). The results show on-demand, design and analysis and applied, industrial and process engineering have the highest means, mostly due to some outliers in both subfields (*resource- and energy efficient bioprocesses, macromolecular design, novel feedstocks, minimal cells, new enzymes*). Hence, regarding the mean the attributed innovations, environmental and health biotechnology show higher values than applied, industrial and process engineering, meaning that the first half of innovations have a higher maturity. Regardless of the indicators, plant & marine biotechnology has the lowest patent to publications ratio, while on-demand, design and analysis has the highest one.

Table 20. Patent to publication ratio indicators for the subfields (world wide patents and publications for the time period 2014-2017)

	On-demand design, engineering and analysis	Applied, industrial, and process engineering	Environmental and health biotechnology	Plant and marine biotechnology
Mean	3,74	3,33	0,83	0,43
Median	1,10	0,19	0,40	0,12

Method analysis

Next to the TRL level analysis, the approach to the method analysis has been fully developed. For this approach, 40 papers were analysed within the four defined subfields with the addition of 10 papers within the field of chemistry. In order to minimise bias, the papers were selected in a methodological manner. There are many potential methodologies imaginable to obtain these 50 papers. We have selected a methodology that minimises biases and uncertainties. Each uncertainty in the methodology is discussed below as well.

For a method analysis, it is important that the analysed papers include experimental results. Therefore, only research papers are selected and reviews, letters, opinion articles, etc. are excluded.

First, the most impactful journals were selected using the journal citation reports. Here, a list of relevant categories was selected to filter the journals of interest to the field of life and biological science:

- Biochemical research methods
- Biochemistry and molecular biology
- Biotechnology and applied microbiology

- Environmental sciences
- Mathematical and computational biology
- Microbiology
- Plant sciences

From each of these categories, the top ten journals were selected based on impact factor of the latest available year (2018). Next, journals that contain only review papers were excluded, for example 'Annual Review of Plant Biology' and 'Nature Reviews Microbiology'.

From the remaining list of journals, sorted on impact factor, the top ten research articles were selected from 2019, based on the highest number of citations. These research articles were then categorised in the four subfields. This process was repeated down the list of journals, until three out of four subfields had at least ten papers assigned. These papers will be analysed in the method analysis.

For the third category (applied, industrial, and process engineering), a different citation culture leads to lower citation numbers and lower overall impact factors in its respective journals compared to the other three categories. Therefore, journals that have a specific interest in this subfield were selected to obtain papers for this subfield. This selection was done by selecting the highest impact factor journals from the list, where only journals with an interest in applied, industrial, and process engineering were selected.

This approach leads to the selected papers as shown in Table 20. Here the number of research articles selected from each journal is presented.

Finally, for the field of comparison, the same methodology was applied. Here, the category 'multidisciplinary chemistry' was selected. With the exclusion of review journals, the list was led by a couple of very specific journals in 'Energy and Environmental Science' and 'Advanced Materials'. The journal that shows a broad range of multidisciplinary chemistry with the highest impact factor is 'Nature Chemistry', which was third on this list. The ten highest cited research papers from this journal were selected in order to benchmark the method analysis and serve as a field of comparison.

Table 21. Amount of papers from each selected journal, categorised by subfield

Plant and marine biotechnology		**Environmental and health biotechnology**		**Applied, industrial and process engineering**		**On-demand design, engineering, and analysis**	
Journal	**Amount**	**Journal**	**Amount**	**Journal**	**Amount**	**Journal**	**Amount**
Nature Climate Change	2	Cell	4	Nature Chemical Biology	1	Cell	4
Nature Plants	8	Nature Biotechnology	1	Microbiome	1	Nature Biotechnology	6
		Nature Medicine	5	Metabolic Engineering	7		
				ISME	1		

As discussed, each methodology brings a certain amount of uncertainties and biases. Here, the most important benefits and issues related to this methodology are described.

The selection method is strongly based on citation, and in extend, impact factor. Citations give a good indication of the importance of a paper, since less impactful research will be cited less often than more impactful research in the same field. However, this also brings some pitfalls. First, the citation culture is not equal in each field of research. Therefore, selecting highly cited papers will bring a bias to the research fields with a generally higher citation count. Second, the selection on citation basis results in the selection of first discovery papers. It is common practice to cite the first discovery in each research paper. Therefore, selecting the highest cited papers could lead to higher frequency of first discoveries, which by definition show a lower maturity. Third, by selecting the higher impact journals, a bias arises for the scientifically exciting, new discoveries. These less mature, new discoveries tend to be published in the higher impact journals. This would result in a lower estimated maturity based on this method analysis.

The first issue is minimised by ensuring ten papers for each subfield. This method prevents certain subfields, such as applied, industrial, and process engineering, to be left out due to a lower citation culture than the other subfields. The second and third issues are minimised by only selecting papers from 2019. This will minimise the number of first discovery papers. Moreover, the same selection principles are applied to the field of comparison. This means that the benchmark should show a similar decrease in maturity and negate these effects to some extent.

Another important aspect is that as a comparison, the multidisciplinary field of chemistry was selected, rather than a specific subfield within chemistry. This will lead to a more overall maturity level of the field of chemistry, rather than the maturity of a smaller subfield. This is an important property of the benchmark in order to compare the subfield of life and biological sciences to an overall maturity level. If the selected subfield of chemistry does not give the desired results, other subfields will be selected.

For each of the 50 papers, the number of quantitative analysis methods and the number of qualitative analysis methods were counted. Next, a boxplot was drawn to show the spread of the number of qualitative and quantitative methods per paper per subfield. This boxplot is presented in Figure 17.

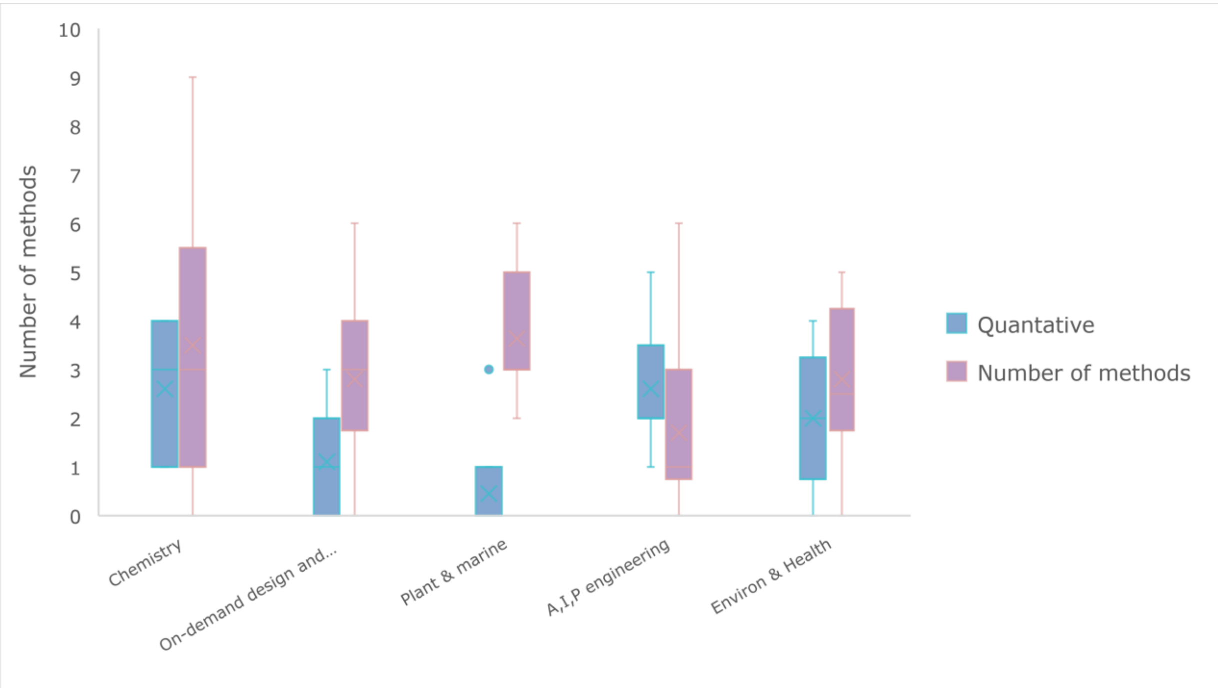

Figure 17. Average quantitative and qualitative methods used in 50 papers, 10 per subfield.

The boxplot presented in Figure 17 shows the spread of the quantitative and qualitative methods used per paper for each of the four subfields and within the field of chemistry as a comparison. The box represents the 2^{nd} and 3^{rd} quartile, the whiskers represent the 1^{st}

and 4th quartile, and the x represents the mean. Any datapoints outside the whiskers are represented by a dot.

The field of chemistry as a whole shows a roughly equal amount of qualitative and quantitative analysis methods. When the four subfields are compared to the field of chemistry, A, I, P engineering shows a relatively higher use of quantitative analysis methods and on-demand design and analysis and environmental and health show a relatively lower use of quantitative analysis methods. Finally, a strong difference can be seen for plant and marine biotechnology, which shows a severely lower use of quantitative analysis methods. Therefore, based on the method analysis alone, the following ranking can be made of the maturity of the subfields:

- Applied, industrial and process engineering
- Chemistry
- Environmental & health biotechnology
- On-demand, design and analysis
- Plant & marine biotechnology

A full analysis of the maturity of the different subfields is made at the end of this section.

Maturity conclusions

The three quantitative methods to determine the maturity were combined with the feedback from experts during expert interviews and an online survey. Combining all the data obtained, the four subfields are ranked below based on their maturity.

1. Applied, industrial, and process engineering

This subfield was shown in the method analysis as the most mature, even more mature than general chemistry. In the rather exploratory patent to publication approach the subfield showed an average maturity. But, the overall notion that this is a very mature subfield was confirmed by the experts. This maturity stems from the subfield directly answering the needs of the industry and being very application oriented by nature. Moreover, industrial biotechnology has multiple tools. For example, genome editing can be achieved in multiple ways, which makes the subfield less vulnerable to GMO regulations.

2. Environmental and health biotechnology

From the quantitative analysis, environmental and health biotechnology appears to be roughly average when it comes to maturity. This observation was confirmed by experts during the interviews. Health biotechnology is more advanced than environmental biotechnology, which can be explained by the different drivers. Health biotechnology is a subfield where companies can make profits, whereas environmental biotechnology is often seen as an investment, sometimes enforced by legislation. Moreover, health biotechnology can advance easier than plant biotechnology, since biotechnology in medicine and pharmacy is easier accepted by the public than biotechnology for food and chemical applications.

3. On-demand design, engineering and analysis

On-demand design, engineering and analysis showed a rather high patent to publication ration, but was second-to-last in the method analysis. Moreover, it was the only subfield that showed significantly lower TRLs in the TRL analysis. Expert interviews indicated that there are indeed young fields in this subfield, such as synthetic biology. It is a challenge for these subfields to develop beyond the lab-scale, due to a lack of companies that bring the innovations to practice.

4. Plant and marine biotechnology

Finally, it becomes clear from the patent to publication ratio and the method analysis that plant and marine biotechnology is the least mature subfield of the selected four subfields. This finding is confirmed by experts in the fields. It should be noted that a difference exists between the maturity of plant biotechnology and marine biotechnology, where especially marine biotechnology is a young field. In this field, there are still a lot of unknowns and research is mostly focused at fundamental level without leading to immediate applications yet. For plant biotechnology, there is a strong global development. However, developments beyond lab-scale is challenging in Europe, due to regulations and public perception of GMO crops.

Specific needs and development opportunities

Now that the maturity level of each predetermined subfield is well defined, this section will identify strengths and weaknesses within the subfields of which actions will be proposed on turning such strengths and weaknesses into opportunities.

Approach and Methodology

Approach

For the identification of development opportunities, the same predetermined subfields will be assessed on their strengths and weaknesses. The identification is based on the assessment of literature reviews of the respective subfields. Furthermore, several roadmaps will be evaluated in which relevant information can be extracted from its development recommendations. For each subfield, several strengths and weaknesses will be selected and translated into development opportunities. Hence, those opportunities combine the needs of the bio and life science field together with experiences and development in other fields and industries for further progress to realise technological and societal potentials. Each development opportunity will be compiled into a database and a score will be assigned to each opportunity dependent on criteria such as impact, feasibility, and effort.

After the evaluation of literature reviews and roadmaps, the opportunities will be validated and further developed in interaction with relevant experts. This will be carried out in the form of dedicated interviews with approximately ten experts from the predetermined subfields. Experts will be invited from academia and industry to fine tune the opportunity database, assign scores and shift priorities accordingly.

Based on the assessment of reviews and roadmaps, as well as the input given by experts, the top five opportunities will be established and elaborated to indicate the way forward.

Methodology

The identification and analysis of development opportunities is performed using available literature reviews, which are representative of the respective subfield. Reviews are of particular interest as the status and recommendations, distinctive of the subfield or sector, are often discussed. Table below depicts the reviews that have been analysed for the identification of the development opportunities. The references are grouped by subfield.

Subfield	Title	Publisher	Reference
Applied, industrial and process engineering	A roadmap to a thriving industrial biotechnology sector in Europe	Bio-tic roadmap	http://www.industrialbiotech-europe.eu/wp-content/uploads/2015/08/BIO-TIC-roadmap.pdf
Environmental and health biotechnology	Environmental Biotechnology: Achievements, Opportunities and Challenges	Global Science Books	https://www.researchgate.net/publication/260322506
On-demand design, engineering and analysis	Barriers to integration of bioinformatics into undergraduate life sciences education: A national study of US life sciences faculty uncover significant barriers to integrating bioinformatics into undergraduate instruction	Plos One	https://doi.org/10.1371/journal.pone.0224288
	Bioinformatics for Marine Products: An Overview of Resources, Bottlenecks, and Perspectives	MDPI	https://doi.org/10.3390/md17100576
	The long journey towards standards for engineering biosystems	EMBO reports	https://doi.org/10.15252/embr.202050521
Plant and marine biotechnology	Realising the potential of marine biotechnology: CHALLENGES & OPPORTUNITIES	Industrial biotechnology	https://doi.org/10.1089/ind.2009.5.077
	A New Network for the Advancement of Marine Biotechnology in Europe and Beyond	Frontiers in Marine Science	https://doi.org/10.3389/fmars.2020.00278

The development opportunities were compiled into a database and analysed for their potential impact, feasibility of the realisation of such opportunity, and the amount of effort required to realise such opportunity. The sum of the allocated scores for the three indicators determines the position of each opportunity. As such, the top 5 will contain the most promising opportunities that show both high impact and relatively low effort. The scores for the three aforementioned indicators have been allocated as follows:

	Impact	Feasibility	Effort
++	Significant impact	Highly feasible	Significantly low effort
+	High impact	Feasible	Low effort
+/-	Moderate impact	Moderately feasible	Moderate effort
-	Low impact	Low feasibility	High effort
--	No impact	Unfeasible	Significantly high effort

Finally, the database containing the development opportunities and the allocated scores were validated with experts from the respective subfields during interviews. Here, experts shared their view on the completeness of the database and the appropriateness of the scores. Moreover, experts were asked to name sectors and subfields, which were doing particularly well and could be used as best practice examples. This allowed for an efficient iterative process.

Results

By evaluating available reviews and roadmaps, a total of 20 development opportunities have been identified. Subsequently, these 20 opportunities have been condensed into 15 opportunities after several rounds of expert consultations. The final list of development opportunities is listed in the table below. Generally, the opportunities have impact on all four subfields, however, some are distinctive for a single subfield. For instance, accessibility of genetic resources is a major opportunity within the field of Marine Biotechnology as it is now discouraged by the Nagoya protocol and related benefit sharing obligations. On the contrary, trans- and interdisciplinarity has been found to be lacking in all subfields according to literature and expert consultations. The development opportunities are defined below, whereby the top 5 is further elaborated.

#	Development opportunity	Impact	Feasibility	Effort
1	Trans- and interdisciplinarity	++	++	+
2	Digitalisation, automation, and AI	++	++	+
3	Inclusion of the entire value chain	++	+	+
4	Knowledge infrastructure	++	++	+/-
5	Improve access to finance for large-scale prototype	++	+	+/-
6	Public perception and broad communication	++	+/-	+
7	Accessibility of genetic resources (physical/legal)	++	-	++
8	Stimulation of public-private partnerships	+	+	+
9	Data management systems	++	+/-	+/-
10	Standardisation of biological parts	+	+/-	+
11	Feedstock availability and logistics	-	+	+
12	Common data formats for use in machine learning	+/-	+	+/-
13	Integrated data collection	+/-	+/-	+
14	Revision of GMO regulation	++	--	-
15	Design rules; standard computational frameworks	+/-	-	+/-

Top 5 opportunities

Trans- and interdisciplinarity

Interdisciplinary research involves collaboration among investigators and engineers from different disciplines that work interdependently to share leadership and responsibility. Collaboration allows researchers to address complex problems, which are unable to be addressed, by individual researchers or a single discipline. Furthermore, interdisciplinary research can accelerate the translation of knowledge from laboratory scale to demonstration scale to commercial scale. Yet, we are living in a rapidly changing, hyper-connected world in which we face global and complex problems such as the environmental crisis. Such complex problem cannot be appropriately addressed from the sphere of individual disciplines because it is interrelated and intrinsically linked in a meta-system of problems. Complex problems require what has been defined as a trans-disciplinary approach. A transdisciplinary approach to innovation differs from inter-disciplinary approaches in that it is not solely based on operating towards a shared goal or having separate disciplines interact with and enrich each other. Instead, transdisciplinary innovation engages in these interactions in an integrated system with a social purpose, resulting in a continuously evolving and adapting practice (. More recently, transdisciplinarity is increasingly relevant to innovators whose technologies or solutions are aimed at addressing complex societal issues. This larger-scale emphasis moves innovation beyond „customer-centred" to a „society-centred" perspective, which requires active collaboration with public and private sector organisations.

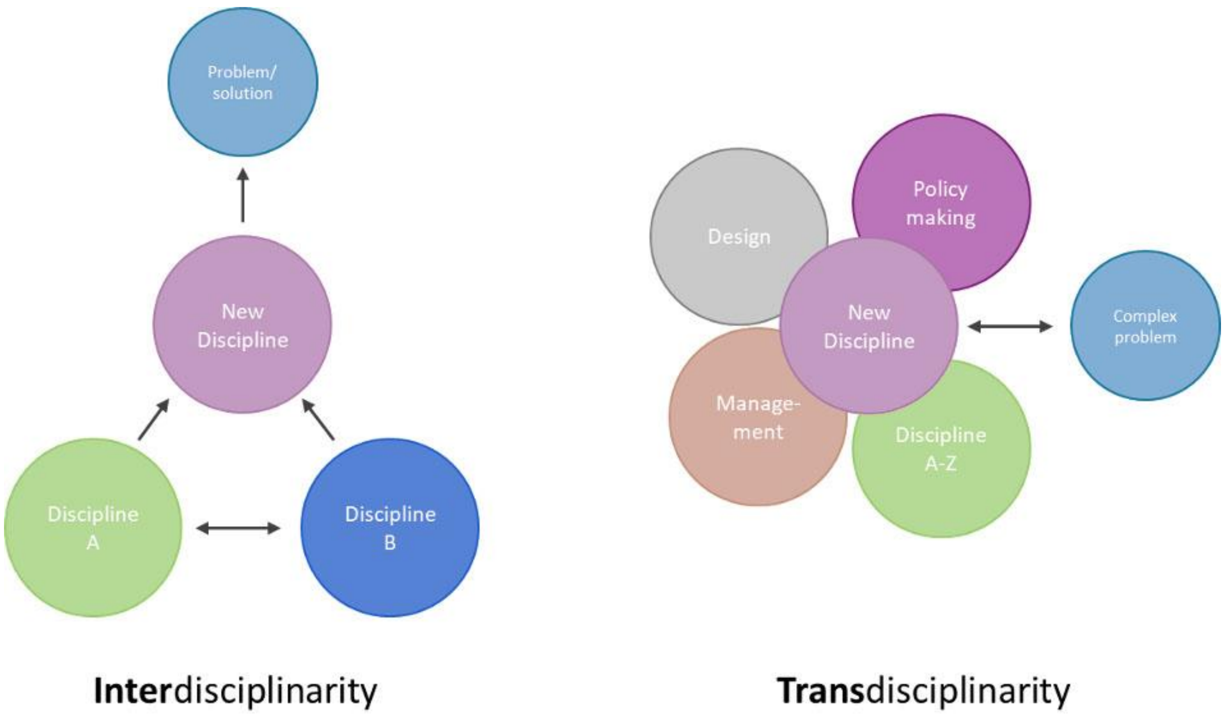

Figure 18: Concepts of inter- and transdisciplinarity

Scientists from across disciplines and knowledge domains have already been called to work together to solve complex issues facing society. Frameworks including Horizon 2020 and the BBI require trans- and interdisciplinary research to solve these complex issues. Trans- and interdisciplinary research can respond to complex problems through a unique approach to co-designing, testing, and scaling innovative, science-based, intervention strategies to breakthrough outcomes. Hence, increased implementation of trans- and interdisciplinary research could have a significant impact on the innovation potential within bio-based life science and biotechnology. Trans- and interdisciplinary research is already being encouraged within EU funded projects and have gained increased importance in education (Tan-Wilson et al. 2020; Tripp und Shortlidge 2019). The expert consultation confirmed the importance of trans- and interdisciplinary research and acknowledged the position within the Top 5.

Digitalisation, automation, and AI

Digitalisation is a very broad definition and has the potential to revolutionise the industry and to reshape innovation throughout the economy. Digitalisation is facilitating convergence among technologies, a hallmark of innovation. The reason for this convergence is that digital technologies can be easily combined due to the shared numerical basis of different digital devices. Furthermore, science can represent more of the natural world in the form of digital information. For instance, materials science is advancing in a transformational way due to the growing ability to observe, represent in computer models and then simulate the properties of a material's microstructure. This is also the case in metabolic pathway engineering, where computer models are used to predict the outcome of genomic deletions on the product of interest.

Digitalisation shapes innovation throughout the economy. The digital transformation is multidimensional that is affecting innovation in all sectors of the economy. Breakthroughs come into view across innovation processes, from research (e.g. large-scale computerised experiments, big data analytics), to development (e.g. new techniques of simulation and prototyping) and commercialisation (e.g. use of marketplace platforms). Essentially, data is changing the nature of business innovation, and is achieving this through four key factors:

1. <u>The utilisation of data as core input</u>. Data is a means to get critical insights about market trends, consumer demands and the behaviour of competitors. Furthermore, (real-time) data utilisation facilitates the optimisation of the development, production and distribution processes, and allows for the development of completely new services and business models. A clear example of a business enhanced by data analytics is UPS, a multinational logistics company. UPS uses a fleet management system that allows for route optimisation, increasing the efficiency and flexibility of delivery processes and the reduction of fuel consumption.

2. <u>Servitisation (e.g. providing innovative services to complement goods).</u> Digitalisation allows for the creation of new digitally enabled services. A clear example of servitisation is the software platform developed by John Deere that provides farm-management support services based on sensor data.

3. <u>The acceleration of innovation cycles.</u> Digital innovations open the door to new and swift innovation cycles by accelerating the processes of product design, prototyping and testing. 3D printing and simulation software postulates the acceleration of innovation cycles.

4. <u>Fostering of collaboration.</u> Business increasingly interact with research institutions and other firms. The reason for this increased collaboration is the ability to share data for research and innovation purposes, thereby expanding the pool of expertise and skills. Furthermore, it allows for costs and risk sharing of uncertain investments and reduces costs of communication.

Digital technologies are at the heart of advanced production. Advanced production within the industry, also known as „Industry 4.0", refers to the transformation of the industry in which all stages of manufacturing are controlled by digital technology. Industry 4.0 technologies can raise productivity in many ways, such as the reduction in machine downtime when intelligent systems predict maintenance needs, and the application of robotics to that results in a more precise and consistent process. The use of AI is becoming increasingly important within the Industry 4.0 revolution. With respect to AI, the greatest commercial potential for advanced manufacturing is expected in supply chains, logistics and process optimisation.

Convergence for the bio-based industries. Bio-based industries heavily rely on developments in biosciences, especially biotechnology and synthetic biology. Biology has experienced a transition from being a data-poor discipline to being a data-rich discipline and is therefore more responsive to greater computational analysis. As such, the convergence of the digital and biological world may greatly change the design and handling of production processes and their products. A promising feature of such convergence is that it can speed up the test phase within the engineering design cycle. Currently, the test cycle is the primary bottleneck as it is an iterative process of designing, building and testing until an optimal design is realised. The incorporation of AI for instance, would remove the need for laborious, time-consuming human intervention between iterations. For example, data from metabolic engineering studies that report on yield and productivity in response to genetic and fermentation conditions, could be built into machine-learning models. This could increasingly remove human involvement in the design-build-test cycle. At a later stage, when upscaling from lab-scale to pilot-scale is desirable, predictive modelling of the production process and realistic models of reactor types could help identify potential bottlenecks prior to expensive piloting operations. Such models have the potential to aid the extrapolation of lab results to large-scale processes.

The automotive sector can be considered as good example where rapid developments in digital technologies completely reshaped the industry. For instance, this sector is a leader in developing „smart factories”. It is adopting a variety of Industry 4.0 applications, such as internet-connected robotics and data analytics. Furthermore, digital technologies gave rise to the possibility of autonomous driving.

It becomes clear that integration and deployment of digital technologies could accelerate science and technology’s ability to resolve global challenges. Digitalisation and automation effectively increase productivity and have the potential to give critical insights and thereby improve processes along the value chain. This is exemplified by many innovations in the top 50, for example: Deep Learning, Computational Protein Design, and Process Models. Expert consultation confirmed the importance of the converging the digital world with the biological world and acknowledged the position within the Top 5.

Inclusion of the entire value chain

The inclusion of the entire value chain refers to the integration of production and processes throughout the supply chain (i.e. supply chain integration). Supply chain integration (SCI) is defined overall as a process of redefining and connecting entities through coordinating or sharing information and resources (Katunzi 2011). The dimensionality of SCI is important to understand the concept of SCI. There are diverse dimensions of SCI which can ultimately be joined into three dimensions: customer, supplier, and internal integration. Customer and supplier integration are commonly referred to as external integration or co-creation, which is the degree to which a manufacturer partners with its external partners to structure inter-organisational strategies, practices and processes into collaborative, synchronised processes (Flynn et al. 2010) (Figure 19).

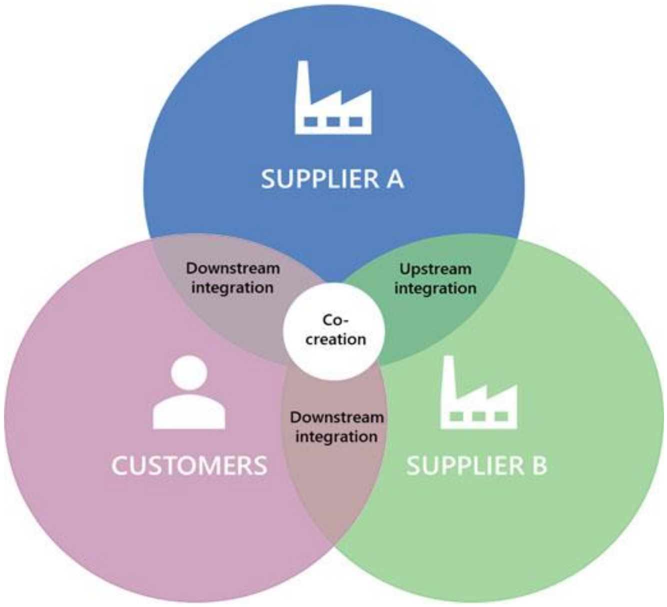

Figure 19: Graphical representation of the dimensionality of SCI. Supplier integration is commonly referred to as upstream integration and customer integration is commonly referred to as downstream integration

Customer integration is also known as downstream integration, while supplier integration is known as upstream integration. For supply integration, integration back down to the suppliers represents a change in attitude away from conflict to cooperation, starting from product development, the supply of high-quality products, processes and specification change information, technology exchange and design support.

Thus, supplier-partnering initiatives bring all the participants in the product life cycle into the product development process early so that suppliers can provide input to each other's processes. A specific challenge for the use of biomass feedstock is the heterogeneity of the feedstock and the difference in characteristics of each batch. Either the distinct process conditions or inhibitory products formed affect the performance of the process both at the economic and technical level. These issues should be resolved from both supplier side, for example by increasing the homogeneity of the feedstock supply, and from the producer side, for example by mixing multiple batches or increased monitoring of the process. As such, supplier collaborating could efficiently speed-up the innovation cycle and increase supply-chain optimisation, while sharing benefits and risks.

Above, an example was given of technology integration at processing site. Another relevant type of integration is the cooperation between the biomass supply sector and all downstream industries. Currently, there is a lack of cooperation and knowledge exchange between different actors in the value chain. Support is required for actors to cooperate across-sectorial borders to overcome the barriers between processing and feedstock supply.

Expert consultation confirmed the importance of supply chain integration to achieve faster innovation cycles as well as the increased supply-chain optimisation and alignment. Furthermore, experts acknowledged the position of such development opportunity within the top 5.

Knowledge infrastructure

Bottom-up development of skills. The development opportunity „knowledge infrastructure" is interconnected with development opportunities such as trans- and interdisciplinarity and digitalisation, automation and AI. Digitalisation raises the demand for digital skills. Case in point, rapid improvement in AI systems have led to an overall scarcity of AI skills. Furthermore, now that biology has become a data-rich discipline, occupations such as industrial data scientist and bioinformatics scientists are increasingly desired. Rising demand for digital skills has implications for economic productivity. In terms of productivity, the ability of education and training systems to respond to changing skills demand affects the pace of technology adoption. Thus, tackling such a problem requires a bottom-up approach where new courses and curricula may be needed to keep pace with rapid changes brought forth by digitalisation. Besides new courses and curricula, existing curricula may also need to change.

As indicated previously, issues to be tackled within the bioeconomy are interrelated and intrinsically linked in a meta-system of problems. These problems cannot be solved from the sphere of individual disciplines, and therefore, problem-solving skills on a trans- and interdisciplinary level becomes increasingly important. Hence, at the heart of the bioeconomy's future is the need for a different kind of workforce with trans- and interdisciplinary skills. This, and familiarising with digital skills such as programming and data science should be key attributes professionals possess in future bio-based industries in order to tackle complex problems such as the environmental crisis.

Integrated facilities. Besides the bottom-up development of skills and knowledge, this could also be achieved by co-locating scientists from different disciplines in an integrated facility. Face-to face interaction between academic and industrial partners could, for instance, help break down the barriers between applied and commercial scientists to promote the exploitation of ideas. Furthermore, core facilities available to researchers and companies also speed up innovation. For example, the Centre for Process Innovation, situated in the UK, makes bioreactors easily accessible for saline and non-saline fermentations for the purpose of process parametrisation as well as the associated downstream processing. Such a core facility and expertise is otherwise not available to start-ups and academia to take a process from lab-scale to production scale.

Improving the knowledge infrastructure through the bottom-up development of skills and increased accessibility to integrated facilities could help to efficiently address complexities of our contemporary society, such as the environmental crisis, and to bring innovative European ideas to the market. The expert consultation confirmed the importance of improving the knowledge infrastructure and acknowledged the position within the Top 5.

Improve access to finance for large-scale prototype

Developing new and innovative products requires scale-up from the lab to a commercial product. Essentially, this is required to examine whether the technology is scalable and reproducible outside the laboratory environment. Access to finance is a major barrier to the commercialisation of new and innovative products. Already now, several funding frameworks are available for the bio-based industries, such as Horizon 2020 and BBI JU at the European level, and ERA-NET and EUREKA at the transnational level. Currently, the Public Private Partnership BBI JU is bridging some of the funding gaps with the flagship projects. Nevertheless, it cannot support all commercial scale projects and thus access to funding remains an issue.

Public perception and broad communication

The public perception/awareness on bioscience and bio-based products derived thereof is at a relatively low level. This lack of awareness arises from the fact that bioscience is used as a technology which is difficult to explain and thoroughly comprehend, despite being commonly used to produce food (e.g. beer, cheese, bread) and medicines (e.g. vaccines). In addition to the complexity of bioscience, the challenge also touches upon people's general awareness of the origins of everyday products that originate from fossil carbon. The lack of awareness of the existence of bio-based products that are produced using bioscience, together with the lack of understanding their benefits, presents a significant barrier to technology uptake and the creation of new markets. Broad communication through various channels could improve public perception/awareness. Recent Horizon 2020 projects, such as BioCannDo, and expert consultation pointed out the relevance of transferring the benefits of the bio-based product, rather than focusing on the fact that a product is bio-based.

Accessibility of genetic resources (physical/legal)

The accessibility of genetic resources, both at the physical and legal level, is a major hurdle in marine biotechnology towards realising its full potential. Nowadays, very few facilities have the ability to access the deep ocean, whose average depth of 4000 meters presents substantial engineering challenges. Therefore, infrastructure and engineering development is crucial to provide access to the deep oceans for academic and applied purposes. The second issue regarding the accessibility of genetic resources concerns the compliance with the legal requirements of equitable benefit sharing (ABS). The ABS obligations have been adopted in the Nagoya Protocol and obliges the user to seek the prior informed consent from the provider country and negotiate mutually agreed terms to ensure equitable sharing of benefits arising from the utilisation of genetic resources. It has been found that the ABS regulation creates a high administrative burden and is perceived as an obstacle for further R&D opportunities. While a clear policy on genetic resources is important, there is also a general sense among researchers and industry that the current system is increasing the potential for misuse, leading to perceptions that countries are using ABS as a trade barrier and blocking the use of certain genetic resources as a way of gaining commercial and political leverage[46]. Expert consultation pointed out the relevance of addressing legal certainty and thereby decreasing administrative burden and the associated costs.

Stimulation of public-private partnerships

Public-private partnerships involve collaboration between a government agency and a private-sector company that fund research and innovation projects. Such a stimulation could improve networking, cooperation, partnering and knowledge exchange. Currently, the BBI is an integrated and fundamental tool under Horizon 2020 to realise the bio-based industry vision. It is focused on developing EU-based value chains and accelerating the transition to advanced feedstock for biorefineries. However, there is too much competition for the available calls and therefore only a small part of the proposals can be permitted and financially granted, leaving many ideas unexplored. Additional sources would be required to further finance public-private partnerships.

Data management systems

Due to the recent surge in information technologies and automatic data collection systems, many fields in life science and technology are faced with large amounts of data that cannot be processed without automatic systems. In order to manage large data, data management systems are required to extract full value from the potential of the data sets and to prevent data overflow issues. Specific issues to biological data arise due to the inherent heterogeneity of the data sets, combined with a relatively large amount of noise. Common data management systems would allow for easier mapping and integration of these data sets. These data management systems would ideally be based on the open source principle (Mayer et al).

Standardisation of biological parts

With a greater understanding of genetic circuits, there has been a shift towards standardisation of the design process. This involves the creation of a library of standardised parts like promoters, terminators and protein tags of different strengths that are interchangeable and contain compatible ends that can be joined into desired sequences. These functional sequences can then be joined to form more complex genetic circuits for any desired application. Standards are commonplace in many industries, where they facilitate the successful integration, commercialisation and scaling up of the serial creation of products or services. Employing standards allows for reproducibility and would open way to better predictions for experimental procedures. Initiatives such as the iGEM foundation[47]

[46] Analysis of implications of compliance with the EU ABS Regulation for research organisations and private sector companies. May 2020.
[47] https://igem.org/Main_Page

and the EU funded BioRoboost[48] project, have emerged to address the insufficient implementation of standards and provide recommendations to narrow the existing gap.

Feedstock availability and logistics

It is obvious that the presence of a sufficient amount feedstock is key to the production of bio-based materials. Even though there is sufficient biomass present that is currently under used, the availability of this biomass can often be limited. This can be due to the biomass not being available in the right type, season, or location. The disconnect between the biomass feedstock and the biomass users can partially be bridged by a better integration of the value chain (see: inclusion of the entire value chain). However, other solutions, such as biomass hubs, could potentially aid towards making biomass more readily available in a sustainable manner and give excess to the full potential of bio-based feedstock.

Common data formats for use in machine learning

For an innovation to thrive, an optimal climate needs to be created, where multiple parties can contribute to the innovation for it to mature. This type of collaboration, where parties can build on each other's work and collaborate to the same goals can only be achieved when the same language is used. This is especially important in machine learning, where multiple data formats exist. Similar to databases, where there are several standards, such as XML and SQL, common data formats need to be developed for the use in machine learning as well.

Integrated data collection

Data collection systems have significantly increased in popularity and practice. However, the data collection is now separate, where each sector has their own data collection systems. When the issues on data management systems and common data formats are tackled, it is important to address the issue on integrated data collection as well. This would allow to extract the most possible information from the large amount of data available.

Revision of GMO regulation

The EU have adapted a comprehensive GMO regulation which addresses the development of GMOs, the stepwise release into the environment, the general cultivation and seed production, marketing, labelling, enforcement and the whole agro-food chain, up to the consumption by humans and animals. Organisms obtained by mutagenesis, including those using new genomic techniques (NGTs) are GMOs within the meaning of the GMO Directive, in so far as the techniques and methods of mutagenesis alter the genetic material of an organism in a way that does not occur naturally. These organisms fall within the scope of the GMO Directive and are subject to the obligations laid down by that directive. As a result, only contained use is possible but suffers from lengthy, and above all, costly administration. GMO legislation is a widely debated topic, which requires precise and clear legislation that does not allow misuse of GMOs and at the same time does not create unnecessary burdens for innovation development. For the purpose of balanced policy-making, especially on the new genomic Techniques, it would be beneficial if an informed discussion on the benefits and drawbacks of gene editing takes place. In this light the study regarding the status of novel genomic techniques under Union law[49] as requested by the Council in light of the Court of Justice's judgment in Case C-528/16, should be welcomed. For more information see also section 3.6.4.

[48] http://standardsinsynbio.eu/

[49] COUNCIL DECISION (EU) 2019/1904 of 8 November 2019 requesting the Commission to submit a study in light of the Court of Justice's judgment in Case C-528/16 regarding the status of novel genomic techniques under Union law, and a proposal, if appropriate in view of the outcomes of the study.

Design rules; standard computational frameworks

Standards come in various aspects throughout the innovation pipeline. Besides standard biological parts to enhance reproducibility and comparability, standards exist for protocols and computational frameworks. Nowadays, computational biologists face significant standardisation challenges due to the incompatibility of computational tools and inconsistent nomenclature. For example, the analysis of omics data to inform subsequent designs can be complicated by the plethora of databases and tools that are not always compatible with each other. Using standard computational tools and nomenclature facilitates efficient electronically exchange of designs and enhance scientific reproducibility.

Best practice examples from other fields

Next to identifying the top 5 development opportunities, it can be a useful exercise to identify other sectors or subfields, which already excel in these areas. From these sectors and subfields, examples can be taken as best practice examples. However, full identification of all best practice examples is not possible without being an expert in all fields. Moreover, a direct comparison cannot always be made, and differences exist between the field of comparison and the field of life and biological sciences, which can complicate a direct translation of the best practices. Below the identified comparisons, as well as their shortcomings are described.

Within the top 5, an important best practice example can be identified for digitalisation, automation, and AI. Here, the automotive sector has undergone rapid developments in digital technologies, which completely reshaped the industry. For instance, this sector is a leader in developing „smart factories". It is adopting a variety of Industry 4.0 applications, such as internet-connected robotics and data analytics. Furthermore, digital technologies gave rise to the possibility of autonomous driving. Other examples include the software platform developed by John Deere that provides farm-management support services based on sensor data, and the data analytics used by UPS, a multinational logistics company. UPS uses a fleet management system that allows for route optimisation, increasing the efficiency and flexibility of delivery processes and the reduction of fuel consumption. Even though these cases exemplify best practices, they are challenging to directly translate to digitalisation, automation and AI for life and biological sciences due to the inherent heterogeneity of biology, which is absent from the automotive and logistics sector.

For the development opportunity of improving the knowledge structure, an example can be taken from the rise of information technologies. In the past decades, the field of computer science developed from a class within mathematics, via a its own programme and has now fully developed into its own subfield. This change in knowledge structure at universities was paired with a change in society and an increasing demand for students educated into computer science. A similar demand is seen for scientists with a bio-based background and the knowledge structure for bio-based life and biological sciences, or perhaps bio-based sciences, could learn from the history of the development of computer sciences. Finally, there are is one best practice example that can serve as a comparison outside of the top 5 development opportunities. The search for standards in the field of biology has many fields of reference where examples can be found. One such an example is the field of electronics, where all electronic devices work within specifically design ranges in order for companies to combine and assemble electronic parts into larger electronic devices. A similar goal is envisioned within the field of biological sciences, where biological parts from different sources can easily be combined into a larger biological system. However, this faces many challenges due to the heterogeneity of the biological systems and the need for different levels of detail for the standards depending on the subfield.

Besides looking at other sectors for best practices, it is of crucial importance to also identify good examples within the field of bio-based life and biological sciences itself. For example, the BBIJU flagship projects have been identified as an important method to improve access to financing scaling up innovations.

Annex III: Background Material for policy mapping and assessment

Contribution of the top 50 bio-based innovations to SDGs

		No poverty	Zero hunger	Good health and well-being	quality education	Gender equality	Clean water and sanitation	affordable and clean energy	Decent work and ec. Growth	industry, innovation and infra.	reduced inequalities	sustainable cities and communities	responsible cons. and prod.	Climate action	Life below water	Life on land	peace, justice and strong institutions	Partnerships for the goals
#	**Short title SDG**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	Analytical techniques and bioprospecting		5	5			2			5			2		5	5		
1	Screening biodiversity		1	1						1					1	1		
2	-omics technologies		1	1						1					1	1		
3	Analysing microbial consortia		1	1						1					1	1		
4	Lab-on-a-chip		1	1			1			1			1		1	1		
5	Biosensing		1	1			1			1			1		1	1		
2	Design and engineering of biomolecules for desired functions		3	3			2	2		3			2		3	3		
6	Macromolecular design		1	1						1					1	1		
7	Multi-enzyme biocatalysis		1	1			1	1		1			1		1	1		
8	New enzymes		1	1			1	1		1			1		1	1		
3	Design and eng. of biol. systems, cell fact.; synth. biology		3	4						5			1		4	3		
9	Precision genome editing		1	1						1					1	1		
10	Synthesis and assembly of long DNA fragments		1	1						1					1	1		
11	Modular cloning systems		1	1						1					1	1		
12	Minimal cells			1						1			1		1			
13	Expansion of the genetic code									1								
4	Digital technologies		5	4				2		5			2		5	5		
14	FAIR principle for databases		1	1						1					1	1		
15	Deep Learning		1	1						1					1	1		
16	Computational protein design		1	1			1	1		1			1		1	1		
17	Computational cell factory engineering		1	1			1	1		1					1	1		
18	Process models		1				1			1			1		1	1		

5	Novel industrial production concepts		2	2			2	2		3			2	2	2	1		
19	Novel microbial cell factories		1	1			1	1		1			1	1	1			
20	Engineering microbial consortia		1	1			1	1		1			1	1	1	1		
21	Microbial Electrosynthesis									1								
6	Enabling bio-based production at industrial scale		2				2	2		5			2		2	2		
22	Optimising biorefineries		1				1	1		1			1			1		
23	Biorefineries for new feedstock		1				1	1		1			1		1	1		
24	Reactor design and process monitoring									1					1			
25	Cell heterogeneity									1								
26	Stress-tolerant production organisms									1								
7	Sustainable exploitation of novel feedstock		3				2	1	2	1		2	3	3	3	3		
27	Novel feedstock		1				1	1	1			1	1	1	1	1		
28	Using side and waste streams		1				1		1			1	1	1	1	1		
29	Supply and pretreatment of novel feedstock		1							1			1	1	1	1		
8	Eff. and sust. Ind. prod. and products with min. env. impact		2				2	1		6		2	6	3	4	4		
30	Resource- and energy efficient bioprocesses		1				1	1		1			1		1	1		
31	Carbon-neutral bioprocesses									1			1	1				
32	CO_2-based chemicals									1			1	1				
33	Climate-gas mitigation of microbial activities		1				1			1			1	1	1	1		
34	Biodegradable plastics									1		1	1		1	1		
35	Plastic degrading enzymes									1		1	1		1	1		
9	Bio-based intermediates, materials and product groups		1	1						5		1	4	4	1			
36	Smart drop-ins									1			1	1				
37	Dedicated bio-based chemicals									1			1	1				
38	Bio-based materials									1		1	1	1				
39	Bio-functional materials									1				1				
40	Novel algae products		1	1						1			1		1			
10	Contributions to sustainable agriculture		6				3			2		1	2	4	3	6		
41	Crop improvement targeting genome and epigenome		1											1		1		
42	de novo domestication		1													1		
43	Asexual reproduction of seeds		1													1		
44	Increasing and maintaining soil fertility		1				1							1	1	1		

45	Novel farming concepts		1				1			1		1	1	1	1	1		
46	Novel protein sources		1				1			1			1	1	1	1		
11	Health and well-being		4	4			1								2	1		
47	Health-promoting ingredients		1	1											1	1		
48	Novel antimicrobial agents		1	1														
49	Probiotic sanitation strategies		1	1			1											
50	Veterinary DNA vaccines		1	1											1			
	Total	**0**	**36**	**23**	**0**	**0**	**16**	**10**	**2**	**40**	**0**	**6**	**26**	**16**	**34**	**33**	**0**	**0**
	Percentage of top 50 (%)	**0**	**72**	**46**	**0**	**0**	**32**	**20**	**4**	**80**	**0**	**12**	**52**	**32**	**68**	**66**	**0**	**0**

Description of main EU implementation programmes

Horizon 2020

Horizon 2020[50] is the eighth framework programme funding research, technological development, and innovation. It provides grants to research and innovation projects through open and competitive calls for proposals. It is designed to support all stages in the innovation chain, especially activities closer to the market. Horizon 2020 is a seven-year program running from 2014 to 2020 having a total budget of 77 billion Euro, which is distributed over the following three distinct priorities:

- **Excellent Science**; supposed to raise the level of excellence in Europe's science base.
- **Industrial Leadership**; supposed to make Europe a more attractive location to invest in research and innovation. It provides major investments in key industrial technologies and supports innovative SMEs to grow into world-leading companies.
- **Societal Challenges**; supposed to address major concerns shared by citizens in Europe and elsewhere.

In particular for the priority **Societal Challenges** and the specific objective leadership in enabling and industrial technologies (part of priority **Industrial Leadership**), there is a particular emphasis on research and innovation activities complemented with activities which operate close to the end-users and the market, such as demonstration, piloting or proof-of-concept. The priority **Excellent Science** supports the activities of the European Research Council (ERC) on frontier research, future and emerging technologies, Marie Sklodowska-Curie actions (MSCA), and European research infrastructures. The ERC promotes frontier research and has full authority over decisions on the type of research to be funded. It stimulates novel ideas and nurtures emerging research themes. Furthermore, the ERC fosters new skills by means of excellent initial training of research (MSCA). The MSCA is open to training and career development activities within all domains of research and innovation, from basic research up to market uptake and innovation services. Thus, the research and innovation fields as well as sectors can be chosen freely by the applicants.

One of the specific objectives of the priority **Industrial Leadership** is to boost Europe's industrial leadership through research, technological development, demonstration and innovation in the following enabling and industrial technologies:

[50] Council decision (2013/743/EU)

- Information and communication technologies (ICT)
- Nanotechnologies
- Advanced materials
- Biotechnology
- Advanced manufacturing and processing
- Space.

The EC clearly seeks to incorporate several Key Enabling Technologies (KETs) simultaneously, thereby enhancing product competitiveness, providing new opportunities, and to tackle societal challenges. Demand side actions are implemented to complement the technology push of the research and innovation initiatives. Engagement with stakeholders and the general public, for nanotechnology and biotechnology in particular, is encouraged to raise the awareness of benefits and risks.

Biotechnology is acknowledged as KET and is therefore vital to boost Europe's industrial leadership. It is also an integral part of the production of advanced materials although not explicitly mentioned. For instance, to ensure efficient, safe and sustainable development and scale-up to enable industrial manufacturing of future design-based products, biotechnological tools could be utilised to achieve that challenge. The TERMINUS project[51] funded through the Horizon 2020 framework is a clear example of the utilisation of biotechnological tools for the development of advanced materials. In this case, enzyme-containing polymers are used in packaging materials to enable intrinsic self-biodegradation.

The specific objective of biotechnology research hand innovation is to *„develop competitive, sustainable, safe and innovative industrial products and processes and contribute as an innovation driver in a number of European sectors, like agriculture, forestry, food, energy, chemicals and health"*[52]. It sets out the **development of emerging technology areas** such as synthetic biology, bioinformatics, and systems biology, as well as exploiting the convergence with other enabling technologies such as nanotechnology (e.g. bionanotechnology) and ICT, with the great aim to facilitate effective transfer and implementation into new applications. Enabling the European industry to **develop new products and processes** that meets industrial and societal demands, requires both biotechnology-based alternative production methods and biotechnological tools for detecting, monitoring, preventing and removing pollution. This includes research and innovation on novel enzymes with optimised biocatalyst functions, enzymatic and metabolic pathways, industrial scale bio-process design, integration of bio-processes in industrial production processes, advanced fermentation, up- and down-stream processing, and gaining insight on the dynamics of microbial communities. The specific objective also includes the **development of platform technologies** (e.g. genomics, meta-genomics, proteomics, metabolomics, molecular tools, expression systems, phenotyping platforms and cell-based platforms). These platform technologies should be used to enable exploration, understanding and exploitation in a sustainable manner of terrestrial and marine biodiversity for novel applications.

The priority **Societal Challenges** is designed to increase the effectiveness of research and innovation in responding to key societal challenges by supporting excellent research and innovation activities. Here, all challenges must contribute to the overarching objective of sustainable development. Biotechnology is an integral part in the following specific objectives:

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[51] https://cordis.europa.eu/project/id/814400
[52] https://ec.europa.eu/programmes/horizon2020/en/area/biotechnology

- **Preventing disease**; maintaining and enhancing the ability to combat disease and undertake medical interventions that depend on the availability of effective and safe antimicrobial drugs.

- **Sustainable agriculture and forestry**; all stages of the food and feed production chain will be addressed to cope with social, environmental, climate and economic change, including packaging, waste reduction and by-product valorisation.

- **Unlocking the potential of aquatic living resources**; support will be given to further explore and exploit the large potential offered by marine biodiversity to bring new innovative and sustainable processes, products and services on the markets.

- **Sustainable and competitive bio-based industries**; development of bio-based products and biologically active compounds for industries and consumers with novel qualities, functionalities and improved sustainability will be targeted. In addition, the economic value of renewable resources, bio-waste and by-products will be maximised.

- **Enabling the transition towards a green economy through eco-innovation**; Eco-innovations are supposed to reduce pressure on the environment and increase resource efficiency. The aim is to improve resource efficiency by reducing, in absolute terms, inputs, waste and the release of harmful substances along the value chain and to foster re-use, recycling and resource substitution. One example of such eco-innovation is to move wastewater treatment from being primarily a sanitation technology towards a bio-product recovery industry and a recycled water supplier (EU funded project INCOVER through Horizon 2020)[53].

Within this pillar, it becomes clear that biotechnology must support progress towards low-carbon, resource-efficient and sustainable industries, where activities must be focused on non-food-competitive biomass, including bio-waste and by-products, together with the exploration and exploitation of marine biodiversity (i.e. „blue" economy).

Horizon Europe

The Commission's proposal for Horizon Europe[54] is an ambitious European research and innovation framework programme to succeed Horizon 2020. The EC has begun a strategic planning process of which the result will be set out in a multiannual Strategic Plan to prepare the content in the work programs and calls for the proposals. Horizon Europe will be structured in three pillars:

- **Open Science**; will reinforce EU scientific leadership through the ERC, MSCA and Research Infrastructure.

- **Global Challenges and European Industrial Competitiveness**; will take forward the societal challenges and enabling industrial technologies to better address EU and global policy and accelerate industrial transformation.

- **Open innovation**; will focus on stimulating, nurturing and deploying disruptive and market-creating innovations through the new EIC.

[53] https://cordis.europa.eu/project/id/689242
[54] COM(2018) 436 final

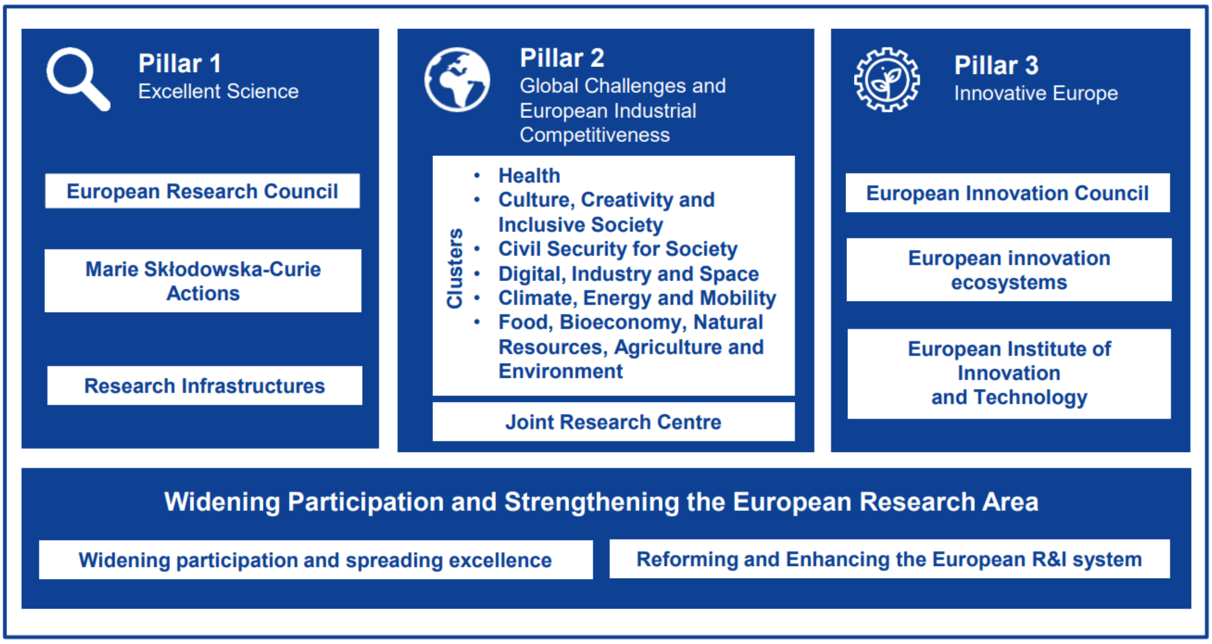

Figure 20: The three pillars of Horizon Europe.

Source: European Commission (2019)[55]

Horizon Europe sets out two legal acts. The first legal act lays down the structure, rules for participation and dissemination, the other contains the Specific Program that sets out thematic clusters and the broad lines of action for future research and innovation activities. Unlike the Horizon 2020 program, Horizon Europe combines global challenges with industrial competitiveness. Research and innovation under the second pillar is grouped into integrated clusters of activities. Rather than addressing specific sectors, the investments aim at systemic changes for society. This means that all type of actors needs to be involved and therefore no thematic cluster is intended for just only one set of actors. It has been emphasised that the thematic clusters must develop and apply digital, key enabling and emerging technologies as part of a common strategy to promote the EU's industrial leadership. The following six clusters have been set out within the new Horizon Europe framework programme:

- Health
- Inclusive and Secure Society
- Digital and Industry
- Climate, Energy and Mobility
- Food, Bioeconomy, Natural Resources, Agriculture and Environment.

Within the cluster *Digital and Industry*, great emphasis is placed on making the digitised, circular, low-carbon and low-emission economy a reality. The EU wants to ensure that all industrial players, and society at large, can benefit from advanced and clean technologies and digitalisation. Here, the Strategic Plan will support manufacturing by fostering breakthrough innovations that make use of different enabling technologies (e.g. converging technologies, artificial intelligence, data analytics, industrial robotics, bio-

[55] European Commission (2019) Horizon Europe, Based on the Commission Proposal for Horizon Europe, the common understanding between co-legislators and the Partial General Approach, both approved in April 2019, presentation by DG R&I, June 2019, https://ec.europa.eu/info/sites/info/files/research_and_innovation/ec_rtd_he-presentation_062019_en.pdf

manufacturing) across the value chain. Furthermore, The EU wants to improve the recyclability of materials, reduce the carbon and environmental footprint, and drive cross-sectoral industrial innovation by supporting new applications in all industrial sectors. This includes, for instance, the support in materials (including plastic and biomaterials) which are designed with new properties and functionalisation while meeting regulatory requirements.

The EC also wants to remain at the forefront of the global transition towards a circular economy, and therefore the industry should become circular. The objective is to develop breakthrough innovations and deploy a combination of advanced technologies and processes to extract maximum value from all resources. The Strategic Plan sets it sight towards industrial symbiosis with resource flows between plants across-sectors and urban communities, in order to re-use resources and valorise by-products, waste and CO_2.

Within several areas of intervention of the cluster Food, Bioeconomy, Natural Resources, Agriculture and Environment, life sciences and biotechnology can play a pivotal role. To deliver a resilient and sustainable farming and forestry system the Strategic Plan[56] will foster, among others, the sustainable management and efficient use of natural resources (e.g. soils, water, nutrients and biodiversity including genetic resources), and intents to tackle the use of contentious pesticides used against plant pests. The Strategic Plan also addresses the current food system. The future food system needs to deliver sufficient safe, healthy and quality food for all, underpinned by resource efficiency and sustainability. To secure the food system, it must adapt to climate change, which requires the exploration of the potential and use of the microbiome and forgotten crops. The Strategic Plan further seeks to foster bio-based innovation systems which lays the foundations for the transition away from a fossil-based economy. It capitalizes on the potential of life sciences and industrial biotechnology for new discoveries, products and processes. Here, specific interest is shown in the convergence of life sciences with digital technologies for prospecting, understanding and sustainable use of biological resources. Biotechnology is one major area of activity, including cross-sectoral cutting-edge biotechnology for application in competitive, sustainable and novel industrial processes, environmental services and consumer products.

Horizon 2020 funds of 111 selected projects linked to top 50 bio-based innovations

By careful assessment of the CORDIS database, we have identified 111 Horizon 2020 projects (including BBI-JU projects) that funded the identified top 50 of bio-based innovations. See Table 22. Please note that the details of the project are also available through Power BI tool developed within the project.

[56] https://ec.europa.eu/research/pdf/horizon-europe/ec_rtd_orientations-towards-the-strategic-planning.pdf

Table 22: Selection of 111 Horizon 2020 projects (including BBI-JI) that funded the top-50 of bio-based innovations.

Project	#[a]	Project	#	Project	#	Project	#
ABACUS	6	DEEP PURPLE	6	INGREEN	7	RESOLVE	9
AFTERBIOCHEM	6	DELLATECH	10	INMARE	1	Rhizomia	10
AgriChemWey	7	DiViNe	8	INTERCOME	9	ROBOX	2
agroCYAN ECO	10	DOC	1	LIGNOFLAG	6	Rosalind	3
ALGAE4A-B	1	EC-Cat	3	LIPES	8	Sea4Pain	1
AlgaeCeuticals	9	ECOHELIX	7	MACBETH	6	SENSE	1
APEX	7	EMBRACE	6	MACRO CASCADE	6	SHERPACK	9
AQUABIOPRO-FIT	7	EmPowerPutida	5	MAGNIFICENT	6	SHIKIFACTORY100	4
BioBarr	9	ENBIOSURF	9	Marigold	10	SinFonia	9
BioCatPolymers	6	ENGICOIN	8	METAFLUIDICS	1	SMARTBOX	4
BIOCONCO2	8	EnzOx2	2	MIAMi	4	SpiralG	6
BIOCOPY	1	EUCALIVA	7	MicroArctic	1	SUSFERT	10
BIOFOREVER	6	EXCornsEED	7	MIX-UP	8	SynBio4Flav	5
BIOnTop	8	FALCON	7	MossTech	6	TERMINUS	9
BioRECO2VER	8	FIRST2RUN	6	MYRES	8	TESS	10
BIOrescue	6	FUNGUSCHAIN	6	NeoCel	9	TYCHOBIO	6
BIOSEA	6	GHaNa	1	Newcotiana	10	UNRAVEL	7
CARBAFIN	6	Glaukos	9	NEWPACK	8	URBIOFIN	6
CARBAZYMES	2	GPCR-Sensor	1	OLEFINE	6	US4GREENCHEM	7
CARBOSURF	9	GRACE	7	OPTimized	6	ValChem	9
CELBICON	8	GREENER	8	OXYTRAIN	2	VALUEMAG	6
Cells-in-drops	1	GreenProtein	10	P4SB	5	VEHICLE	7
CHASSY	4	HEATSENS_S	1	PEFerence	9	VEnvirotech	7
CHIC	10	Ifermenter	6	PERCAL	7	VIPRISCAR	9
COSMOS	10	I-GENE	3	Prolific	7	WASEABI	7
CRISPAIR	3	INCOVER	7	PROMINENT	10	WHEY2VALUE	8
DAFIA	7	INCYPRO	2	ProteinFactory	5	Zelcor	7
DD-DeCaF	4	inDIRECT	6	Rafts4Biotech	5		

[a)] The numbers refer to the subfields of the top 50 bio-based innovations:
1 Analytical techniques and bioprospecting
2 Design and engineering of biomolecules for desired functions
4 Digital technologies
5 Novel industrial production concepts
6 Enabling bio-based production at industrial scale
7 Sustainable exploitation of novel feedstock
8 Efficient and sustainable industrial production and products with minimised environmental impact
9 Bio-based intermediates, materials and product groups
10 Contributions to sustainable agriculture
11 Health and well-being

Figure 21 shows the budget allocation by innovation. Biorefineries for new feedstock, optimising biorefineries, using side and waste streams and bio-based materials are innovations that received most funding within the pool of 111 selected projects. Flagships impact the total budget per innovation substantially. Some innovations such as biosensing, analysing microbial consortia, synthesis and assembly of long DNA fractions did not receive much funding. This could have different causes: first of all it could be the case that these innovations indeed have received not much EU funding, secondly, our selection of 111 project may not have included all relevant projects[57]; thirdly it may me that this type of research is typically performed in commercial classified R&D projects without EU funding.

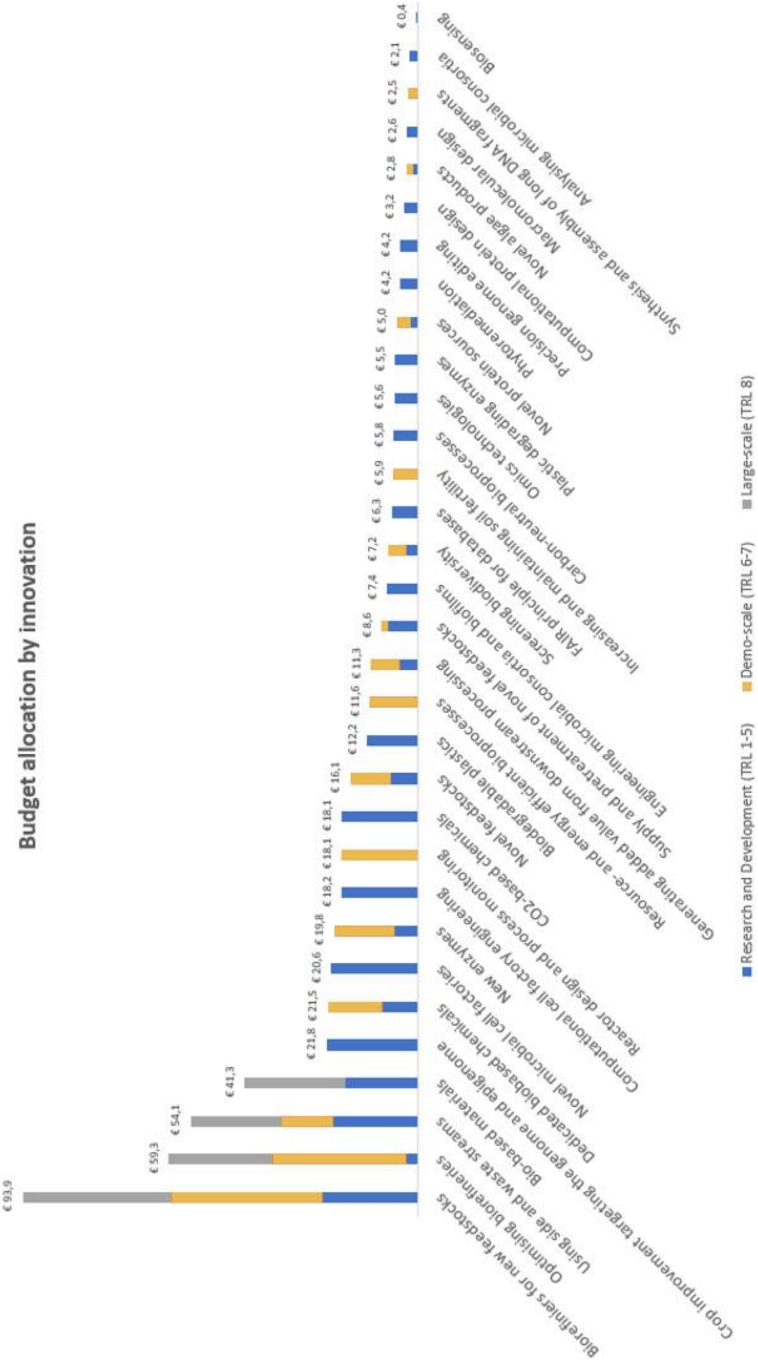

Figure 21: Allocation of EU contribution to 111 selected H2020 projects between the top 50 bio-based innovations Source: own assessment solely based information available in the CORDIS database.

[57] This assessment of projects was not required following the terms of reference of the project, and performed within limited time.

Figure 22 shows which actors in the 111 selected projects received most funds. These are mainly large private companies that received budget for Flagship projects. CSIC and Denmarks Tekniske Universitet and BBEPP are the top three organisations that received most budget for research and development (TRL1-5). Figure 23 shows these are also the actors that participate in the highest number of projects within the selected 111 H2020 projects. The figures can also be found at country level in the country fiches (See Annex V).

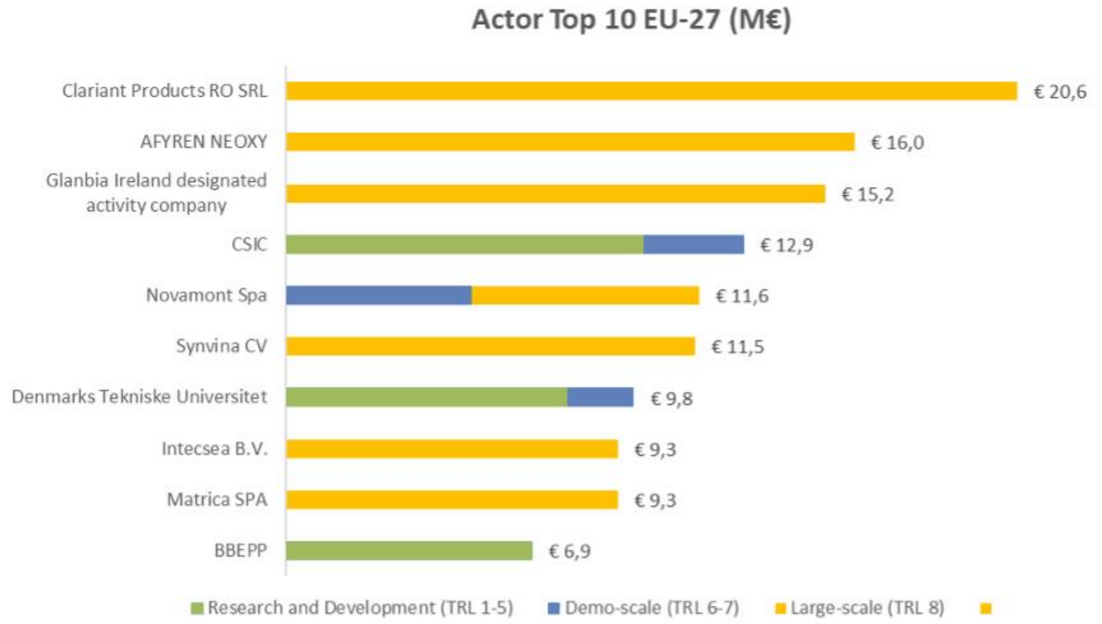

Figure 22: Actors of the 111 selected H2020 projects that received most EU contribution. Source: own assessment solely based information available in the CORDIS database.

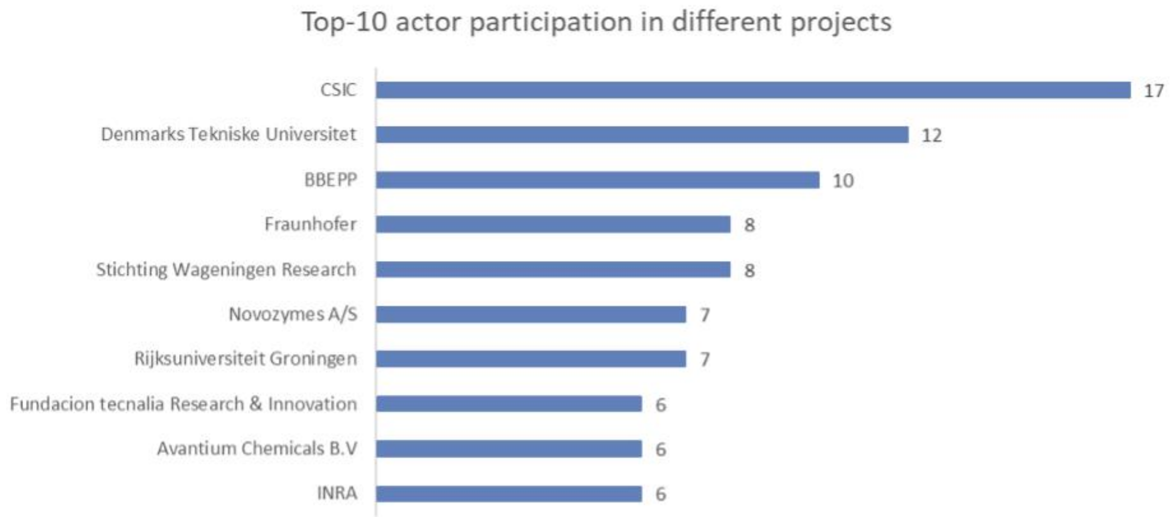

Figure 23: Number of selected 11 H2020 projects in which the top 10 of actors participated. Source: own assessment solely based information available in the CORDIS database.

What is a circular bioeconomy?
According to the Bioeconomy Strategy 2018, *„the **bioeconomy** covers all sectors and systems that rely on biological resources (animals, plants, microorganisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services"*.

According to Regulation 2020/852 (…) on the establishment of a framework to facilitate sustainable investment[58], Art 2(9) *'**circular economy**' means an economic system whereby: the value of products, materials and other resources in the economy is maintained for as long as possible, enhancing their efficient use in production and consumption, thereby: reducing the environmental impact of their use, minimising waste and the release of hazardous substances at all stages of their life cycle, including through the application of the waste hierarchy*.

At present, no legal binding EU definition of circular bioeconomy is in place. Stegemann et al. (2020) investigated define the term circular bioeconomy via a literature review and analysed the concept's role in north-west European bioeconomy clusters through interviews, resulting in the following definition:

The circular bioeconomy focuses on the:

- sustainable, resource-efficient valorisation of biomass in integrated, multi-output production chains (e.g. biorefineries) while …
- … also making use of residues and wastes and optimising the value of biomass over time via cascading.
- Such an optimisation can focus on economic environmental or social aspects and ideally considers all three pillars of sustainability.
- The cascading steps aim at retaining the resource quality by adhering to the bio-based value pyramid and the waste hierarchy where possible and adequate.

Potential contribution of the top 50 bio-based innovations to the circular economy
According to the proposed European Partnership for a Circular Bio-based Europe (CBE) the bioeconomy is the „green motor" of the circular economy. The bioeconomy is the supplier of bio-based carbon, which is renewable carbon from all types of biomass. Other suppliers of renewable carbon are direct CO_2-utilisation and carbon from recycling of already existing plastics and other materials[59]. The bioeconomy and circular economy share some of their targets: a more sustainable and resource efficient world with a low carbon footprint. Both avoid using additional fossil carbon to contribute to climate targets. To make the potential contribution of bio-based innovation to the circular economy tangible in operational terms, the list of circular economy aspects as found in Regulation 2020/852 Article 13 can be used, as presented in Box 1.

[58] REGULATION (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (Text with EEA relevance)
[59] As described in Nova (2020) nova-Paper #12: „Renewable Carbon – Key to a Sustainable and Future-Oriented Chemical and Plastic Industry" http://bio-based.eu/nova-papers/#novapaper12

Box 6: An economic activity shall qualify as contributing substantially to the transition to a circular economy, including waste prevention, re-use and recycling, where that activity

a. uses natural resources, including **sustainably sourced bio-based and other raw materials**, in production more efficiently, including by:
   - (i) **reducing the use of primary raw materials or increasing the use of by-products and secondary raw materials**; or
   - (ii) **resource and energy efficiency measures**;

b. increases the **durability, reparability, upgradability or reusability** of products, in particular in designing and manufacturing activities;

c. increases the **recyclability** of products, including the recyclability of individual materials contained in those products, inter alia, by substitution or reduced use of products and materials that are not recyclable, in particular in designing and manufacturing activities;

d. substantially **reduces the content of hazardous substances** and substitutes substances of very high concern in materials and products throughout their life cycle, in line with the objectives set out in Union law, including by replacing such substances with safer alternatives and ensuring traceability;

e. **prolongs the use of products**, including through reuse, design for longevity, repurposing, disassembly, remanufacturing, upgrades and repair, and sharing products;

f. **increasing the use of secondary raw materials** and their quality, including through high-quality recycling of waste;

g. **prevents or reduces waste generation**, including the generation of waste from the extraction of minerals and waste from the construction and demolition of buildings

h. increasing **preparing for re-use and recycling of waste**;

i. increases the **development of the waste management infrastructure** needed for prevention, for preparing for re-use and for recycling, while ensuring that the recovered materials are recycled as high-quality secondary raw material input in production, thereby avoiding downcycling**;**

j. minimises the incineration of waste and avoids the disposal of waste, including landfilling, in accordance with the principles of the waste hierarchy;

k. avoids and reduces litter; or

l. enables any of the activities listed in points (a) to (k) of this paragraph in accordance with Article 16.

Source: Regulation 2019/2088 Article 13

Table 23 shows how the different subfields of the top 50 bio-based innovations contribute to the circular economy according to the above criteria. The subfield #8 *efficient and sustainable industrial production and products with minimised environmental impact*[60] contributes almost solely to circular economy targets. Subfield #9 bio-based intermediates obviously contributes to criterion 'a' *using natural resources, including sustainably sourced bio-based and other raw materials*, as well as many other subfields (#2, 4, 5, 6, 7, 11).

Especially the cross-cutting technologies (e.g. #1 *analytical techniques*, #3 *design and engineering of biological systems, cell factories and synthetic biology*) that are further from the market may not have impacts directly attributable to circular targets. They could, however, bring up new possibilities which are currently not foreseeable. Moreover, they

[60] Subfield #8 contains the following innovations: resource and energy efficient bioprocesses, carbon-neutral bioprocesses, CO_2-based chemicals, climate gas mitigation of microbial activities, and biodegradable plastics and plastic degrading enzymes.

can be important enablers of many other innovations that have a direct link with circular economy aspects.

Table 23: Direct linkages of the subfields of the top 50 bio-based innovations to the circular economy criteria of Regulation 2019/2088 Article 13.

#	Subfield of top 50 bio-based innovations	Contri-butes to:	Example / remark
1	Analytical techniques and bioprospecting	-	No direct contribution identified of these cross-cutting innovations.
2	Design and engineering of biomolecules for desired functions	a	New enzymes that increase energy efficiency and reduce environmental impacts.
3	Design and engineering of biological systems, cell factories; synthetic biology	-	No direct contribution identified of these cross-cutting innovations.
4	Digital technologies	a	Digital technologies like process models support the efficiency of industrial processes.
5	Novel industrial production concepts	a	Utilisation of CO_2 or non-sugar feedstock as carbon source
6	Enabling bio-based production at industrial scale	a, f	Biorefineries, reactor design
7	Sustainable exploitation of novel feedstock	a, f, h	Using side and waste streams, pretreatment novel feedstock
8	Efficient and sustainable industrial production and products with minimised environmental impact	a, c, d, f, i, j	Resource and efficient bioprocesses, CO_2 based chemicals, climate gas mitigation of microbial activities
9	Bio-based intermediates, materials and product groups	a, d	Smart drop-ins, dedicated bio-based chemicals
10	Contributions to sustainable agriculture	-	Increasing agricultural yield not included in criteria Regulation 2019/2088 Article 13
11	Health and well-being	-	Novel antimicrobial agents as alternatives to classical antibiotics

While the role of several subfields in the production and end of life phase of products is significant, these subfields have less an obvious contribution to circularity aspects that are related to the usage phase of products such as (e) prolonging the use of products, (g) prevention or reduction of waste, (k) avoiding and reduction of litter. Similarly, Stegmann et al (2020) found that topics regarding biorefinery, wastes and residues as well as waste management are significantly covered in the circular bioeconomy literature, while social aspects, cascading, circular product design, and aspects related to product use seem to be underrepresented in circular bioeconomy literature.

Overview of bioeconomy clusters

Table 24 provides an overview of relevant bioeconomy clusters.

Table 24: Overview of a number of relevant regional bioeconomy clusters

Name	Level	Nation(s)	Topic	Website
BIO.NRW	Regional	Germany	Biotechnology	https://bio.nrw.de/
Bio-based Delta	Regional	Netherlands	Circular bio-based economy	https://bio-baseddelta.com/
BioEAST	International	Eastern Europe	Circular bioeconomies	https://bioeast.eu/
Bioeconomy Cluster	National	Slovakia	Innovation in bioeconomy	http://bioeconomy.sk/
BioVale	Regional	UK	Circular bioeconomy	https://www.biovale.org/
CLIB	International	German focus	Industrial biotechnology	https://www.clib2021.de/en/
Flanders Bio-based Valley	Regional	Belgium	Bio-based economy	http://www.fbbv.be/en
Food+i La Rioja	Regional	Spain	Food and agriculture	https://www.clusterfoodmasi.es/en/
Health and Life Science Cluster	National	Bulgaria	Life sciences	http://biocluster.bg/
IAR	National	France	Bioeconomy	https://en.iar-pole.com/
Norwich Research Park	Regional	UK	Food, diet, and health	https://www.norwichresearchpark.com/
The Lombardy Green Chemistry Cluster	Regional	Italy	Bioeconomy	https://www.chimicaverdelombardia.it/en/

EU legislative framework on GMO & New Genomic Techniques

EU legislation on GMOs

The EU policy on GMOs is comprehensive as it addresses the development of GMOs, the stepwise release into the environment, the general cultivation and seed production, marketing, labelling, enforcement and the whole agro-food chain, up to the consumption by humans and animals. The legal framework of the European Union for the genetically modified microorganism (GMO) legislation consists of[61]:

- Directive 2009/41/EC on contained use of genetically modified microorganisms.
- Directive 2001/18/EC on the deliberate release of GMOs into the environment
- Regulation (EC) 1829/2003 on genetically modified food and feed.

[61] http://plantbiotech.bg/en/i-want-to-know/gmo-legistaltion-in-europe/

- Directive (EU) 2015/412 amending Directive 2001/18/EC as regards the possibility for the Member States to restrict or prohibit the cultivation of GMOs in their territory

- Regulation (EC) 1830/2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms.

- Regulation (EC) 1946/2003 on transboundary movements of GMOs.

Directive 2009/41/EC on contained use of genetically modified microorganisms
EU legislation makes a distinction between (1) contained use of genetically modified microorganisms (GMM), which falls under Directive 2009/41/EC and (2) deliberate release, which is basically any activity with GMOs that is not contained use, and falls under Directive 2001/18/EC (see next paragraph). All contained use procedures are based on classification of risk - as decided by the appropriate authority:

- Class 1: No or negligible risk, level 1 containment
- Class 2: Low risk, level 2 containment
- Class 3: Moderate risk, level 3 containment
- Class 4: High risk, level 4 containment.

First, the user shall carry out an assessment of the contained uses as regards the risks to human health and the environment, resulting in the classification, and associated containment levels. Depending on the class and subject to the way Member States have implemented Directive 2009/41/EC, notification and permit procedures have to be followed involving one or more competent authorities. See Gielkens et al (2018)[62] for examples of Netherlands, Belgium, Denmark, France, Germany and Sweden.

Directive 2001/18/EC on deliberate release of GMOs into the environment
Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms sets the procedure for granting consent for the deliberate release and placing on the market of genetically modified organisms. The directive provides[63]:

- A system for assessing case-by-case the environmental risks associated with releasing GMOs;

- Common objectives for monitoring GMOs after their deliberate release on the market; and

- A mechanism that modifies, suspends or terminates deliberately released GMOs once information regarding the risks of releasing becomes available.

- GMO labelling and public consultation is made compulsory. The European Commission is obliged to consult the competent scientific committees on any question affecting human health or the environment.

- Registers must be established for the purpose of recording information on genetic modifications in GMOs alongside their location. Rule on the operation of these registers are laid down in Decision 2004/204/EC.

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[62] Gielkens et al (2018) Regulatory framework and Daily practices regarding Contained Use GMO licensing in several EU countries, National Institute for Public Health and the Environment https://ggo-vergunningverlening.nl/sites/default/files/2019-07/Daily%20practices%20Contained%20Use%20GMO%20licensing%20v1.0_0.pdf

[63] Summary as provided by http://plantbiotech.bg/en/i-want-to-know/gmo-legistaltion-in-europe/summary-of-directive-200118ec/

The Commission must publish a report on the experience of GMOs placed on the market and a summary of the measures taken by EU countries to implement this directive every 3 years.

Regulation (EC) 1829/2003 on genetically modified food and feed

Regulation (EC) 1829/2003 lays down rules on how genetically modified organisms (GMOs) are authorised and supervised, and on how genetically modified food and animal feed is labelled. It requires the establishment of a Community register of genetically modified food and feed. The Community register of GM food and feed[64] shows that around 70 types of genetically modified types of maize, oilseed rape, soybean, and sugar beet have been registered for import and use in food and feed. Currently only on GM maize event is authorised for cultivation (MON810).

Directive (EU) 2015/412 limiting the cultivation of GMO crops in Member States

While the GMO directive 2001/18/EC allows EU countries to restrict or prohibit the release of GMOs that constitute a risk to human health and the environment, Directive (EU) 2015/412 amends it allowing for EU countries to prohibit or restrict the cultivation of GMO crops on wider grounds such as town and country planning, land use, socio-economic impacts, co-existence and public policy. In total 18 Member States have made use of the possibility to exclude EU approved GMO crops from (part of) their territory[65]. This means that the only crop authorised for cultivation (MON810) can only be cultivated in Belgium (Flanders and Brussels), Czech Republic, Estonia, Finland, Ireland, Portugal, Romania, Slovakia, Spain and Sweden. So far, MON810 maize has been mainly grown in Portugal and Spain[66].

Proposal for a Regulation limiting the use of GMO food and feed in EU Member States

Shortly after the successful adoption of the Directive on the 2015/412 giving Member States to limit the ***cultivation*** of GMO crops on their territories, on 22 April 2015 the European Commission submitted proposal COM (2015)177[67] for a Regulation (…) as regards the possibility for the Member States to restrict or prohibit the ***use*** of genetically modified food and feed on their territory. This proposal was rejected by the European Parliament as it could lead to the reintroduction of border controls between pro and anti-GMO countries, would be unworkable and incompatible with the WTO rules[68].

Regulation (EC) 1830/2003 concerning the traceability and labelling of GMO

Regulation (EC) 1830/2003 concerning the traceability and labelling of genetically modified organisms and the traceability of *food and feed products* produced from genetically modified organisms. It puts in place rules to ensure products containing GMOs and food and animal feed derived from them can be traced at all stages of the production and distribution chain. The rules cover labelling, monitoring environmental and health risks, and the ability to withdraw products where necessary[69].

[64] See https://webgate.ec.europa.eu/dyna/gm_register/index_en.cfm

[65] See https://ec.europa.eu/food/plant/gmo/authorisation/cultivation/geographical_scope_en for territories and crops. United Kingdom became non-EU country on 1 Feb 2020.

[66]https://ec.europa.eu/environment/europeangreencapital/countriesruleoutgmos/#:~:text=So%20far%20the%20only%20GM,and%20sold%20across%20the%20EU.

[67] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015PC0177

[68] https://www.europarl.europa.eu/legislative-train/theme-union-of-democratic-change/file-restriction-of-the-use-of-gmos-for-food-and-feed

[69] http://plantbiotech.bg/en/i-want-to-know/gmo-legistaltion-in-europe/summary-of-regulation-ec-no-18302003/

Regulation (EC) 1946/2003 on transboundary movements of GMOs

Regulation (EC) 1946/2003 applies to the transboundary movements of GMOs, stipulating notification and information procedures for export to third countries of (1) GMOs intended for deliberate release into the environment, (2) GMOs intended for direct use as food or feed, or for processing and (3) GMOs intended for contained use.

New genomic techniques (NGT) within the EU GMO legislation

After the implementation of the GMO directive in 2001, new genomic editing techniques (NGTs) such as CRISPR/Cas, TALENs, Zinc-Finger Nucleases, Meganucleases, Oligonucleotide-Directed Mutagenesis and base editing have been developed enabling a precise modification of DNA sequences. Such techniques provide options for simple, time-saving and cost-effective applications compared to other breeding techniques and hence genome editing has already been promoted for a wide range of plant species (Modrezejewki, Hartung et al. 2019)[70]. These NGTs are mutagenesis techniques, which are unlike transgenesis, a set of techniques which make it possible to alter the genome of a living species without the insertion of foreign DNA. Mutagenesis techniques have made it possible to develop seed varieties which are resistant to selective herbicides.

Court of Justice Case C-528/16 - organisms obtained by mutagenesis are GMOs

According to the GMO Directive a genetically modified organism (GMO) means *an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination.* Lists of techniques complete this definition and specify the scope of that Directive. The definition and the lists of techniques have been drafted in the light of those breeding techniques that were available and used at the time of the adoption of Directive 2001/18/EC. Annex I B of the GMO Directive, excludes mutagenesis from the Directive.
However, in Case C-258/16 of the Court of Justice of the European Union, Confédération paysanne and the other associations argue that mutagenesis techniques have evolved over time. Prior to the adoption of the GMO Directive, only conventional or random methods of mutagenesis were applied in vivo to entire plants. Subsequently, technical progress has led to the emergence of in vitro mutagenesis techniques which make it possible to target the mutations in order to obtain an organism resistant to certain herbicides. Confédération paysanne and the other associations take the view that the use of herbicide-resistant seed varieties carries a risk of significant harm to the environment and to human and animal health, in the same way as GMOs obtained by transgenesis (EU Court of Justice 2018)[71].

The Court of Justice has decided that organisms obtained by mutagenesis are GMOs within the meaning of the GMO Directive, in so far as the techniques and methods of mutagenesis alter the genetic material of an organism in a way that does not occur naturally. It follows that those organisms come, in principle, within the scope of the GMO Directive and are subject to the obligations laid down by that directive. The GMO Directive does not apply to organisms obtained by means of certain mutagenesis techniques, namely those which have conventionally been used in a number of applications and have a long safety record. The Court nevertheless specifies that the Member States are free to subject such organisms, in compliance with EU law (in particular the rules on the free movement of goods), to the obligations (EU Court of Justice 2018).

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[70] Modrzejewski, D., F. Hartung, Th. Sprink, D. Krause, C. Kohl and R. Wilhelm (2019) What is the available evidence for the range of applications of genome-editing as a new tool for plant trait modification and the potential occurrence of associated off-target effects: a systematic map, Environmental Evidence (2019)8:27. https://doi.org/10.1186/s13750-019-0171-5

[71] Court of Justice of the European Union (2018) PRESS RELEASE No 111/18, Luxembourg, 25 July 2018 Judgment in Case C-528/16, Confédération paysanne and Others v Premier ministre and Ministre de l'Agriculture, de l'Agroalimentaire et de la Forêt.

Study regarding the status of novel genomic techniques under Union law

In light of the Court of Justice's judgment in Case C-528/16, the Council has requested the European Commission to submit a study regarding the status of novel genomic techniques under Union law[72]. The study will deal with:

- A state-of-play on the implementation and enforcement of the GMO legislation, as regards NGTs, based on 1) contributions from targeted consultations of the Member States and stakeholders; 2) work of the European Union Reference Laboratory, together with the European Network of GMO Laboratories, on the detection of products obtained by new mutagenesis techniques.

- Information on the status and use of NGTs in plants, animals and microorganisms for agri-food, industrial and pharmaceutical applications.

- An overview on the risk assessment of plants developed through new genomic techniques, prepared by the European Food Safety Authority (EFSA), based on its own previous and ongoing work and on work carried out at national level.

- An overview of current and future scientific and technological developments in new genomic techniques as well as of new products that are, or are expected to be marketed, prepared by Joint Research Centre (JRC).

In addition, the study will take into account an analysis of the ethical and societal implications of gene editing that is being developed by the European Group on Ethics in Science and New Technologies. This study is welcomed by the biotechnology industry (Euroseeds 2020)[73], and will be submitted on 30 April 2021[74]. Results from stakeholder consultations held in spring 2020, are expected by the end of 2020 for the synthetic biology and gene drive opinions, and by end of October 2020 for the SDNI and 2/ODM opinion.

[72] COUNCIL DECISION (EU) 2019/1904 of 8 November 2019 requesting the Commission to submit a study in light of the Court of Justice's judgment in Case C-528/16 regarding the status of novel genomic techniques under Union law, and a proposal, if appropriate in view of the outcomes of the study.

[73] Euroseeds (2020) 26 business organisations support a Commission study on „novel genomic techniques" and express their hope for more enabling regulations. Press release 13 January 2020. https://www.euroseeds.eu/news/update-26-european-business-organisations-ask-the-eu-to-submit-a-study-on-the-status-of-novel-genomic-techniques/

[74] https://ec.europa.eu/food/plant/gmo/modern_biotech/new-genomic-techniques_en

Annex IV: Patent and publication analysis for the top 50 bio-based innovations

Table 25. Patent analysis for the Top 50 bio-based innovations (transnational patents)

	Innovation	Total number 2004-207	Total number 2014-2017	Growth world p.a.	2004-2007 Share EU	2014-2017 Share EU
1	Screening biodiversity	n.a.	n.a.	n.a.	n.a.	n.a.
2	-omics technologies	n.a.	n.a.	n.a.	n.a.	n.a.
3	Analysing microbial consortia	40	164	15%	34%	17%
4	Lab-on-a-chip	750	1125	4%	25%	23%
5	Biosensing	410	282	-4%	24%	18%
6	Macromolecular design	1717	3598	8%	23%	15%
7	Multi-enzyme biocatalysis	149	175	2%	38%	19%
8	New enzymes	6440	7327	1%	30%	25%
9	Precision genome editing	n.a.	n.a.	n.a.	n.a.	n.a.
10	Synthesis and assembly of long DNA fragments	593	337	-5%	23%	18%
11	Modular cloning systems	243	78	-11%	26%	25%
12	Minimal cells	1204	887	-3%	39%	22%
13	Expansion of the genetic code	149	252	5%	18%	17%
14	FAIR principle for databases	2	210	59%	0%	16%
15	Deep Learning	48	215	16%	20%	13%
16	Computational protein design	1105	877	-2%	18%	18%
17	Computational cell factory engineering	254	625	9%	14%	17%
18	Process models	575	463	-2%	15%	14%
19	Novel microbial cell factories	22	93	16%	32%	26%
20	Engineering microbial consortia	67	195	11%	28%	21%
21	Microbial Electrosynthesis	14	30	8%	31%	26%
22	Optimising biorefineries	n.a.	n.a.	n.a.	n.a.	n.a.
23	Biorefineries for new feedstock	n.a.	n.a.	n.a.	n.a.	n.a.
24	Reactor design and process monitoring	818	998	2%	31%	31%
25	Cell heterogeneity	n.a.	n.a.	n.a.	n.a.	n.a.

26	Stress-tolerant production organisms	82	88	1%	28%	18%
27	Novel feedstock	234	215	-1%	21%	33%
28	Using side and waste streams	12	48	15%	17%	39%
29	Supply and pretreatment of novel feedstock	35	54	4%	6%	24%
30	Resource- and energy efficient bioprocesses	1277	742	-5%	22%	23%
31	Carbon-neutral bioprocesses	206	198	0%	24%	22%
32	CO2-based chemicals	431	312	-3%	22%	22%
33	Climate-gas mitigation of microbial activities	965	621	-4%	29%	22%
34	Biodegradable plastics	226	189	-2%	24%	32%
35	Plastic degrading enzymes	n.a.	n.a.	n.a.	n.a.	n.a.
36	Smart drop-ins	258	258	0%	39%	26%
37	Dedicated bio-based chemicals	10833	8424	-2%	27%	27%
38	Bio-based materials	339	336	0%	33%	25%
39	Bio-functional materials	256	306	2%	17%	15%
40	Novel algae products	410	591	4%	38%	34%
41	Crop improvement targeting genome and epigenome	3	148	48%	50%	13%
42	de novo domestication	315	303	0%	39%	36%
43	Asexual reproduction of seeds	25	28	1%	23%	3%
44	Increasing and maintaining soil fertility	40	97	9%	15%	21%
45	Novel farming concepts	15	93	20%	60%	18%
46	Novel protein sources	199	212	1%	36%	28%
47	Health-promoting ingredients	1780	2251	2%	26%	16%
48	Novel antimicrobial agents	2079	1788	-1%	29%	23%
49	Probiotic sanitation strategies	27	68	10%	75%	22%
50	Veterinary DNA vaccines	60	28	-7%	35%	34%

Source: Fraunhofer ISI, World Patents Index (WPINDEX)

Table 26. Publication analysis for the Top 50 bio-based innovations

	Innovation	Total number 2004-207	Total number 2014-2017	Growth world p.a.	2004-2007 Share EU	2014-2017 Share EU
1	Screening biodiversity	69	300	16%	14%	21%
2	-omics technologies	134	206	4%	25%	31%
3	Analysing microbial consortia	104	613	19%	34%	27%
4	Lab-on-a-chip	559	1149	7%	26%	34%
5	Biosensing	7580	21548	11%	29%	20%
6	Macromolecular design	137	242	6%	21%	23%
7	Multi-enzyme biocatalysis	2147	2719	2%	31%	28%
8	New enzymes	30	202	21%	39%	37%
9	Precision genome editing	2	190	58%	0%	19%
10	Synthesis and assembly of long DNA fragments	111	149	3%	22%	19%
11	Modular cloning systems	71	93	3%	32%	38%
12	Minimal cells	285	560	7%	28%	29%
13	Expansion of the genetic code	319	969	12%	25%	28%
14	FAIR principle for databases	15	50	13%	24%	29%
15	Deep Learning	1078	2854	10%	24%	22%
16	Computational protein design	228	722	12%	19%	22%
17	Computational cell factory engineering	4	58	31%	50%	59%
18	Process models	34	59	6%	34%	44%
19	Novel microbial cell factories	12	105	24%	50%	33%
20	Engineering microbial consortia	692	2850	15%	31%	26%
21	Microbial Electrosynthesis	3	246	55%	100%	43%
22	Optimising biorefineries	12	376	41%	25%	33%
23	Biorefineries for new feedstock	11	433	44%	55%	40%

24	Reactor design and process monitoring	1078	2206	7%	31%	29%
25	Cell heterogeneity	41	110	10%	49%	40%
26	Stress-tolerant production organisms	234	756	12%	27%	24%
27	Novel feedstock	1452	4618	12%	32%	27%
28	Using side and waste streams	876	2714	12%	32%	29%
29	Supply and pretreatment of novel feedstock	188	2440	29%	28%	23%
30	Resource- and energy efficient bioprocesses	663	3268	17%	36%	28%
31	Carbon-neutral bioprocesses	313	739	9%	25%	20%
32	CO2-based chemicals	278	773	11%	35%	26%
33	Climate-gas mitigation of microbial activities	233	693	12%	38%	24%
34	Biodegradable plastics	127	447	13%	20%	29%
35	Plastic degrading enzymes	1546	2842	6%	35%	29%
36	Smart drop-ins	n.a.	n.a.	n.a.	n.a.	n.a.
37	Dedicated bio-based chemicals	611	3136	18%	35%	28%
38	Bio-based materials	12	206	33%	15%	51%
39	Bio-functional materials	1916	8497	16%	22%	20%
40	Novel algae products	135	741	19%	31%	36%
41	Crop improvement targeting genome and epigenome	145	839	19%	29%	28%
42	de novo domestication	29	144	17%	31%	25%
43	Asexual reproduction of seeds	319	440	3%	38%	33%
44	Increasing and maintaining soil fertility	5214	12060	9%	27%	27%
45	Novel farming concepts	6	117	35%	0%	33%
46	Novel protein sources	351	668	7%	31%	35%
47	Health-promoting ingredients	143	507	13%	57%	39%
48	Novel antimicrobial agents	3035	6779	8%	32%	28%
49	Probiotic sanitation strategies	n.a.	n.a.	n.a.	n.a.	n.a.
50	Veterinary DNA vaccines	385	202	-6%	24%	18%

Source: Fraunhofer ISI, SciSearch

Annex V: Country fiches

Explanatory note

The country fiches aim to provide insight in the status of bioeconomy policy-making and the involvement of each EU country in European research and innovation on life science and biotechnology as engines for bio-based innovation.

The first page of each country fiche is based on an analysis of national bioeconomy strategies, action plans, and bioscience related policies. The national support measures are described in a qualitative way supported with some quantitative data, if available. The second page shows the activity of the country in 111 selected Horizon 2020 projects that have a direct link with the top 50 bio-based innovations identified in this project, allowing a quantitative comparison between Member States. The data is based on information as publicly available in the CORDIS Database and covers the EU-27 Member States plus the United Kingdom.

Below the country fiches are explained item by item.

PAGE 1: Overview availability bioeconomy strategy, action plan, bioscience related policy and national support measures

Meaning of the indicators at the top of the page:

Bioeconomy strategy:

✓	A bioeconomy strategy is available as a separate document
✓	The content of a bioeconomy strategy is (partially) available as part of other policy document(s)
✗	No bioeconomy strategy has been found

Action plan:

✓	A bioeconomy action plan is available as a separate document
✓	The content of a bioeconomy action plan is (partially) available as part of other policy document(s)
✗	No bioeconomy action plan has been found

Bioscience related policy:

✓	A detailed bioscience related policy, covering life science and biotechnology for bio-based innovation, is available
✓	Generic bioscience related policies are available. For instance, life science and biotechnology are mentioned in a bioeconomy strategy, but not in depth covered
✗	No bioscience related policy, covering life science and biotechnology for bio-based innovation, has been found

National support measures:

✓	National support measures are available specifically for biotechnology and life science as engine for bio-based innovation
✓	Generic national support measures are available that among others support life science and bio-based innovation as engine for bio-based innovation
✕	No national support measures have been found

Bioeconomy strategy

The dedicated bioeconomy strategy is briefly introduced, and if not available, other relevant strategies are introduced.

Targeted economic sectors and corresponding priorities

It is specified if and which specific sectors are addressed in the bioeconomy strategy or similar documents. The key priorities are described in general terms.

How is life science and/or biotechnology addressed?

The envisaged role of life science and biotechnology as engine for bio-based innovation is highlighted.

Support measures

Information is given on the availability of specific or generic national support measures to support bio-based innovation.

PAGE 2: information on EU funding per country based on 111 relevant projectS

This page summarises the performance of the country, based on the 111 identified Horizon 2020 projects that have a direct link with the top 50 bio-based innovations. A distinction is made between Research and development (TRL 1-5), demo-scale (TRL 6-7) and large-scale flagships (TRL 8). The analysed funding programmes are provided in Table 27 . All investigated projects started in the period 2014 - 2020. The amounts concern the received funding. In several projects types the participants provide an own contribution as co-financing. This co-financing is not included in the analysis.

Table 27: Overview of funding programmes included in the analysis of 111 Horizon 2020 projects with a direct link to the top 50 bio-based innovations

Funding programme	Abbreviation	TRL	Total of 111 projects (M Euro)	Group
European Research Council grants	ERC	1	2	1. Research and Development
Marie Skłodowska-Curie actions	MSCA	1 - 5	19	
BBI Research and Innovation Actions	BBI-RIA	3 - 5	90	
H2020 Research and Innovation Action	RIA	3 - 5	145	
SME instrument phase 1	SME1	4 - 5	0.5	
H2020 Innovation Action	IA	6 - 7	64	2. Demo-scale
BBI Innovation Actions - Demonstration	BBI-IA-DEMO	6 - 7	108	
SME instrument phase 2	SME2	6 - 7	10	
BBI Innovation Actions - Flagship	BBI-IA-FLAG	8	106	3. Large-scale
Total		1 - 8	544	

Position in EU biotech related projects

This section summarises the total received EU contribution of the 111 relevant projects and a ranking based on the total amount received by the country. As the size of countries differs, also the received budget per capita is provided. The share of funds that went to universities, research funds and private sector has been indicated as well. Furthermore, the subfields that received most budget are mentioned.

Allocation of EU biotech project funding

Actor top 10

The bar chart shows by country which organisations received most budget from the 111 identified Horizon 2020 projects with a direct link to the top 50 bio-based innovations. This gives an impression of the most active players in the country.

H2020 budget allocation by subfield

The top 50 bio-based innovations have been classified according to 11 subfields. The graph shows how much budget went to the different subfields, including the TRL-range, indicating the level of activity of the country in these subfields.

Austria

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The national bioeconomy strategy (Austria's Bioeconomy Strategy) was presented in 2019. It aims to identify concrete measures for the further establishment of the bioeconomy in Austria in order to generate sustained growth spurts for bio-based products, bioenergy and related technologies and services. The report also serves as a cornerstone of the Climate and Energy Strategy. The next step of the strategy process is to develop a detailed action plan.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

Main sector specific priorities include:

- Agriculture: optimized plant breeding, development of special crops
- Forestry: development of new value creation and production concepts to optimize forestry
- Water management: development of new sources of raw materials in closed production systems (i.e. algae or insects for animal feed)
- Materials: increased production and uptake of bio-based chemicals and biopolymers.

By targeting a number of below listed cross-sectoral objectives, significant progress is foreseen towards increasing the size of the Austrian bioeconomy:

- Achieve climate goals
- Promote innovation and economic development & secure and create jobs
- Increased exploitation of renewable raw material sources through the use of residues, by-products, wastes and the production of new raw materials.
- Increase of efficiency along the whole value chain, from raw material generation, logistics and material use to energy recovery, as well as rethinking of consumer behaviour.
- Promote sustainable social transformation

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

In the national Bioeconomy Strategy life sciences and biotechnology have been allocated an important role as enabling technology of the bioeconomy (e.g. in biomass conversion) and as a key technology to produce different products of the bioeconomy (i.e. materials, such as fibres, chemicals, biopolymers etc). The working paper "RTI Strategy for Biobased Industries" back in 2014 already focused on the scientific and technological fundamentals for the design of the bioeconomy with the aim of positioning Austria as an RTI location of excellence globally and emphasizing the importance of basic and applied research (incl. biotechnology).

SUPPORT MEASURES

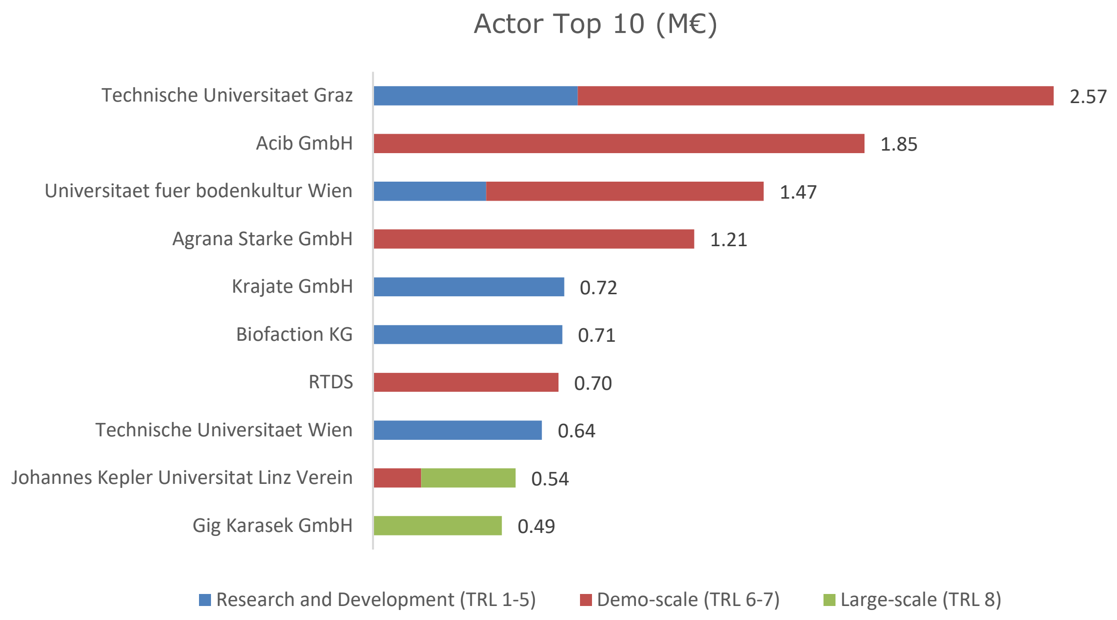
Next to the EU, there are a number of national level supportive measures available. For example, the COMET (Competence Centres for Excellent Technologies) programme that is considered as one of the most successful technology policy initiative in Austria. Support programs for applied research have been developed, such as "Production of the Future" with a focus on "Bio-based Industry", the creation of international networks in the Austrian research system is comprehensively supported by strategies of the Federal Government (amongst others: ERA roadmap). Further policy measures should, among others, focus on development of incentive instruments and adopting the legal framework to better meet the needs of bioeconomy. It is also necessary to shape the criteria of public tenders to meet the sustainability goals.

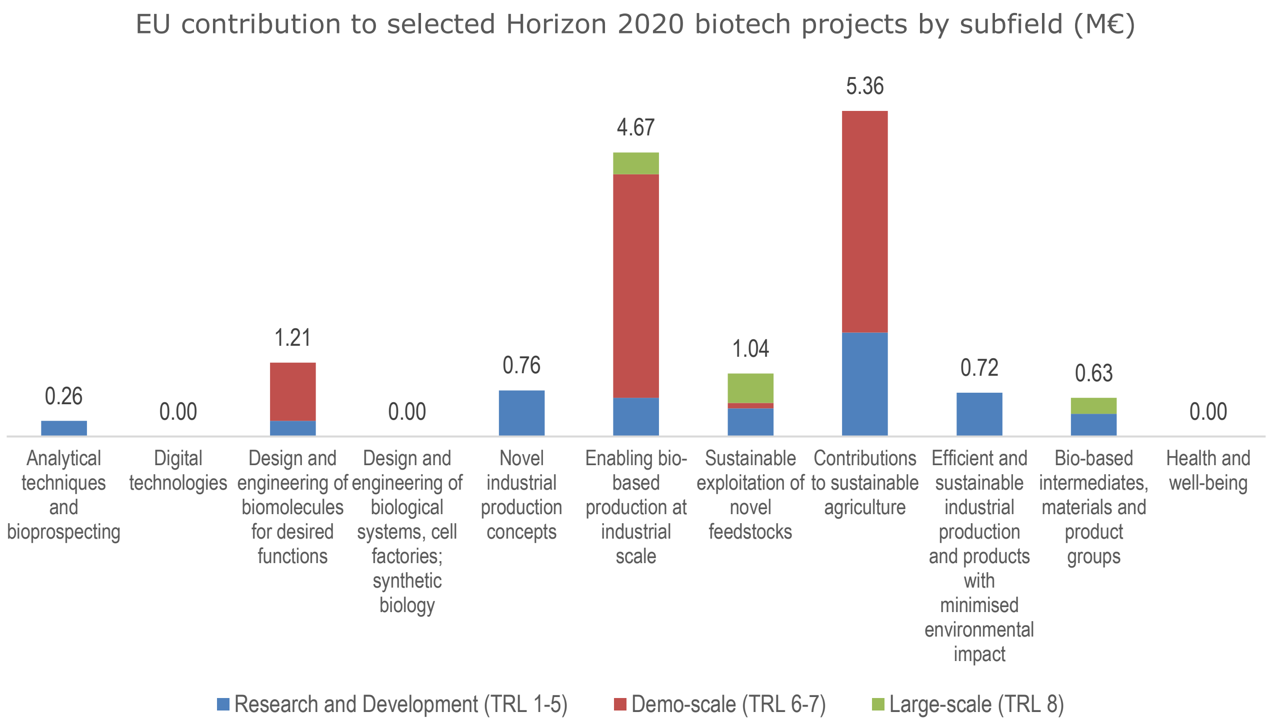
POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Austria has received 14.6 million Euro of H2020 budget for biotech related projects, ranking 13th of all EU-27 countries plus the UK, equalling 1.65 Euro/capita. Approximately 34.9% of that EU budget is allocated to universities, 24.9% to research institutes, and 40.2% to the private sector. Austria shows a clear focus towards **Contributions to sustainable agriculture** and **enabling bio-based**

production at industrial scale, consuming 68% of the total allocated budget. More specifically, **optimising biorefineries and production facilities** together with **increasing and maintaining soil fertility** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Belgium

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Belgium does not have a dedicated national bioeconomy strategy. Bioeconomy policies vary by regions and there is little policy integration between them. Flanders has issued a number of bioeconomy related strategies, including a strategy document "Bioeconomy in Flanders" in 2014. In 2019, Wallonia presented two preliminary reports for the update of the Research and Innovation plans & Strategies for Smart Strategy (RIS3) in health and bioeconomy. The Walloon Sustainable Development Strategy (2016) is aimed as a guidance to promote sustainable development in the public policies.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The "Bioeconomy in Flanders" strategy includes agriculture, forestry, fishing, food, wood, pulp & paper, consumer & logistics, environmental technology, construction, energy, industrial sector (incl. biotechnology sector). The priorities of the strategy are not focussed to specific sectors but cut across sectoral boundaries with a common goal to contribute green growth, job creation and circular economy. These key priorities of the Strategy are:

- coherent policy to support sustainable bioeconomy
- support R&D education and training in different bioeconomy clusters
- sustainable production and use of biomass
- strong market presence of different bioeconomy sectors
- increased international collaboration.

In Wallonia region, bioeconomy is treated within the larger context of green economy. No dedicated bioeconomy strategy exists.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Belgium does not have any national biotechnology related strategies. Biotechnology is included in the Flanders' Bioeconomy strategy, though.

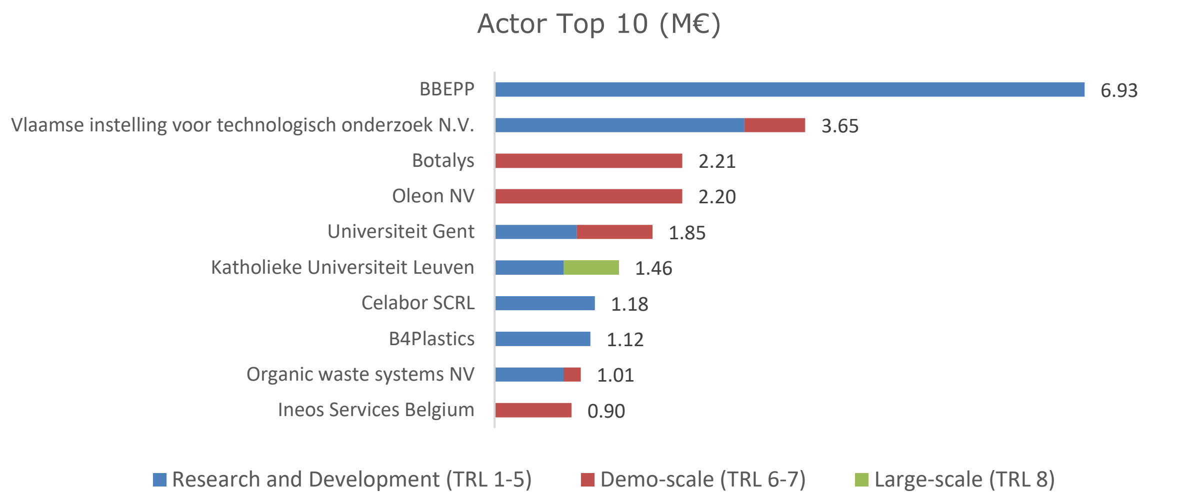
SUPPORT MEASURES

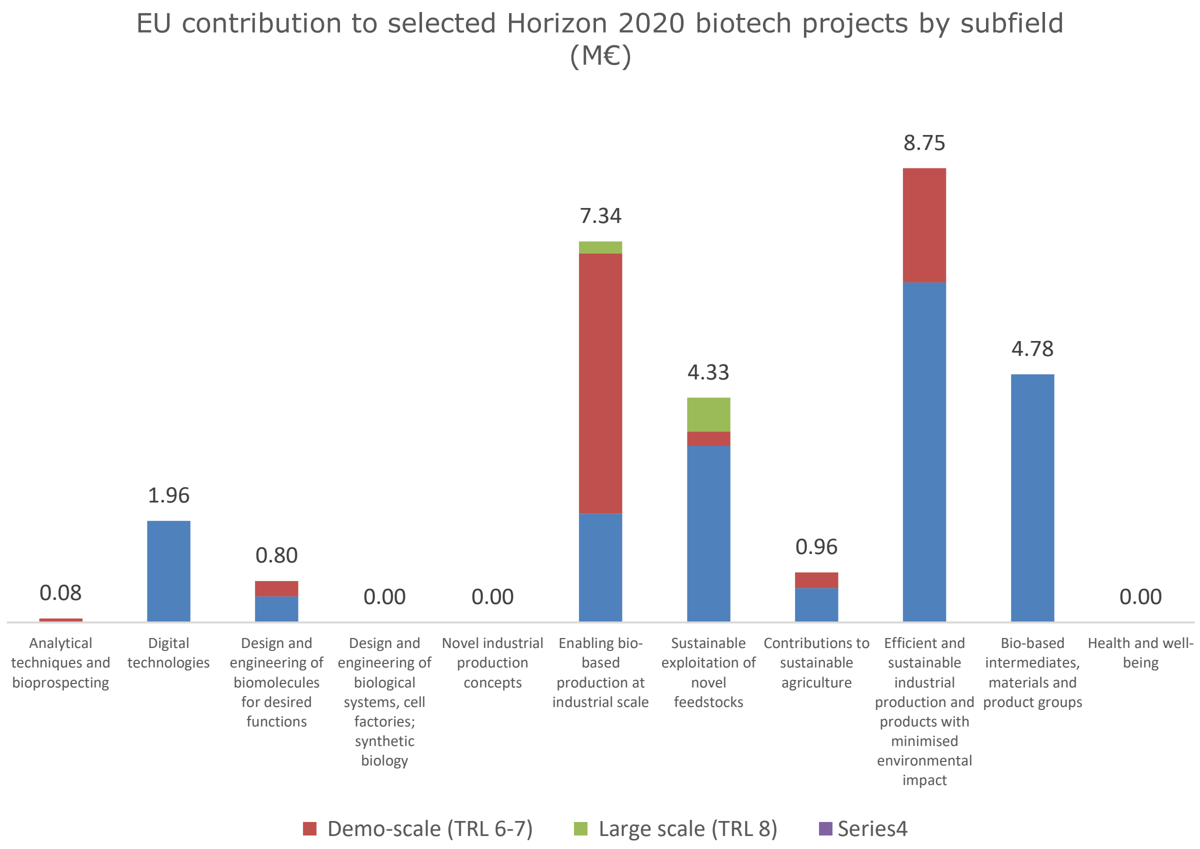
Next to the EU level available funding mechanisms, a number of support instruments also exist on national level, majority of them being applicable on regional level. The main biotechnology research funding organisations are the Department of Economy Science and Innovation (EWI) in Flanders, the Research Foundation - Flanders (FWO) and the Flanders Innovation and Entrepreneurship (VLAIO), Flemish Investment Company (PMW) and Business Angels Network Vlaanderen (BAN Vlaanderen). Wallonia has the Walloon Research Foundation (FNRS) and Fund for Strategic Fundamental Research (FRFS). Wallonia has Greenwin Cluster funds R&D projects, prioritising sustainable technologies and green chemistry. The Belgian Science Policy Office (Belspo) provides funding at the national level. Furthermore, the Government of Belgium offers tax reduction to innovative companies for some expenses.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Belgium has received 29.4 million Euro of H2020 budget for biotech related projects, ranking 6th of all EU-27 countries plus the UK, equalling 2.54 Euro/capita. Approximately 14.5% of that EU budget is allocated to universities, 17.1% to research institutes, and 42.9% to the private sector. Belgium shows a clear focus towards **efficient and sustainable industrial production and products with minimized environmental impact** and **enabling bio-based production at industrial scale**, consuming 46% of the total allocated budget. More specifically, **CO_2-based chemicals** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Bulgaria

✗ BIOECONOMY STRATEGY	✗ ACTION PLAN	✓ BIOSCIENCE RELATED POLICY	✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Bulgaria does not have a dedicated national bioeconomy strategy, but it is foreseen. In May 2020, Bulgarian Agricultural Academy released a "Strategy for Strenghtening the Role of the Agricultural Sector in Bioeconomy". Bulgaria is also part the BIOEAST initiative, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy. The country also has developed a draft Integrated "Energy and Climate Plan of the Republic of Bulgaria", but neither bioeconomy nor biotechnology is mentioned there.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The "Strategy for Strenghtening the Role of the Agricultural Sector in Bioeconomy" sets three strategic cross-sectoral goals: 1) sustainable development of agriculture, forestry and fisheries for sustainable production and provision of renewable resources, 2) development of research activities, collaborations and innovation transfers for experimental purposes and 3) improvement of knowledge and skills. The Strategy also makes specific recommendations for the inclusion of the bioeconomy in the preparation of the Strategic Plan for the New Common Agricultural Policy 2021-2027, which is currently under development by the Ministry of Agriculture, Food and Forestry.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Bulgaria does not have life science and /or biotechnology strategy. The country has developed the "Innovation Strategy for Smart Specialisation of the Republic of Bulgaria 2014 - 2020 " ISS) that was last updated in 2017. This strategy identified biotechnology as one of the key innovative technology areas in Bulgaria. The strategy outlines two main objectives: 1) investing in the key thematic areas to increase their innovation potential and 2) support for accelerated implementation of technologies and methods to improve resource efficiency. In the draft Integrated Energy and Climate Plan, among main dimensions and objectives R&I and competitiveness are also listed. The priority is to encourage the translation of scientific advancement into innovative energy technologies. This could also involve biotechnology.

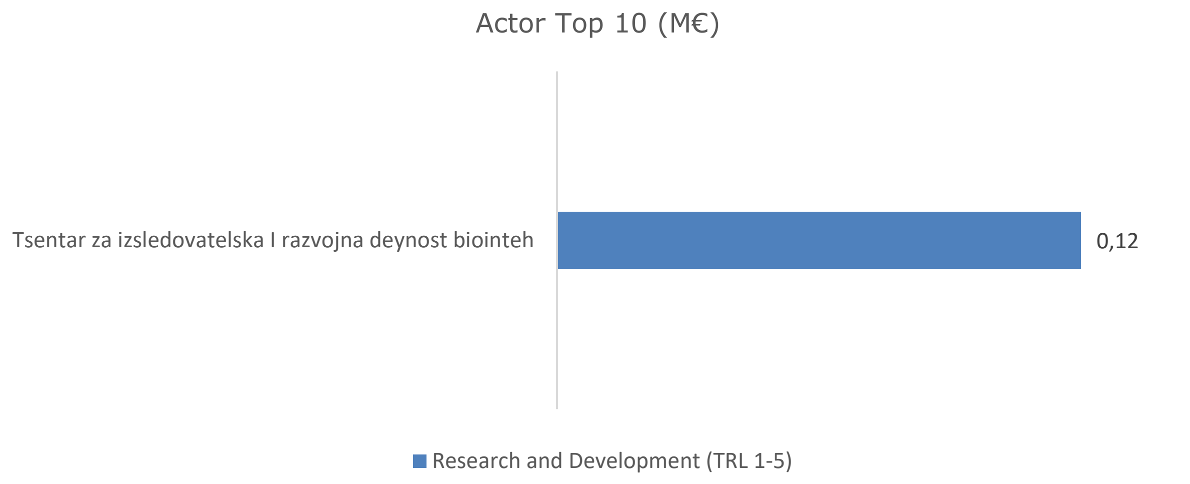
SUPPORT MEASURES

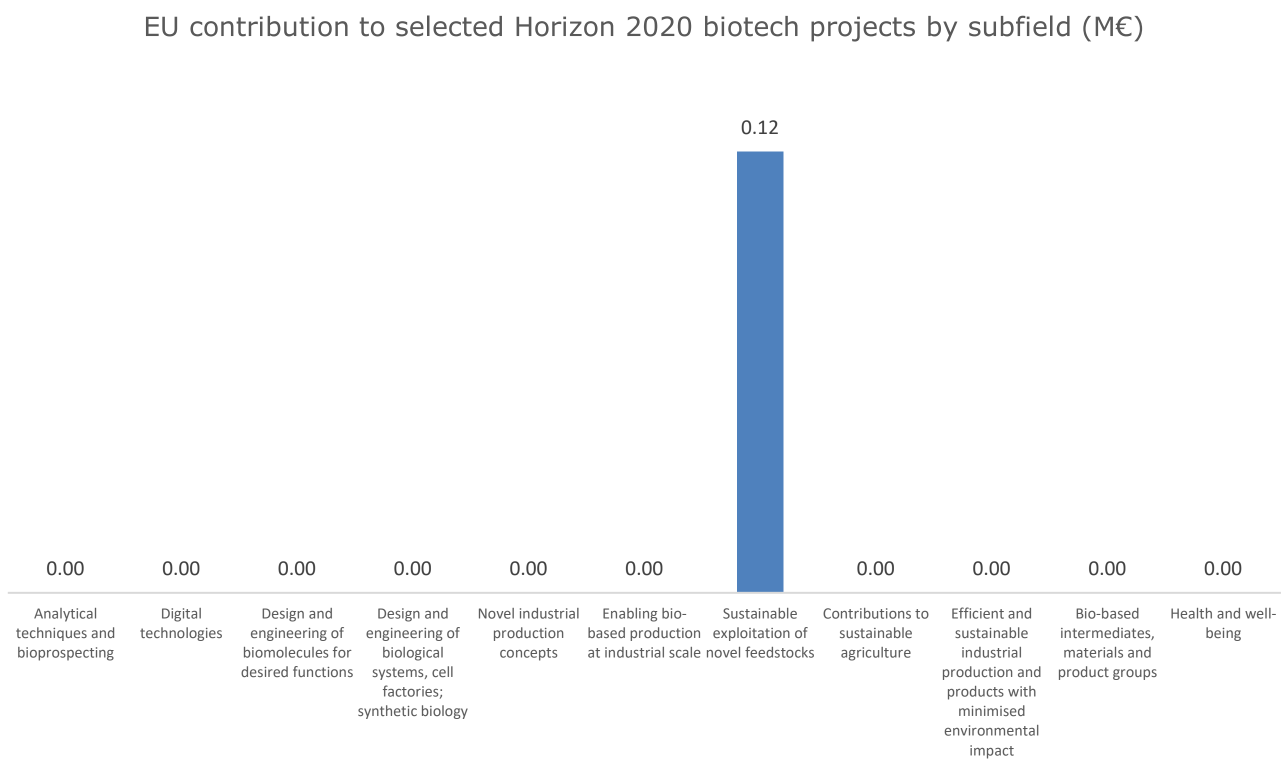
Some national level funding exists, but support measures still depend largely on the flow of European funds. The Executive Agency Science and Education for Smart Growth Operational Programme offers funding opportunities for technology areas in the ISS, including biotechnology. Furthermore, the ISS Strategy outlined a number of biotechnology specific support mechanisms that were implemented until 2020. The Bulgarian National science Fund has several calls, under which biotechnology could be supported.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Bulgaria has received 120 thousand Euro of H2020 budget for biotech related projects, ranking 26th of all EU-27 countries plus UK, equalling 0.02 Euro/capita. 100% of that EU budget is allocated to the private sector. Bulgaria took part in one project related to **sustainable exploitation of novel feedstocks**. More specifically, **using side and waste streams** is the only top 50 innovation that have received EU budget.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Croatia

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

In Croatia, the national bioeconomy strategy is currently under development. There is already an International Committee installed for drafting the national bioeconomy strategy. Furthermore, several strategic documents exist wherein the field is partly reflected, e.g. the "Smart Specialisation Strategy (2016-2020)" (S3), the "National Development Strategy (2020 – 2030)", which recognises green and digital transformation as national development priority and the "Strategy of Agriculture (2020 - 2030)". Croatia is also part of the BIOEAST initiative.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The government demonstrates continuous support for sustainability and bioeconomy. Food production, agriculture, forestry fishery and aquaculture are the backbone of the bioeconomy in Croatia. The corresponding priorities are:

- bio-based inputs to increase the competitiveness of the food and wood industry
- from field to fork approach
- bioenergy to enable decarbonisation of agri-food sector
- increased biomass production for bioeconomy.

Bioeconomy is one of the thematic priority areas in the S3 report. By targeting a number of different sectors, such as agriculture, fishery, and other economies that use renewable biological resources from land and sea, significant progress is foreseen towards increasing the size of the Croatian bioeconomy as a whole.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Biotechnology is recognized as a key development technology that plays an important role in developing, innovating and strengthening the competitiveness of industry in the Integrated National Energy and Climate Plan for the Republic of Croatia for the period from 2021 to 2030 and the Proposal of a low carbon development strategy of the republic of Croatia until 2030 with a view in 2050.Biotechnology is also addressed through two scientific centres of excellence that Croatia has in this area: Scientific Centre of Excellence for Marine Bioprospecting – BioProCro and Centre of Excellence for Biodiversity and Molecular Plant Breeding, and through related research programmes founded by the Croatian Science Foundation.

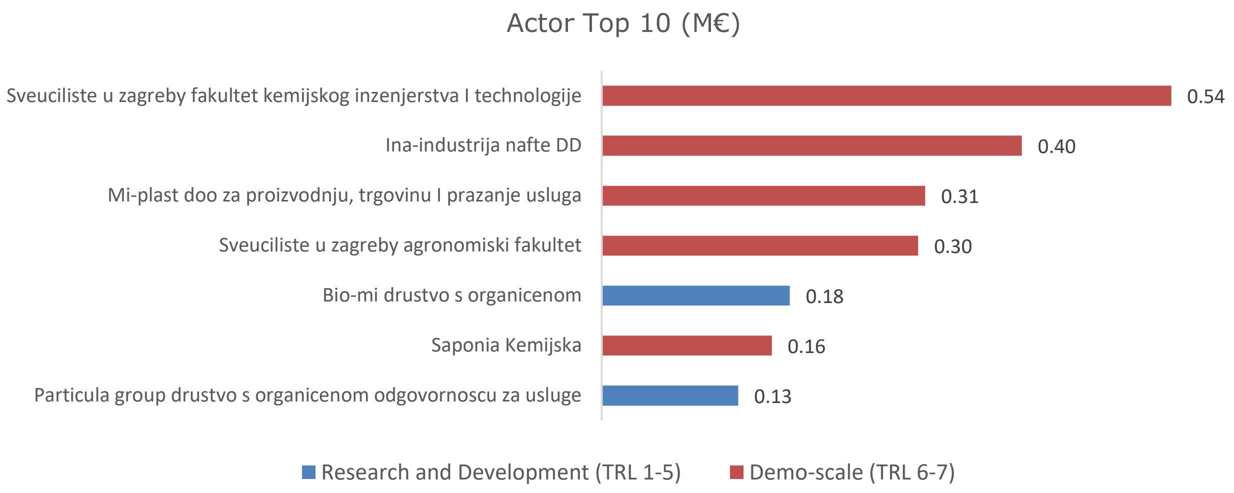
SUPPORT MEASURES

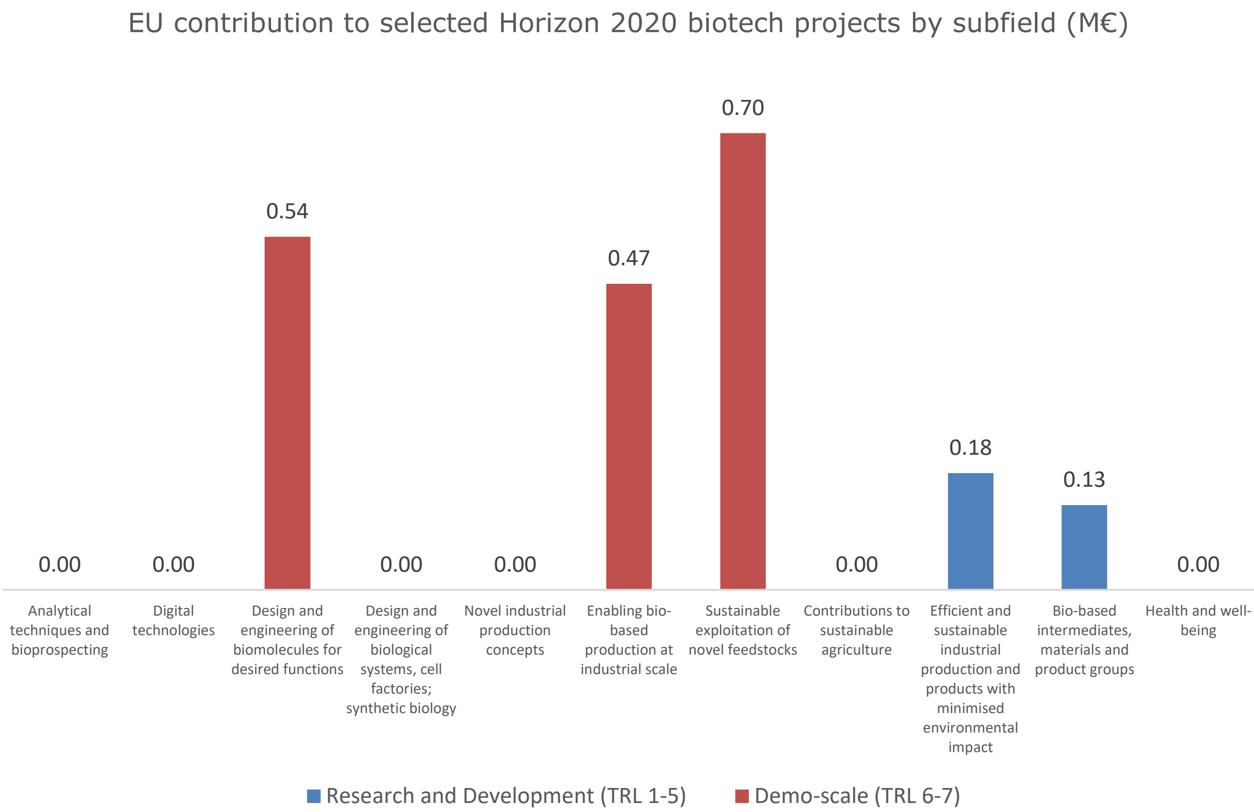
Besides on the EU level available funding opportunities, there are different platforms in place that support the development of biotechnology. The European BBI JU platform has its activities in Croatia revolving mainly around innovation and demonstration of technologies and products in areas such as bio-based food packaging and exploitation of biomass. A number of supportive financial measures for biotechnology are also defined in the S3 strategy and in the "National Development Strategy (2020 – 2030) " sustainable development and enabling technologies around it are regarded as a priority for Croatia for the next decade.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Croatia has received 2 million Euro of H2020 budget for biotech related projects, ranking 19th of all EU-27 countries plus UK, equalling 0.50 Euro/capita. Approximately 41.7% of that EU budget is allocated to universities and 58.3% to the private sector. Croatia shows a clear focus towards **sustainable exploitation of novel feedstocks** consuming 35% of the total allocated budget. More specifically, **novel feedstocks** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Cyprus

✗ BIOECONOMY STRATEGY	✗ ACTION PLAN	✓ BIOSCIENCE RELATED POLICY	✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Cyprus does not have a dedicated national bioeconomy strategy. There are several strategic documents developed in which the field is partly reflected, e.g. "Multiannual National Strategic Plan for Aquaculture 2014 - 2020" prepared in 2014 and "National Strategy on Adaption to Climate Change" in 2017 and "Draft Integrated National Energy and Climate Plan for the period 2021 - 2030" developed in 2019.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

A conclusive list of all the potential economic sectors to be targeted in bioeconomy is not available. Different reports however, reveal several themes that are vital in the development of bioeconomy. These themes address, among others:

- climate change - the goal is to develop a portfolio of regional-specific strategies for climate change mitigation, which take in account the societal challenges of the country
- blue biotechnology - to support different aspects of the blue economy

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Cyprus does not have dedicated life science and/or biotechnology strategies.

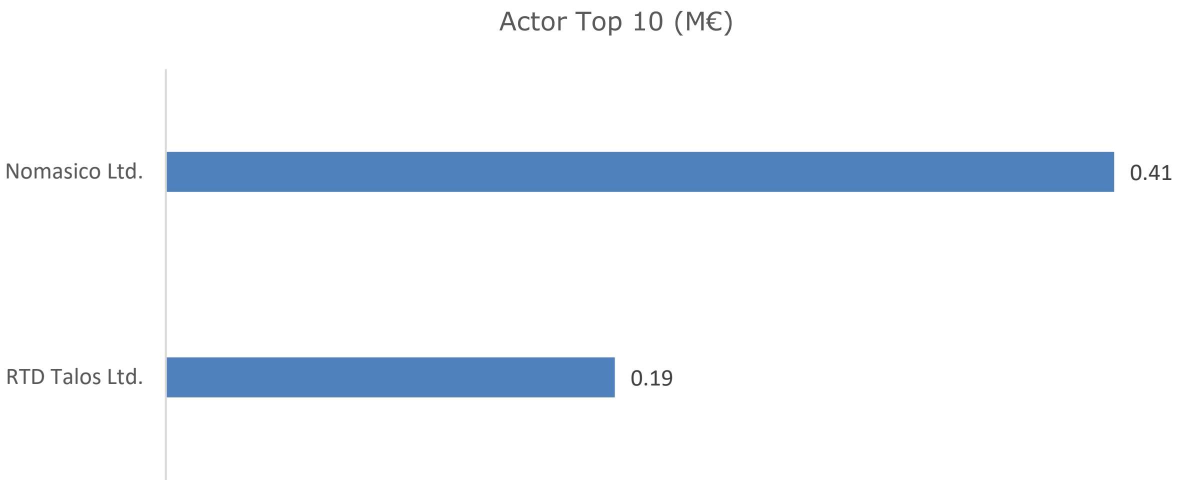
SUPPORT MEASURES

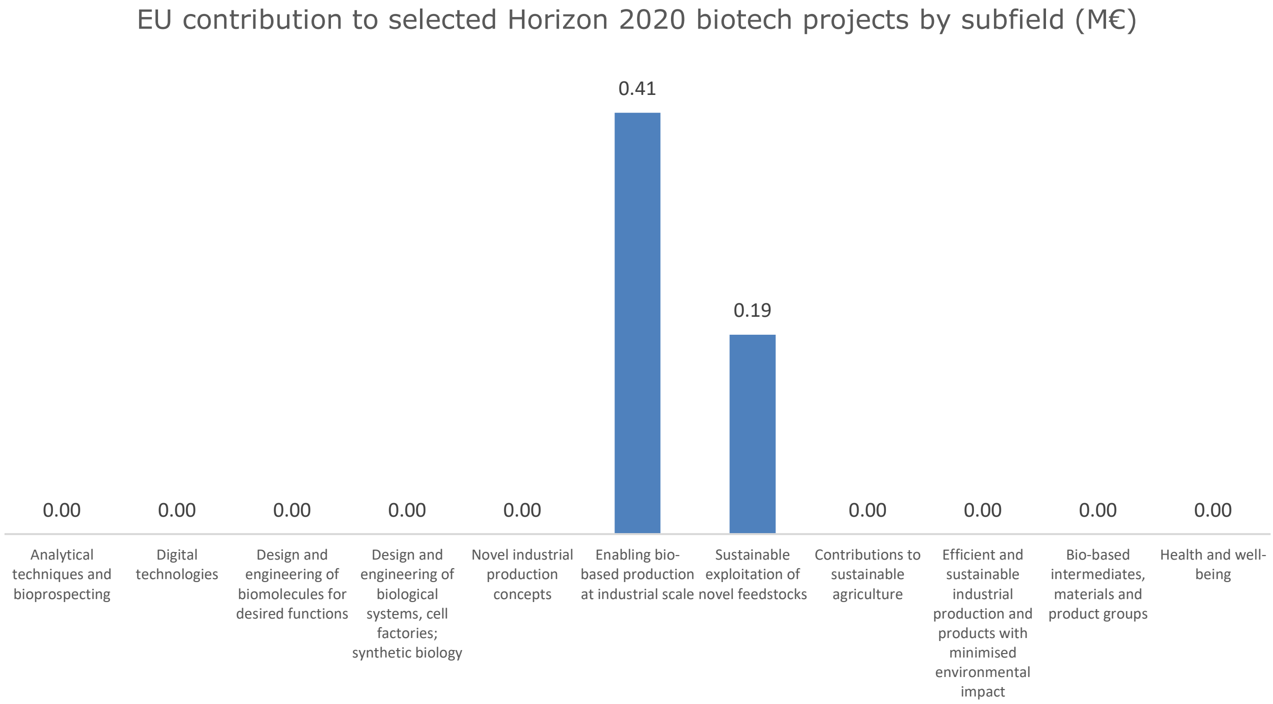
Applied research is a high priority in the R&D agenda of the country. The national strategy on R&I for 2019 - 2023 aims to bring academic research closer to the market to release its economic potential. Under the slogan "Innovative Cyprus" a range of different incentives is introduced. The Cyprus Institute was awarded EUR 15 million by H2020, equally matched by the Cyprus Government to fight climate change, amongst other themes. Also, the island's first Marine and Maritime Institute is being set up, that would act as a centre of R&D and aspires to become the driver behind Cyprus' sustainable blue growth through knowledge and innovation.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Cyprus has received 600 thousand Euro of H2020 budget for biotech related projects, ranking 23rd of all EU-27 countries plus UK, equalling 0.67 Euro/capita. 100% of that EU budget is allocated to the private sector. Cyprus took part in two projects related to **sustainable exploitation of novel feedstocks** and **enabling bio-based production at industrial scale**. More specifically, **biorefineries for new feedstock** and **using side and waste streams** are the only two top 50 bio-based innovations that have received EU budget.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Czech Republic

✗ BIOECONOMY STRATEGY	✗ ACTION PLAN	✓ BIOSCIENCE RELATED POLICY	✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The Czech Republic does not have a dedicated national bioeconomy strategy. However, there are some strategic documents wherein the field is reflected, e.g. The Ministry of Agriculture has prepared a strategic document "Concept of bioeconomy in the Czech Republic from the perspective of the Ministry of Agriculture (2019-2024)". The Czech Republic is also part of the BIOEAST initiative, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

By targeting different sectors, significant progress is foreseen towards increasing the size of the Czech bioeconomy as a whole. The key sectors, identified by the Ministry of Agriculture that are vital in the development of bioeconomy are:

- ecosystems and its services
- rural social sector
- industry and economy sector
- food industry
- innovation and research

Corresponding priorities of the targeted sectors have not been formulated. However, more general policy needs, vital for the development of bioeconomy include: 1) describing the bioeconomy concept at national level, 2) assessing the current state of it on national and EU level, 3) defining policy measures, platforms and initiatives to achieve target goals and 4) leverage on the national and EU policies for sustainable bioeconomy.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

In the Czech Republic Biotechnologies represents knowledge domain of National Research and Innovation Strategy for Smart Specialisation (RIS3; knowledge domains are defined in accordance with the definition of Key Enabling Technologies). Research and development and innovation priorities in RIS3 were identified through the EDP within National Innovation Platforms. Biotechnologies are involved in the National Innovation Platform IV "Medicinal Products, Biotechnologies, Medical Devices and Life Sciences".

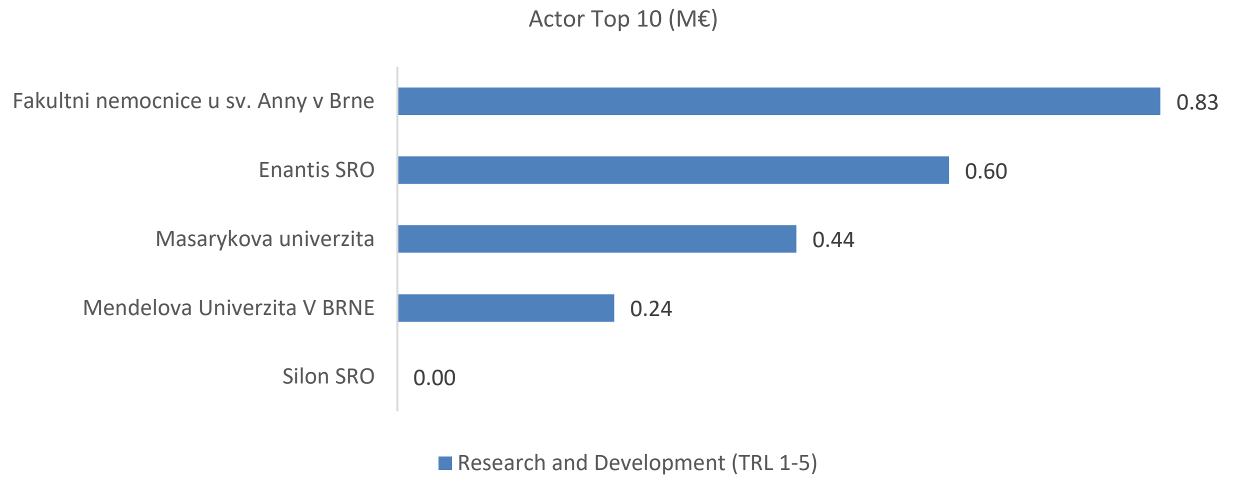
SUPPORT MEASURES

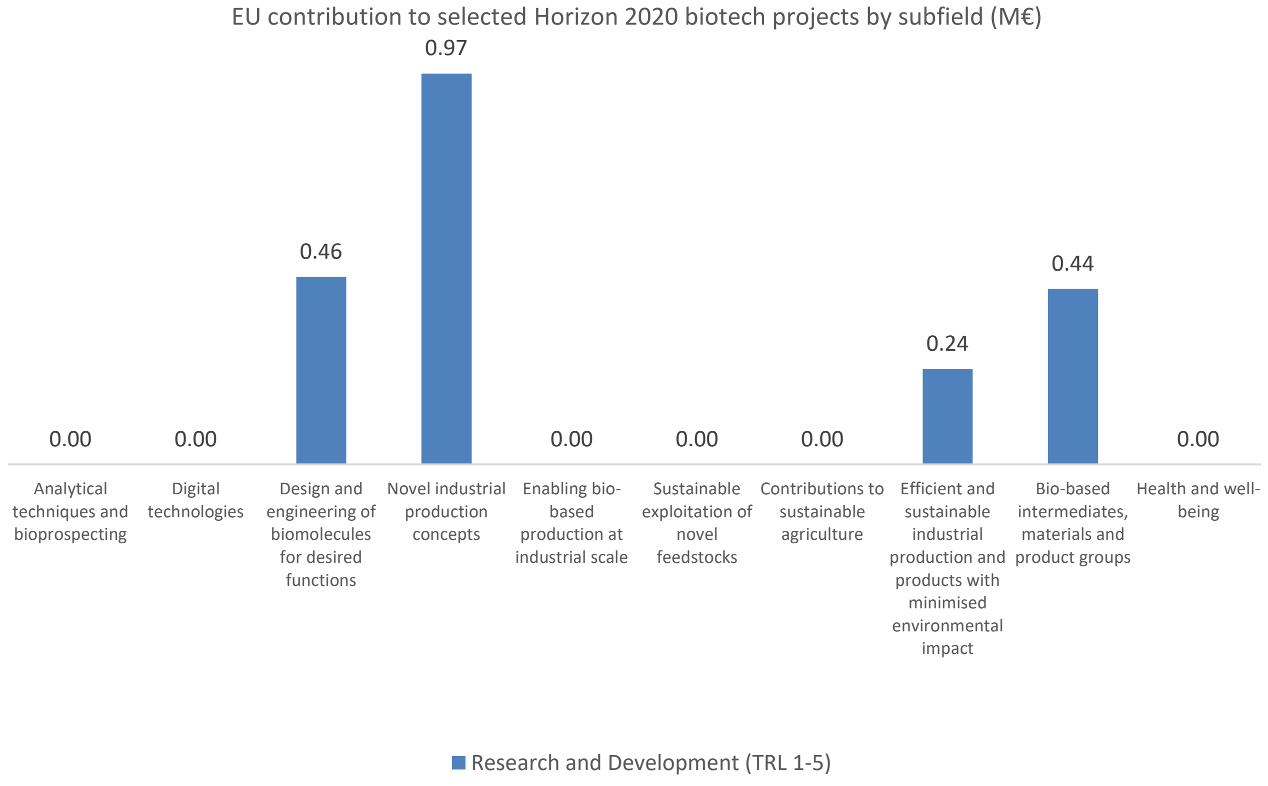
Besides EU and national level available research funds, other support measures exist. For example, the Technology Centre of Czech Academy of Sciences and Czech Biofuels Technology Platform support national stakeholders with relevant information. Furthermore, the National Research and Innovation Strategy for Smart Specialization (RIS3) represents a strategic document providing efficiently focused support to research, development and different innovations areas. As a main activity, it provides in total up to 247.98 bn. CZK funding to the identified key sectors and their corresponding technology areas, including biotechnology.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Czechia has received 2.1 million Euro of H2020 budget for biotech related projects, ranking 18th of all EU-27 countries plus UK, equalling 0.20 Euro/capita. Approximately 71.4% of that EU budget is allocated to universities and 28.6% to the private sector. Czechia shows a clear focus towards novel industrial production concepts consuming 46% of the total allocated budget. More specifically, novel microbial cell factories have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Denmark

X BIOECONOMY STRATEGY | X ACTION PLAN | ✓ BIOSCIENCE RELATED POLICY | ✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Denmark does not have a dedicated national bioeconomy strategy. There are, however, a number of other policy initiatives in place, involving bioeconomy, such as the "Growth Plan for Foods" and the "Growth Plan for Water, Bio and Environmental Solutions" (2013). Furthermore, there are strategical reports for all the industrial sectors, highlighting the importance of sustainable economy. Also, a National Bioeconomy Panel has been set up, involving representatives from all the relevant stakeholder groups to support the government in the transition process towards bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The targeted economic sectors are not defined, as there is no dedicated bioeconomy strategy developed yet. However, the National Bioeconomy Panel refers to bioeconomy as an economy "in which building blocks used for the production of energy, chemicals and materials originate from renewable biological resources, including plants and animals". The "Growth Plan for Water, Bio and Environmental Solutions" defines bioeconomy as a priority area under the action field of bio-based solutions. The further priorities include industrial biotechnology, agricultural sector concerning the production of biomass and biofuels. The "Growth Plan for Foods" focuses on sustainable and resource efficient food production. The document highlights the importance of sustainable use of marine resources. Priority is on R&D and innovative technologies in producing energy, pharmaceuticals and cosmetics from the by-catches.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Denmark has a dedicated life sciences/biotechnology strategy, called "Life Sciences Growth Plan" (2018). Furthermore, in the RESEARCH2025 (2018) catalogue, it is highlighted that life sciences have a key importance in solving a series of global challenges, related to, among other issues, climate change and the environment.

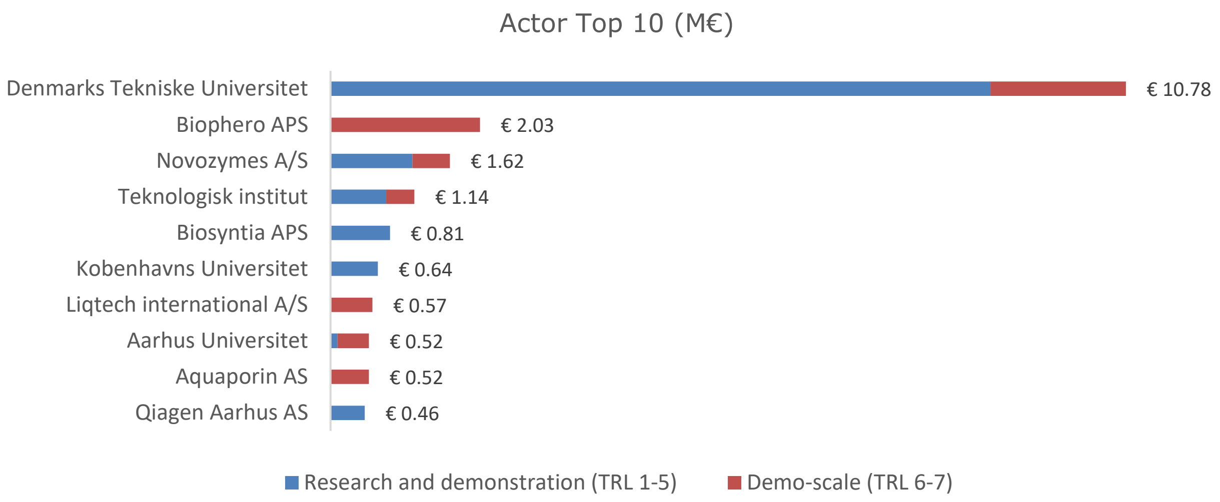
SUPPORT MEASURES

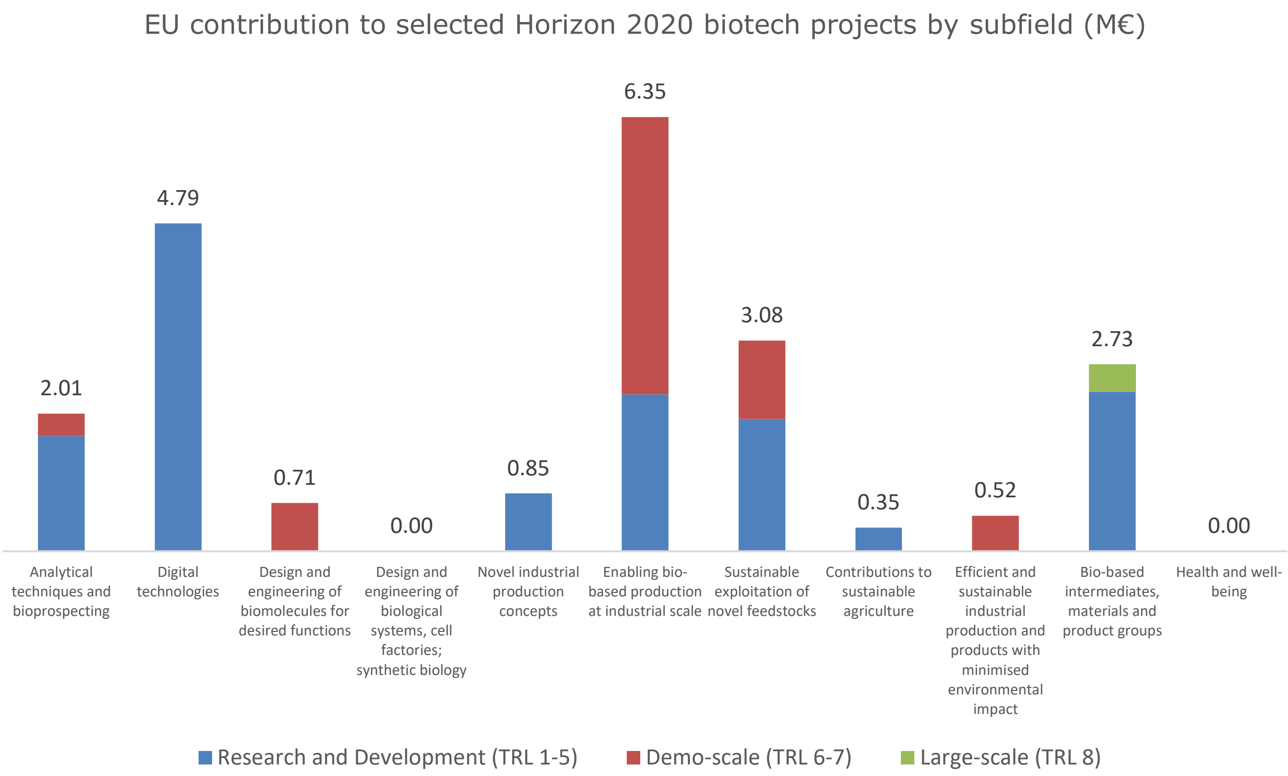
Biotechnology and life sciences have a leading role as enabling technologies behind bioeconomy in Denmark. As a research support measure, in Aarhus University a Centre of Circular Bioeconomy was established in 2017. In 2018 the Danish Government allocated almost DKK 1 billion for different research themes, including "green growth" and "bioresources". In the same year, the "New Life Sciences Growth Plan" was aimed at making Denmark one of the Europe's leading life science nations, by launching 36 specific initiatives for the industry across the entire value chain.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Denmark has received 21.4 million Euro of H2020 budget for biotech related projects, ranking 9th of all EU-27 countries plus UK, equalling 3.67 Euro/capita. Approximately 57.6% of that EU budget is allocated to universities, 5.5% to research institutes, and 36.9% to the private sector. Denmark shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 30% of the total allocated budget. More specifically, **computational cell factory engineering** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Estonia

✗ BIOECONOMY STRATEGY | ✗ ACTION PLAN | ✓ BIOSCIENCE RELATED POLICY | ✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

For bioeconomy, a specific strategy is missing in Estonia at the moment. However, there are several strategic documents underway in which the field will be reflected, e.g. "Agricultural and Fisheries Development Plan 2030" or the Strategy "Estonia 2035+ Agenda". A "National Roadmap for Circular Economy" is currently under development. Estonia is also part the BIOEAST initiative, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The government demonstrates continuous support for bioeconomy throughout different strategic documents. The main cross-sectoral strategic goals of bioeconomy are defined as follows:

- a sustainable, innovative and resource-efficient bioeconomy, including transition to bioresources by saving energy and reducing GHG emissions:
- replacing fossil fuels with renewable biomass fuels
- bio-waste circulation (e.g. biogas production)
- increased uptake of biocompatible and biodegradable products (e.g. bio-based plastics)
- biotechnological innovation in healthcare (drug development, molecular diagnostics)
- bioinformatics and big data management

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Estonia does not have a dedicated life science and/or biotechnology strategy. Yet, on the basis of the analysis conducted by the Estonian Development Fund in 2013 "Smart specialisation - qualitative analysis", biotechnology is one of the key growth areas in Estonia. Biotechnology is addressed in a number of other policy documents: the general national RDI strategy 2014-2020 "Knowledge-based Estonia" mentions among others health technologies & biotechnology as a key specialisation area for Estonia. "The Estonian Strategy for Research, development and innovation in the health system 2015-2020" also tackles innovation in the medical field and biotechnology.

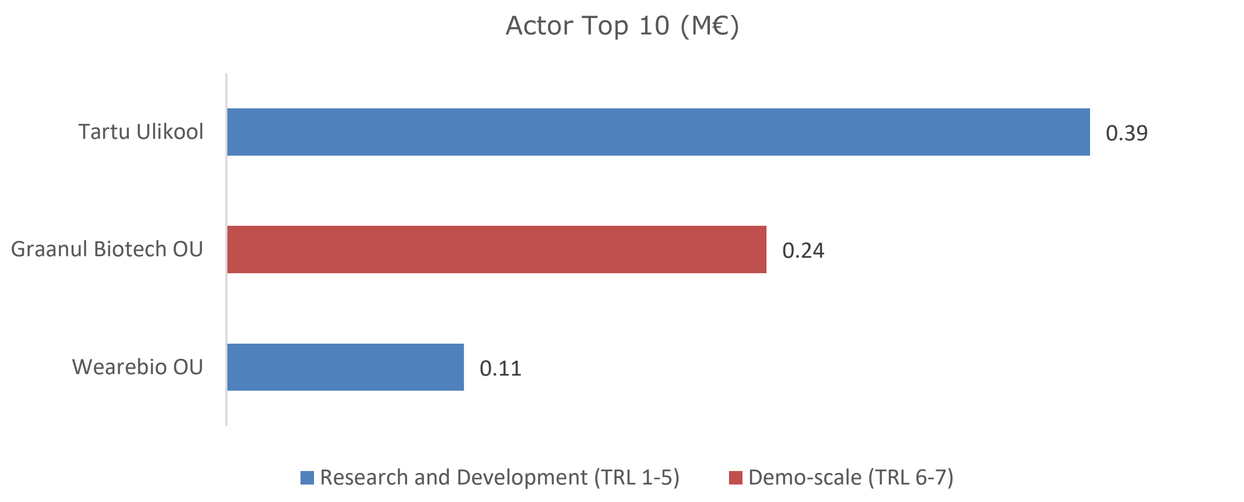
SUPPORT MEASURES

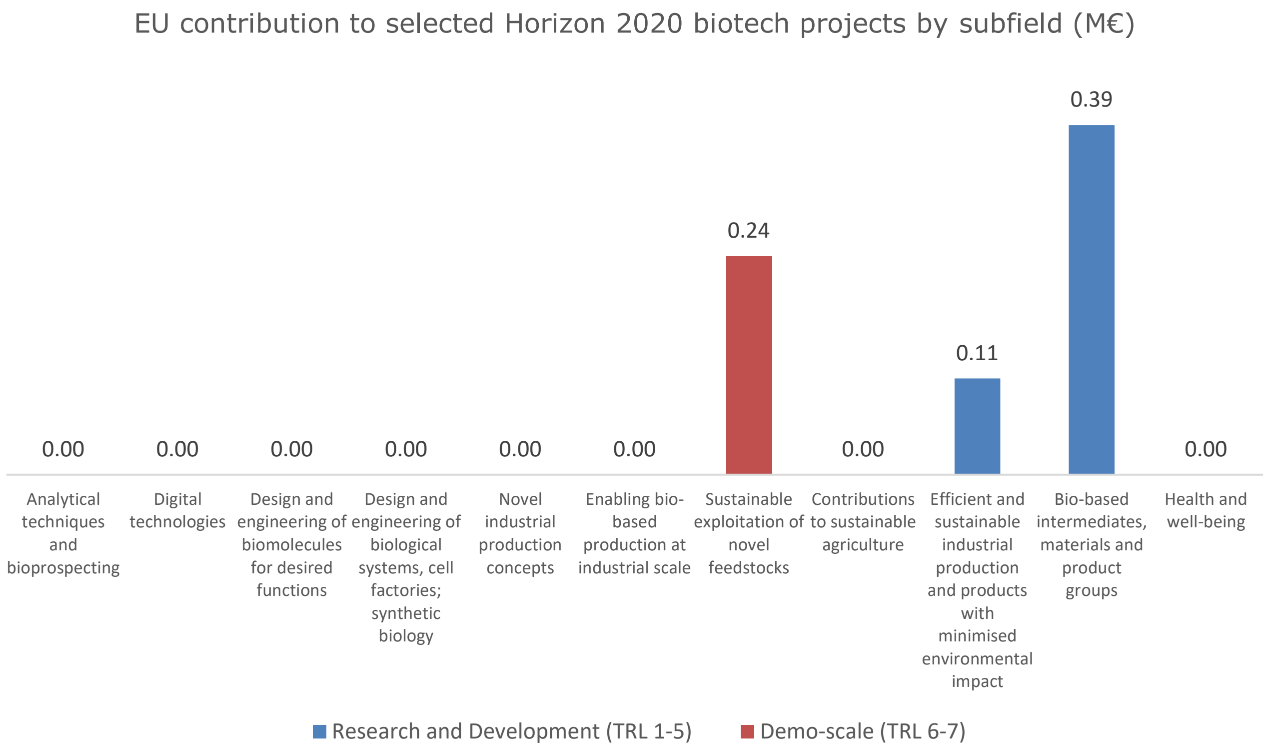
Next to the EU level available funding instruments, several public funding bodies on national level exist : Estonian Research Council, Enterprise Estonia, Environmental Investment Centre, Ministry of Rural Affairs and Estonian Agricultural Registres and Information Board, offering several instruments for both/either academia and private sector through which biotechnology and bioeconomy projects can be funded among others. The public financing of R&D in Estonia was increased by 2015 to 1% of GDP. Although in the intervening years the financing did not reached 1%, it will be reached again in 2021. In addition, the resources of the EU Structural Funds are being used as a support mechanism for R&D.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Estonia has received 741 thousand Euro of H2020 budget for biotech related projects, ranking 21st of all EU-27 countries plus UK, equalling 0.56 Euro/capita. Approximately 52.6% of that EU budget is allocated to universities and 47.4% to the private sector. Estonia shows a clear focus towards **bio-based intermediates, materials and product groups**, consuming 53% of the total allocated budget. More specifically, **bio-based materials** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Finland

BIOECONOMY STRATEGY	ACTION PLAN	BIOSCIENCE RELATED POLICY	NATIONAL SUPPORT MEASURES
✓	✓	✓	✓

BIOECONOMY STRATEGY

The Finnish Bioeconomy Strategy of 2018 is designed to generate economic growth and new jobs in Finland from an increase of the bioeconomy sector. The leading idea of the Strategy is that competitive and sustainable bioeconomy solutions for global problems will be created in Finland, and that new businesses will be generated both in the Finnish and international market, thus boosting the welfare of the whole of Finland.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The bioeconomy in Finland is distinct because of the dominance of the forest sector. However, also other typical bioeconomy sectors are included in the Strategy, such as wood processing, chemistry, renewable energy, construction, technology and food & agriculture, chemicals and pharmaceuticals. The strategy does not explicitly mention any sector specific targets. It does, however, reveal several cross-sectoral themes that are vital in the development of bioeconomy in Finland:

- establishing a competitive operating environment for bioeconomy
- supporting new businesses in bioeconomy
- establishing a strong bioeconomy competence base
- ensuring accessibility and sustainability of biomass.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

No dedicated life-science/biotechnology strategies exist in Finland. The Bioeconomy Strategy acknowledges that Finland is known for high-quality, world-class biotechnology competence, especially industrial biotechnology and its applications (i.e. food, energy, enzyme, mining, pharmaceutical, forest and brewery industries). Furthermore, in the same Strategy, biotechnology is listed as a key enabling technology for growth in the health sector.

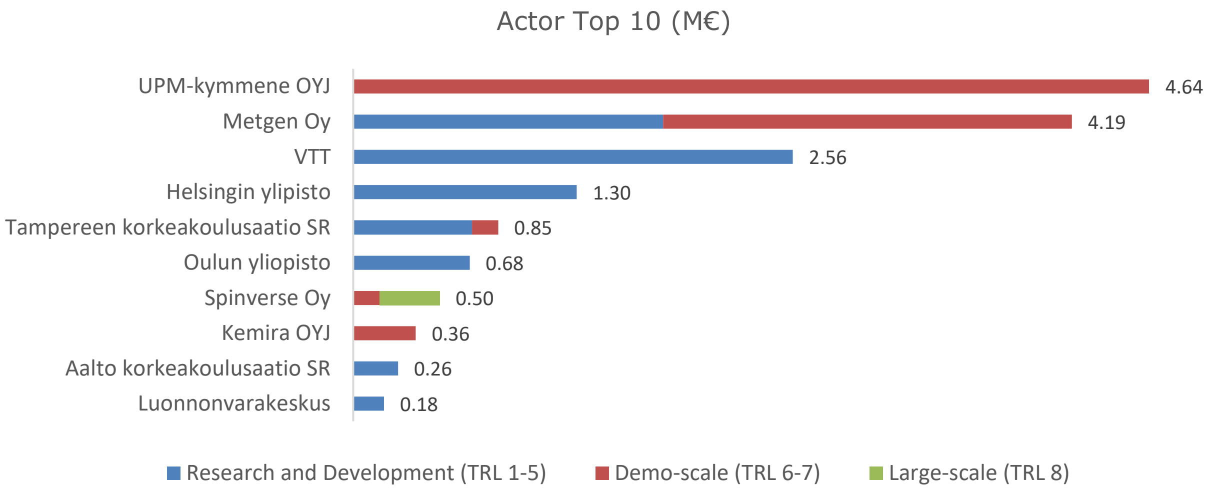
SUPPORT MEASURES

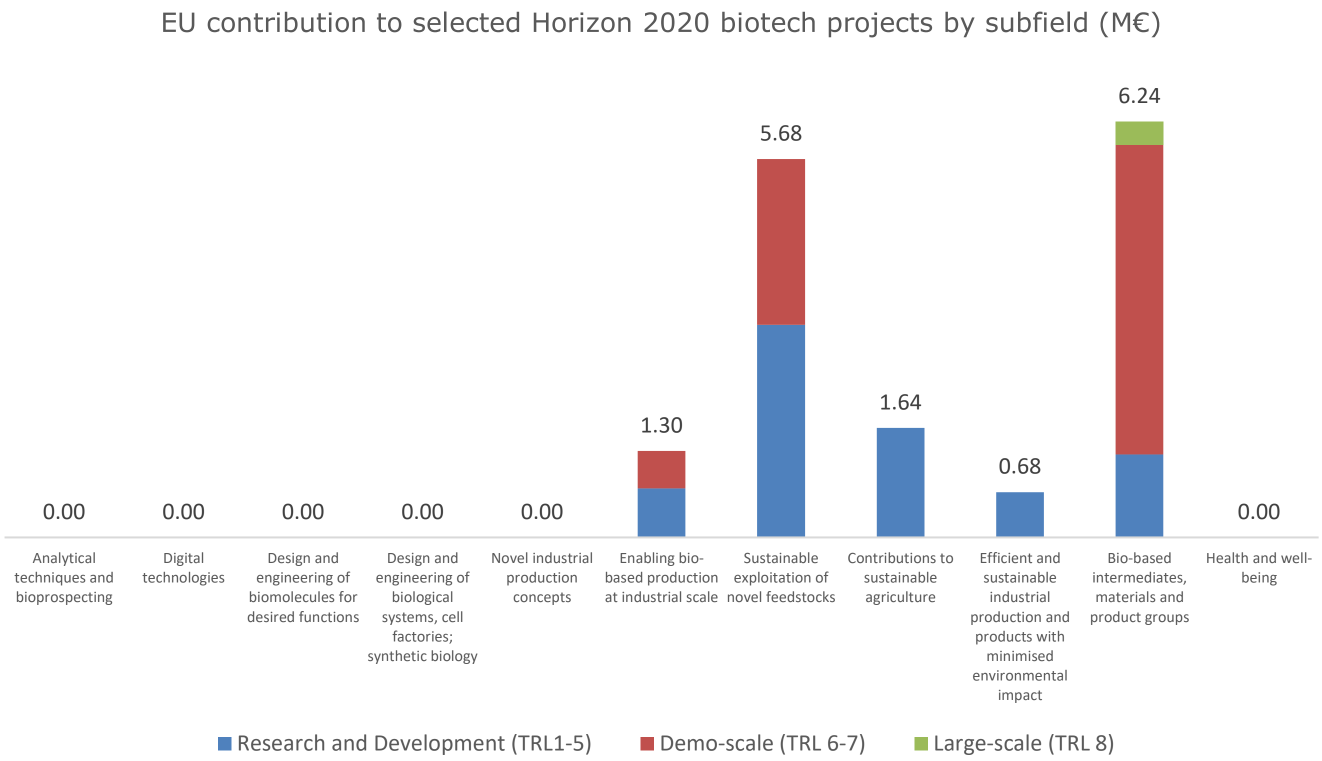
There are more than 100 ongoing programmes and strategies in Finland with a direct link to bioeconomy. The "Finnish Bioeconomy Strategy" sets out a detailed list of actions and measures which include among others implementation of the health sector growth strategy, development of steering methods to support innovative bioeconomy solutions, providing incentives and promoting standards for bioeconomy products uptake, ensuring adequate and flexible funding opportunities, promoting R&D & cooperation across different sectors. Between 2014 and 2024 an estimated EUR 2.1 billion of funding will be needed to reach the objectives for the Strategy. It is distributed between risk funding (1.0 billion), R&D funding (0.5 billion) and supporting piloting and demonstration projects (0.6 billion).

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Finland has received 15.5 million Euro of H2020 budget for biotech related projects, ranking 12th of all EU-27 countries plus UK, equalling 2.81 Euro/capita. Approximately 15.4% of that EU budget is allocated to universities, 17.7% to research institutes, and 66.9% to the private sector. Finland shows a clear focus towards **bio-based intermediates, materials and product groups** and **sustainable exploitation of novel feedstocks**, consuming 76% of the total allocated budget. More specifically, **bio-based chemicals** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





France

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The Bioeconomy Strategy for France was developed in 2017 to support innovation in developing new products and solutions in bioeconomy and strengthen sustainability of the global system. The Strategy was followed by a detailed action plan in 2018 ("A bio-economy for France 2018 - 2020 Action Plan").

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The Strategy is including on all the key bioeconomy sectors: agriculture, forestry, processing in the food and wood industries, energy production from biomass, production of materials and molecules and bio-waste conversion. The corresponding priorities have not been defined in the Strategy, rather the focus is on six cross-sectoral themes:

- making bioeconomy products a market reality
- transition towards innovative and effective bio-based industry
- sustainable production of the necessary bioresources
- sustainability of bioeconomy
- societal awareness of bioeconomy
- supporting the transition towards innovative and high-performance bioeconomy.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

The Strategy acknowledges that research and innovation are essential to the development of the bioeconomy. A number of the applications envisaged in the bioeconomy are innovative and require additional R&D with a support of biotechnology, examples include agri-food sector, marine, bio-based products, materials, bio-waste conversion and innovative molecules production in forestry & wood sector.

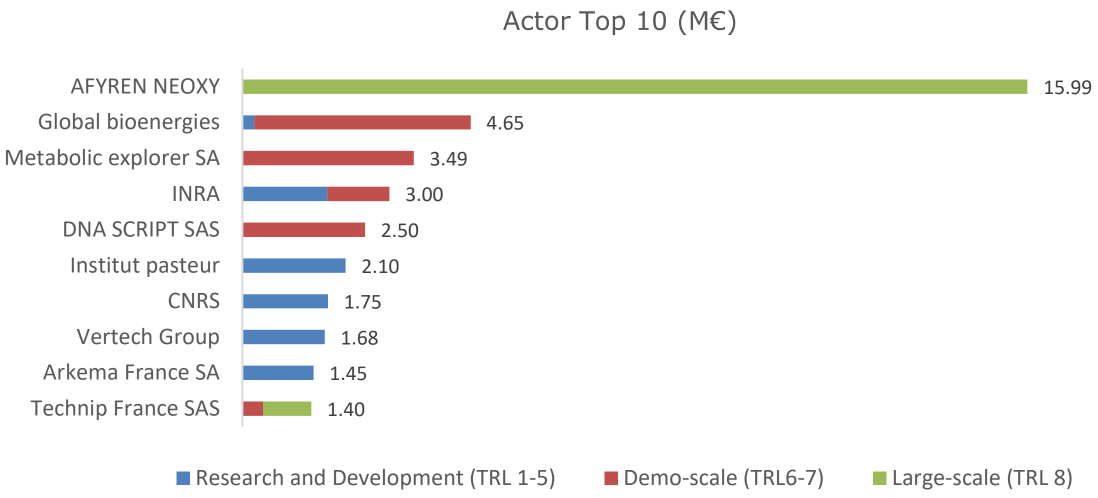
SUPPORT MEASURES

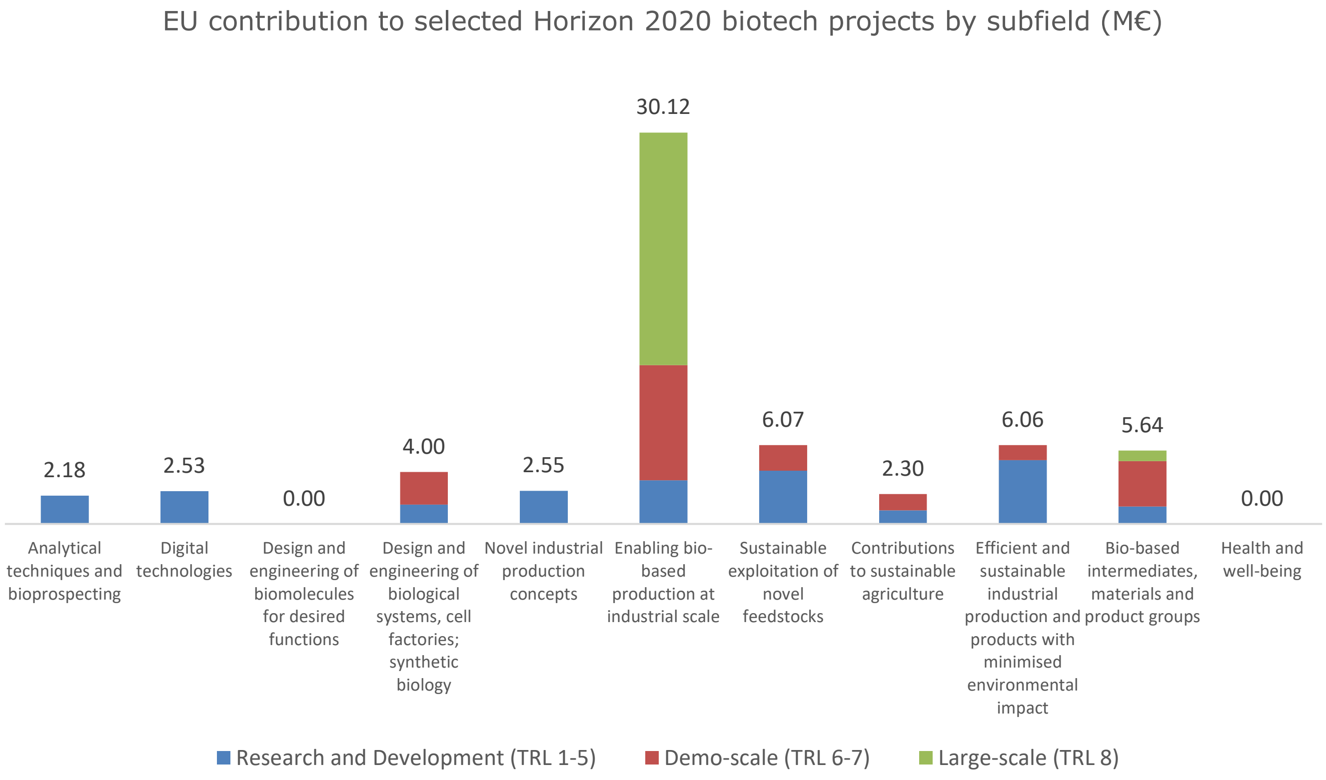
Next to the EU level available support measures, there are a number of support mechanisms in place on national level in France. The French National Research Agency (ANR) provides funding through calls for proposal in all scientific areas, including biotechnology. ADEME provides research funding in specific thematic areas, including energy, circular economy and waste management. The programme Investment for the Future (PIA) has led since 2010 to allocation of EUR 250 million in support of different bioeconomy projects. France also has a scheme for private sector, called Crédit Impôt Recherche (CIR), which offers credit on research expenditure for companies. The Energy Transition for Green Growth Act (2015) has prioritized bio-based products, especially for construction and public procurement.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

France has received 61.4 million Euro of H2020 budget for biotech related projects, ranking 5th of all EU-27 countries plus UK, equalling 0.92 Euro/capita. Approximately 7.1% of that EU budget is allocated to universities, 18% to research institutes, and 74.4% to the private sector. France shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 49% of the total allocated budget. More specifically, **biorefineries for new feedstocks** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Germany

✓ BIOECONOMY STRATEGY | ✓ ACTION PLAN | ✓ BIOSCIENCE RELATED POLICY | ✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The National Bioeconomy Strategy has been launched in January 2020. It succeeds and builds on the earlier National Research Strategy BioEconomy 2030 and the National Policy Strategy on Bioeconomy to pool the various political strands together into a coherent framework. The objective of the strategy is to combine economy and ecology to ensure a more sustainable use of resources. It encompasses a wide set of strategic goals ranging from enhancing and applying biological knowledge, to develop solutions for the UN Sustainable Development goals, but also to Involve society in the bioeconomy and strengthen national and international collaboration.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The strategy does not focus on certain sectors but stresses out the need to generate biogenic resources sustainably (Agri-food), but also to enhance and apply biological knowledge. Regarding the later, it is clear that a wide range of potential sectors is in the focus, except bioenergy and biofuels, which are included in the context of biorefineries. To foster biological knowledge, several building blocks for funding biotechnology are of crucial importance:

- Understand and model biological systems
- Develop novel production organisms for agricultural systems and industry
- Develop and establish innovative process engineering concepts for bio-based production systems
- Use converging technologies such as digitisation, artificial intelligence, nanotechnology, miniaturisation, robotics, and automation for the bioeconomy
- Strengthen interdisciplinary collaboration
- Expand the infrastructure available for research and technology transfer.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

The National Research Strategy Bioeconomy 2030 has explicitly succeeded the biotechnology funding programme in 2010 and now in 2020 it has been followed by the National Bioeconomy Strategy. Hence, the strategy contains most of the relevant federal funding programmes related to non-medial biology and life sciences and comprises the topics mentioned above.

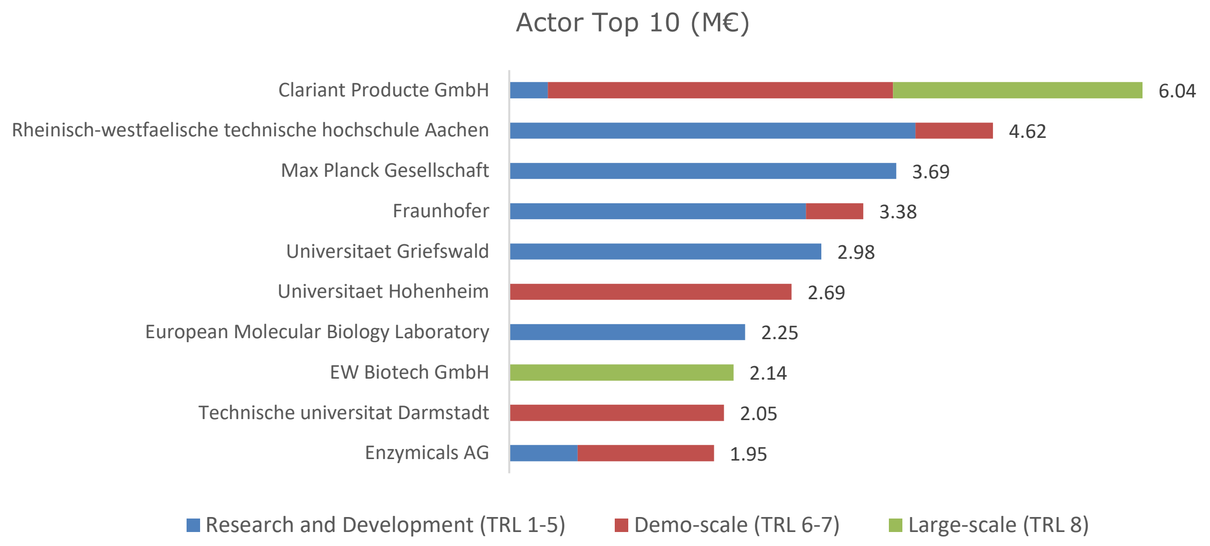
SUPPORT MEASURES

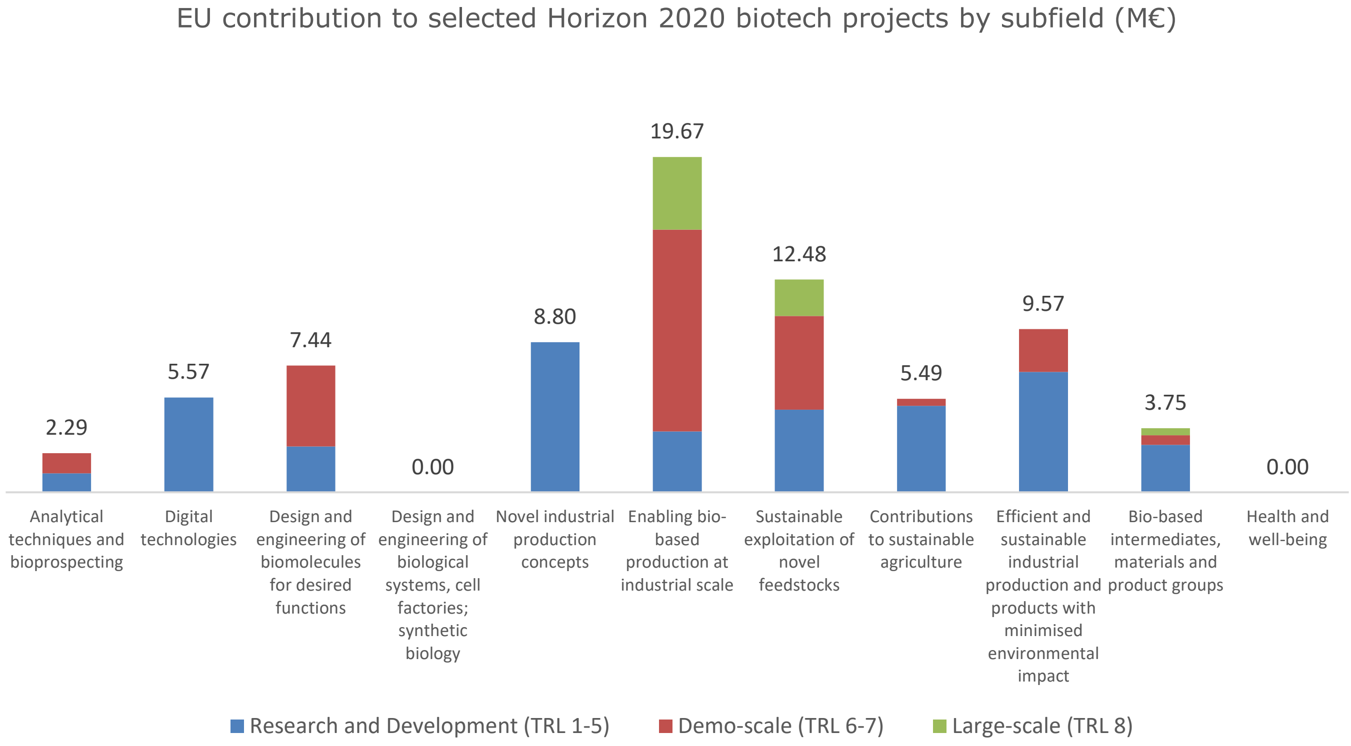
The National Bioeconomy Strategy aims to extend the current instruments for promotion of research and development, international cooperation, support of start-ups and small and medium-sized enterprises etc. by acceleration the launch of bioeconomy products, processes and services on the market via standardization, dialogue formats and public procurement. Regarding R&D support, the National Research Bioeconomy Strategy already comprised more than 40 funding programs for the bioeconomy between 2010-2019 with an annual budget of 280 M€ for 2019. Most current R&D funding programs comprise "Future technologies of the industrial bioeconomy" or larger cluster projects in "Innovation areas for the bioeconomy" covering marine bioeconomy or use of waste streams. Moreover, there are proposal publications at the interface between material and biological science ("bio-hybrid technologies, "biologisation of technology"). Next to national funding, some federal regions ("Bundesländer") have bioeconomy strategies (e.g. Baden-Württemberg) and/or provide significant funding in form of R&D programs, funding demonstration plants or regional activities (e.g. model regions "BioökonomieREVIER Rheinland" or "Bioeconomy Hub" in Central Germany).

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Germany has received 75 million Euro of H2020 budget for biotech related projects, ranking 1st of all EU-27 countries plus UK, equalling 0.90 Euro/capita. Approximately 32.1% of that EU budget is allocated to universities, 24.2% to research institutes, and 40.9% to the private sector. Germany shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 26% of the total allocated budget. More specifically, **optimising biorefineries and production facilities** have received the largest share of the top 50 innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Greece

BIOECONOMY STRATEGY	ACTION PLAN	BIOSCIENCE RELATED POLICY	NATIONAL SUPPORT MEASURES
✗	✗	✗	✓

BIOECONOMY STRATEGY

Greece does not have a dedicated national bioeconomy strategy. The Greek government, however, recognises the importance of the challenges put by the EU and there are several strategic documents wherein the field is reflected, e.g. the "1st National Strategy for the Circular Economy" (2018), the "Strategic plan for the development of research, technology and innovation under the National Strategic Reference Framework 2007 - 2013" that facilitates the transition to a knowledge-based bioeconomy. Furthermore, a Bioeconomy Forum has been established of experts from different disciplines to spread the idea of bioeconomy across Greece and contribute to accelerating the transition to a sustainable and more resource-efficient bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The largest bioeconomy related sectors in Greece are agriculture, forestry, marine, food, bio-based textiles, wood and paper products. By targeting these sectors, significant progress is foreseen towards increasing the size of the Greek bioeconomy as a whole. The government demonstrates continuous support for bioeconomy and there are several themes that are considered vital in the development of bioeconomy in Greece, such as more efficient waste management and recycling, increasing biomass exploitation and lower dependency of fossil based resources for energy, fuels and materials production.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

There is no dedicated strategy in Greece on life sciences and biotechnology. However, Green Growth Strategic Action Programme (2010-2015) presents some opportunities for industrial biotechnology, including solutions for waste management and waste re-use.

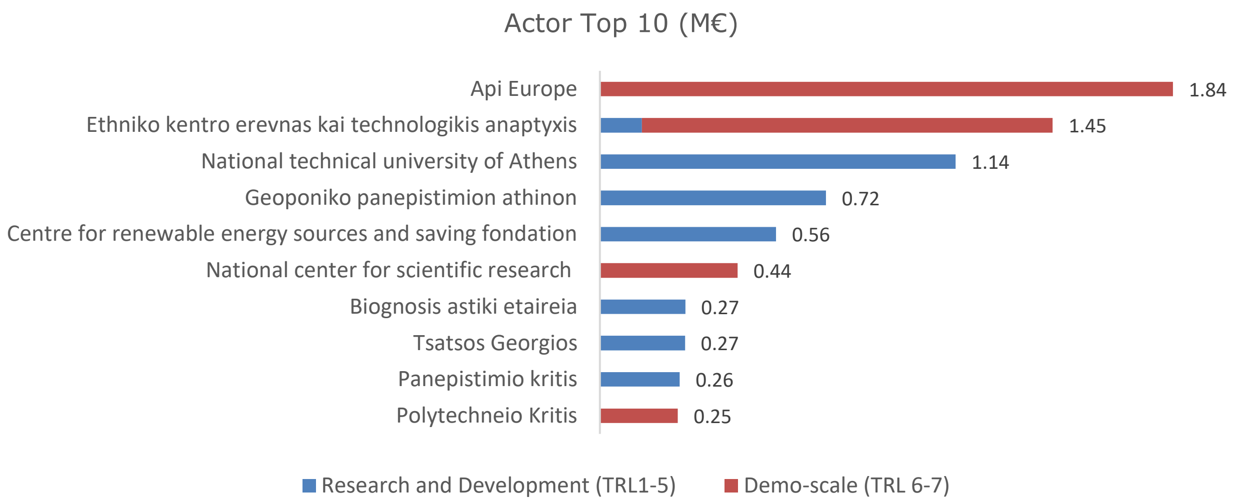
SUPPORT MEASURES

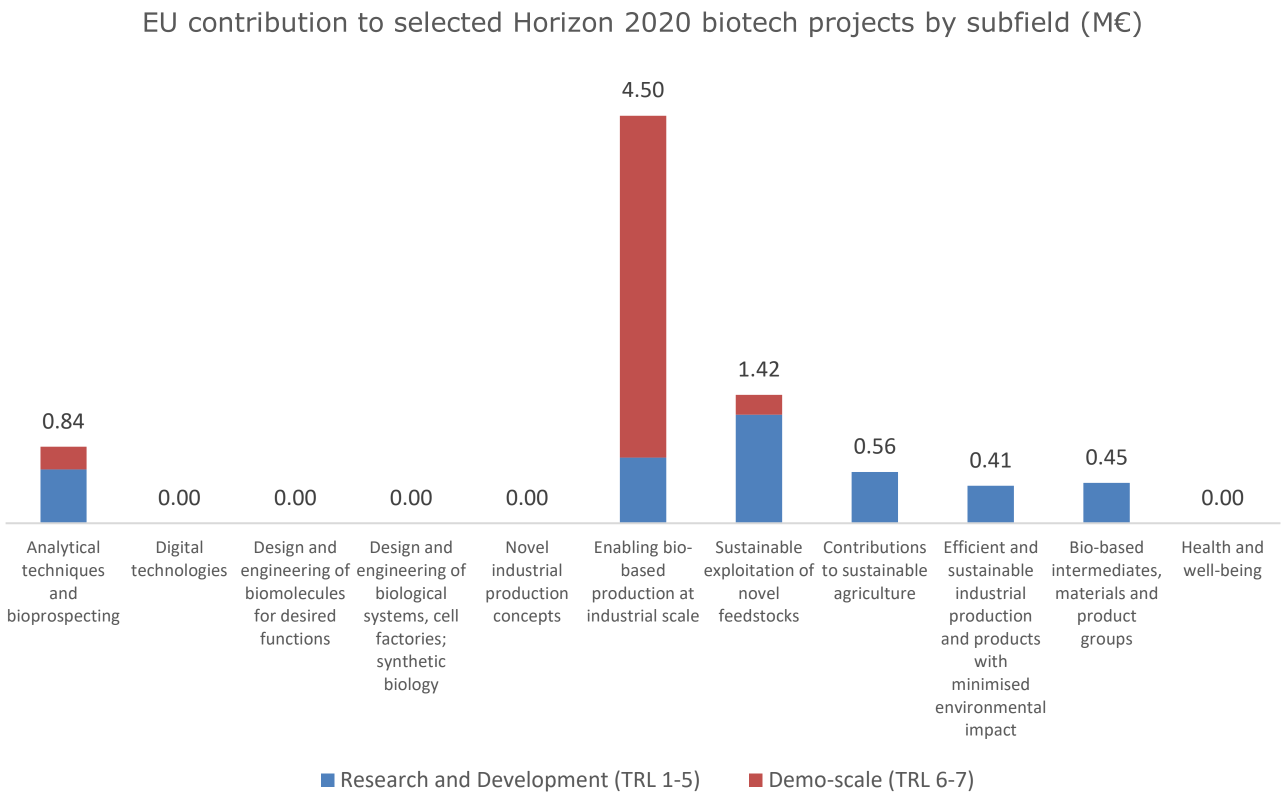
Next to the EU level research funding, bioeconomy is supported indirectly through national funding programmes on research and technology: cooperation in R&D between Greece and Germany, with a specific focus on bioeconomy and biotechnology, budget 9 million euros. Also, cooperation programme with Israel, with focus areas on agri-food, environment and energy. The "Green Growth Strategic Action Programme (2010 - 2015) enabled industrial biotechnology centres to move towards greener solutions and granted easier access to financing.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Greece has received 8.2 million Euro of H2020 budget for biotech related projects, ranking 15th of all EU-27 countries plus UK, equalling 0.76 Euro/capita. Approximately 30% of that EU budget is allocated to universities, 34.6% to research institutes, and 35.4% to the private sector. Greece shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 55% of the total allocated budget. More specifically, **optimising biorefineries and production facilities** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Hungary

✗ BIOECONOMY STRATEGY	✗ ACTION PLAN	✗ BIOSCIENCE RELATED POLICY	✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Hungary does not have a dedicated national bioeconomy strategy. However, there are several strategic documents wherein the field is partly reflected, e.g. a National Smart Specialisation Strategy (2014). and National Research and Development and Innovation Strategy (2020). Hungary is also part the BIOEAST initiative, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

By targeting a number of different sectors, such as agriculture, food, bio-based chemicals, paper, wood products, forestry, significant progress is foreseen towards increasing the size of the Hungarian bioeconomy as a whole. Sector specific priorities are not available.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Hungary does not have life science and/or biotechnology related strategies. However, biotechnology is considered a key technology area in the "National Smart Specialisation Strategy" (2014).

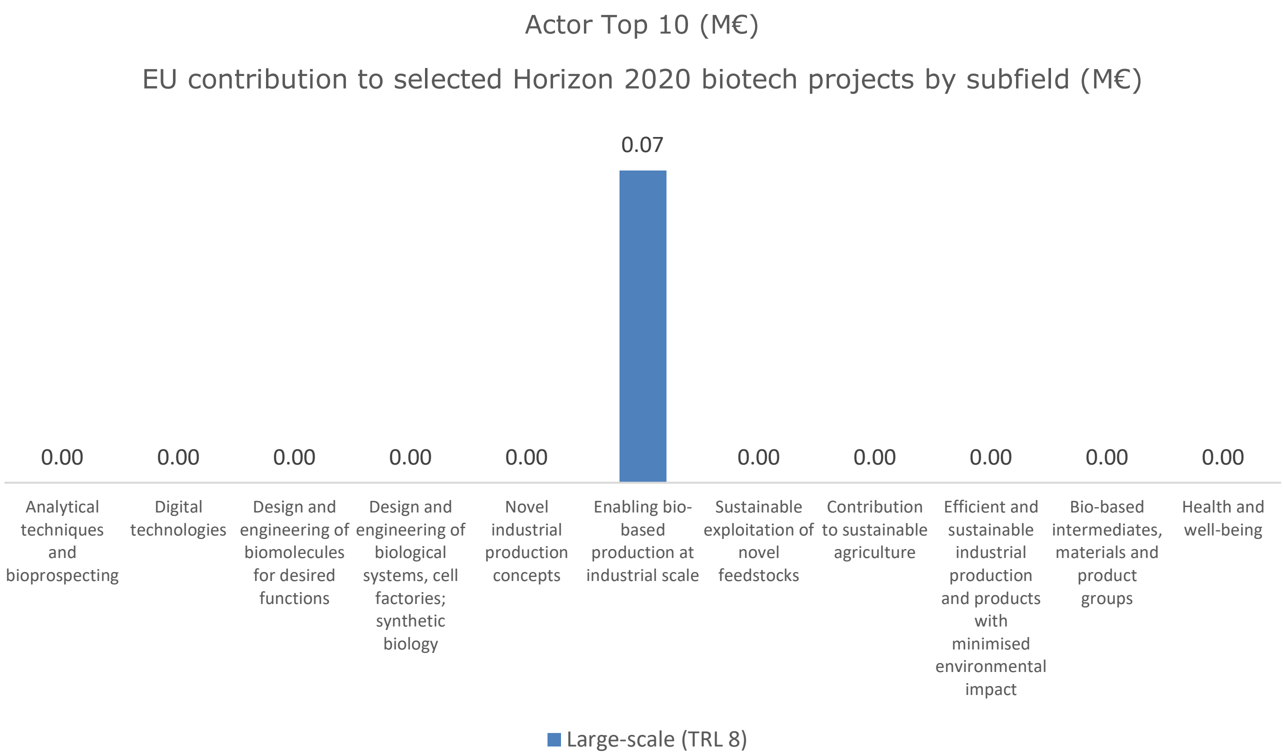
SUPPORT MEASURES

In 2019 a Bioeconomy Cluster was established to facilitate the development and long-term maintenance of Hungary’s bioeconomy. Additionally, there are policies in place which cover different aspects of bioeconomy and improve sustainable development and innovation R&D, such as a National Research and Development and Innovation Strategy 2020. Financing of R&D is covered from different sources, such as National Research, Development, and Innovation Fund, Hungarian Scientific Research Fund, Environmental and Operational Programmes (2014-2020).

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Hungary has received 70 thousand Euro of H2020 budget for biotech related projects, ranking 27th of all EU-27 countries plus UK, equalling 0.01 Euro/capita. 100% of that EU budget is allocated to the private sector. Hungary took part in one project related to **enabling bio-based production at industrial scale**. More specifically, **optimizing biorefineries and production facilities** is the only top 50 bio-based innovation that have received EU budget.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS



Ireland

✓ BIOECONOMY STRATEGY	✓ ACTION PLAN	✓ BIOSCIENCE RELATED POLICY	✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The strategy (Bioeconomy - National Policy Statement) was published in 2018 as a further step towards developing the bioeconomy in Ireland. It aims to expand the bioeconomy by addressing the following key challenges: coherence between different sectors of the bioeconomy, development of innovative bio-based products and their market creation, increased funding opportunities (public/private) on the EU and national level.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

Main targeted sectors are:

- agri-food sector
- marine-based industries
- pharma & biotechnology

The Strategy does not explicitly mention sector specific goals, it does however reveal four themes that are vital for the development of bioeconomy in Ireland:

- sustainable economy and society: to place the economy on a more sustainable footing
- decarbonisation of the economy: innovative practices to increase the efficiency of agriculture and forestry production systems
- jobs & competitiveness: majority of inputs in bioeconomy are sourced nationally to secure jobs in agri-food and marine sector
- regional prosperity - supporting the bioeconomy will slow down rural decline

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Biotechnology is one of the key areas in the Strategy for Ireland. It is expected to enable the change towards sustainability in the productivity of crops, animals and microbes through the application of biotechnology. Furthermore, biotechnology is also expected to wider socio-economic dimensions, such as economic growth, employment and a sustainable society.

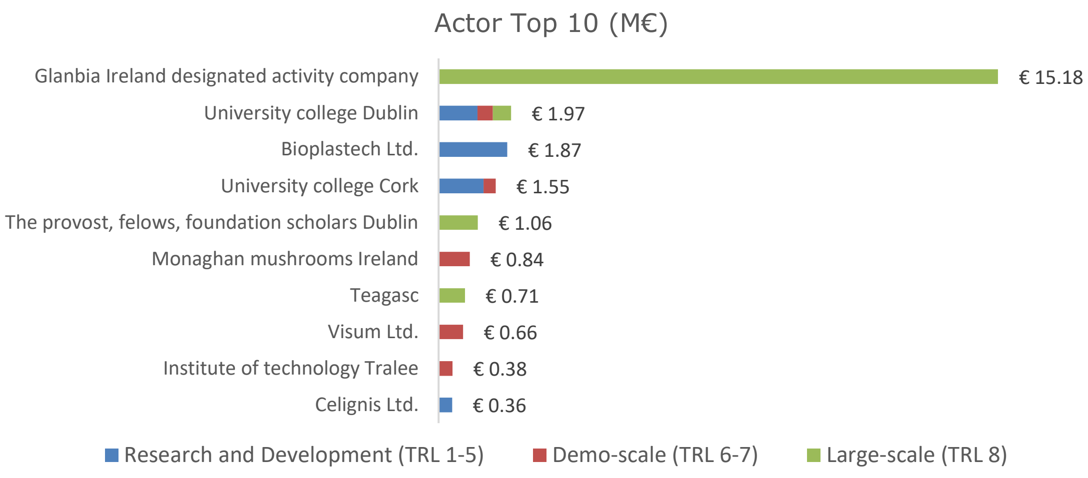
SUPPORT MEASURES

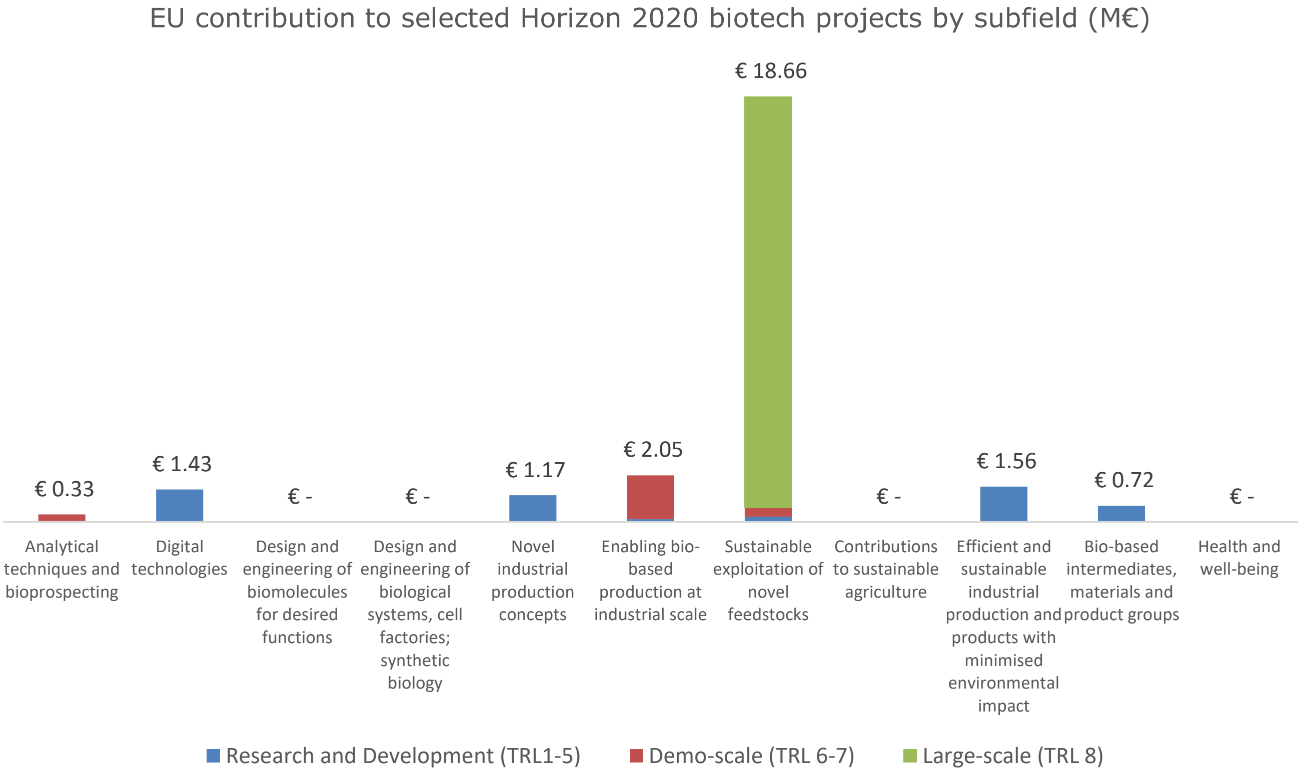
Next to the EU level funding, the Department of Agriculture, Food and the Marine has funded a number of collaborative academic-led bioeconomy related research projects in Ireland. The Irish Bioeconomy Foundation has been established to boost innovation in bioeconomy. In 2017 the Bioeconomy Research Centre (Beacon) was launched, with a purpose to enable the transition to the bioeconomy through R&D to develop new products and technologies and stimulate rural development. Government has provided funding of €14.2 million for Beacon, to explore how to convert marine resources and the residues from production into higher value products. The Government is also providing €4.6 million for the establishment of a Bioeconomy innovation and piloting facility at Lisheen, to scale technologies that convert natural resources (e.g. residues) to products of high value for use in a wide variety of sectors (i.e. food/feed ingredients, pharmaceuticals, natural chemicals, biodegradable plastics etc.).

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Ireland has received 25.9 million Euro of H2020 budget for biotech related projects, ranking 8th of all EU-27 countries plus UK, equalling 5.22 Euro/capita. Approximately 21.4% of that EU budget is allocated to universities, 1.5% to research institutes, and 77.2% to the private sector. Ireland shows a clear focus towards **sustainable exploitation of novel feedstocks**, consuming 72% of the total allocated budget. More specifically, **using side and waste streams** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Italy

✓ BIOECONOMY STRATEGY | ✓ ACTION PLAN | ✓ BIOSCIENCE RELATED POLICY | ✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The bioeconomy strategy (A New Bioeconomy Strategy for a Sustainable Italy) aims to provide a shared vision of the economic, social and environmental opportunities and challenges associated with the creation of a national bioeconomy based on more sustainable value chains. It also serves as an opportunity to increase its competitiveness and role in promoting sustainable growth internationally. The Strategy will be part of the implementation processes of the National Smart Specialization Strategy, focusing in particular on the areas of "Health, Food and Life Quality" and "Sustainable and Smart Industry, Energy and Environment". It will be implemented in synergy with the principles of the Italian National Strategy for the Sustainable Development.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

- Agriculture: promotion of novel and efficient primary production and use of biomass (e.g. their conversion to different biomaterials - biofillers, biopolymers oils etc.)
- Food industry: obtaining new feed and dodders, innovative food ingredients and bioactive compounds from by-products of food processing; adopting innovative processes to exploit by-products from agroindustry processing
- Forestry: implementation of sustainable resource management systems, using forestry residues for the production of bio-based chemicals, nutraceuticals
- Bio-based industry: build on the existing highly successful bio-based industry. Key technologies developed, include green catalysts, microbes, bio-materials, chemicals, cosmetics, pharmaceuticals and fuels.
- Marine bioeconomy: improve the performance of the sea economy in the areas of research, innovation and growth of human capital.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Life science and biotechnology have an important role in the Bioeconomy Strategy. One of the main target sectors of the strategy, bio-based industry, is heavily relaying on the advancements made in biotechnology. In the Action Plan, under Action 2 (Launch of pilot actions to support circular Bioeconomy in different sectors), biotechnology has a key role in achieving sector specific goals.

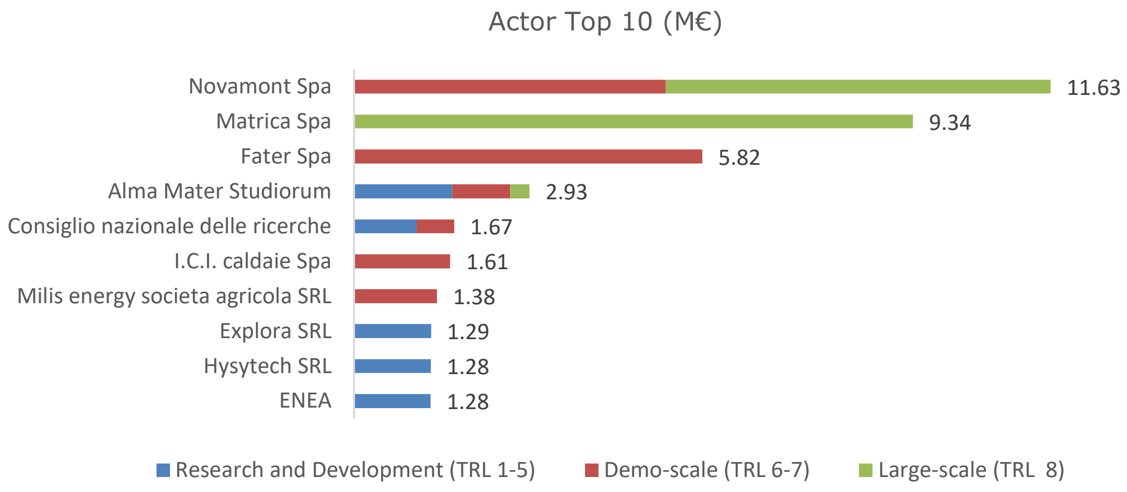
SUPPORT MEASURES

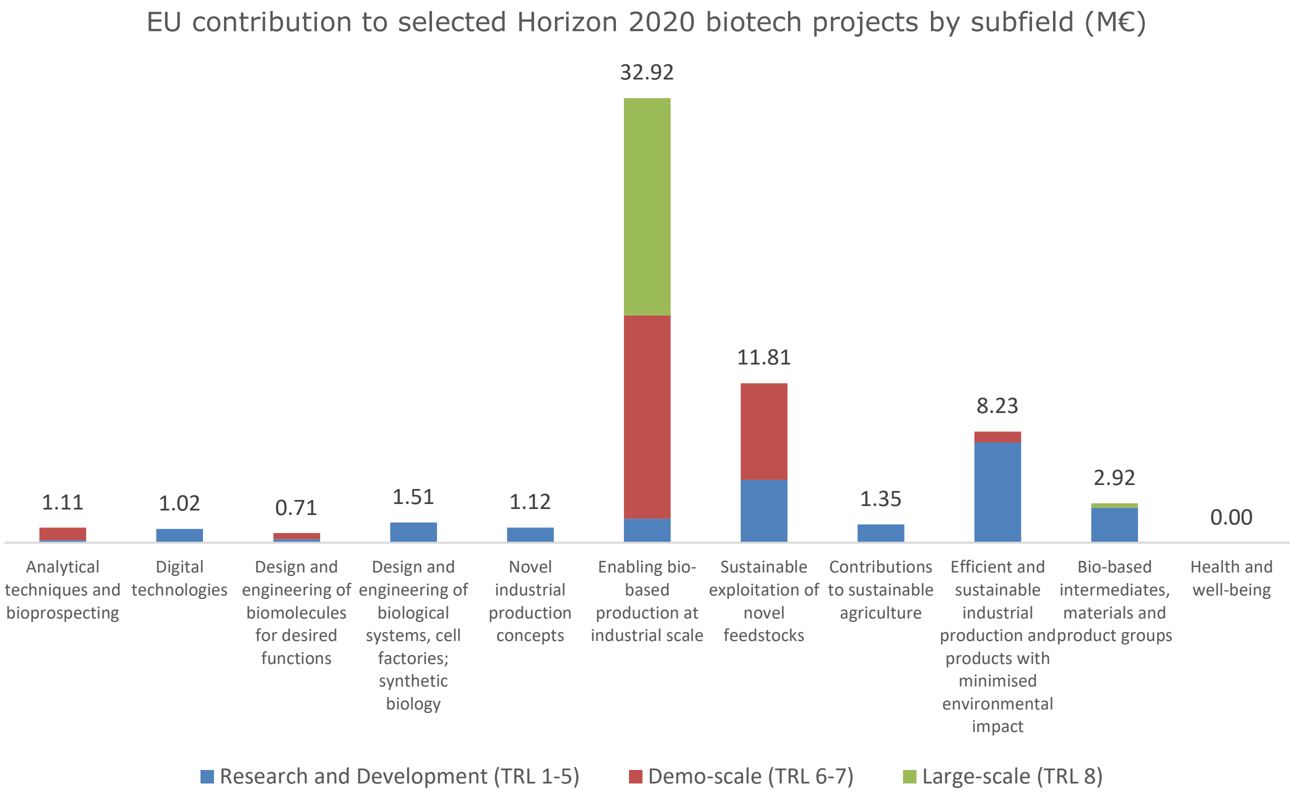
Next to the EU, national and regional level support instruments exist. The Strategy is part of the implementation process of the National Smart Specialization Strategy (SNSI). The SNSI aims to identify priorities for investment in research, development and innovation. In the form of grants and loans, it allocates € 562.7 Million National R&I call was launched in 2017 by the IT Ministry for Education, Research and University that allocated € 30 Million for the bio-based sector. There are different regional funding programmes in place to support the bio-based industry. Such as the new Industry 4.0 plan, which provides opportunities for private sector in bioeconomy domain to enhance R&D and competitiveness.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Italy has received 62.7 million Euro of H2020 budget for biotech related projects, ranking 4th of all EU-27 countries plus UK, equalling 1.04 Euro/capita. Approximately 19% of that EU budget is allocated to universities, 10.1% to research institutes, and 70.1% to the private sector. Italy shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 52% of the total allocated budget. More specifically, **biorefineries for new feedstocks** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Latvia

BIOECONOMY STRATEGY	ACTION PLAN	BIOSCIENCE RELATED POLICY	NATIONAL SUPPORT MEASURES
✓	✗	✓	✓

BIOECONOMY STRATEGY

The Latvian Bioeconomy Strategy 2030 is expected to enable Latvia to achieve the objectives, set in the flagship initiatives "Innovation Union" and "Resource efficient Europe" of the Europe 2020 strategy. The Strategy also sets a number of specific economic goals, i.e. to increase the emplyment in the bioeconomy sectors for 128 thousand people, increase the value added of bioeconomy products to at least EUR 3.8 billion and increase the value of bioeconomy production exports to at least EUR 9 billion by 2030. Latvia is also part the BIOEAST initative, which brings together Central and Eastrn European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The strategy explicitly mentions four economic sectors to be targeted with their corresponding priorities:

- bioresources: increased production of agricultural goods by increasing the efficiency of resources, specify the forest reference level, diversification of the grown species in aquaculture,
- food industry: production of innovative and functional food,
- wood processing and furniture industry: increasing the offer of forestry, export of by-products, reprocessing of currently exported wood products,
- production of chemical processing products: production of modern biofuels for aviation, biochemical basic elements with improved functionality, bio-based plastics and biosurfactants used in detergents
- energy sector: creation of higher added value from bio-based reseources.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Latvia does not have a dedicated life science and/or biotechnology related strategies. Biotechnology is partly included in the "Latvian Bioeconomy Strategy" as a key enabling technology in processing of bio-based resources. Latvia has developed a national smart specialisation strategy (RIS3) in 2014, where biotechnology is listed as one of the knowledge specialisation areas.

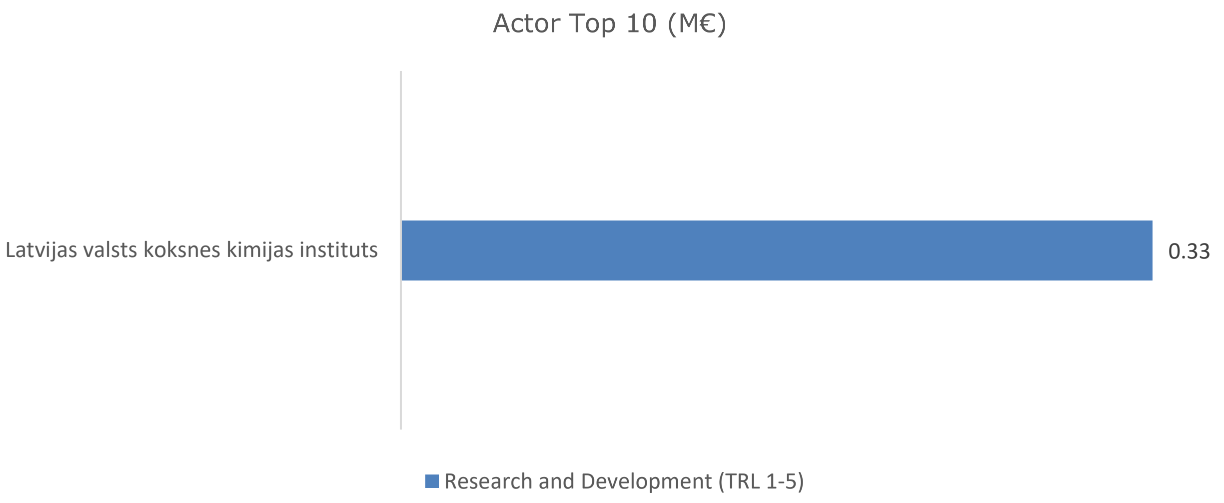
SUPPORT MEASURES

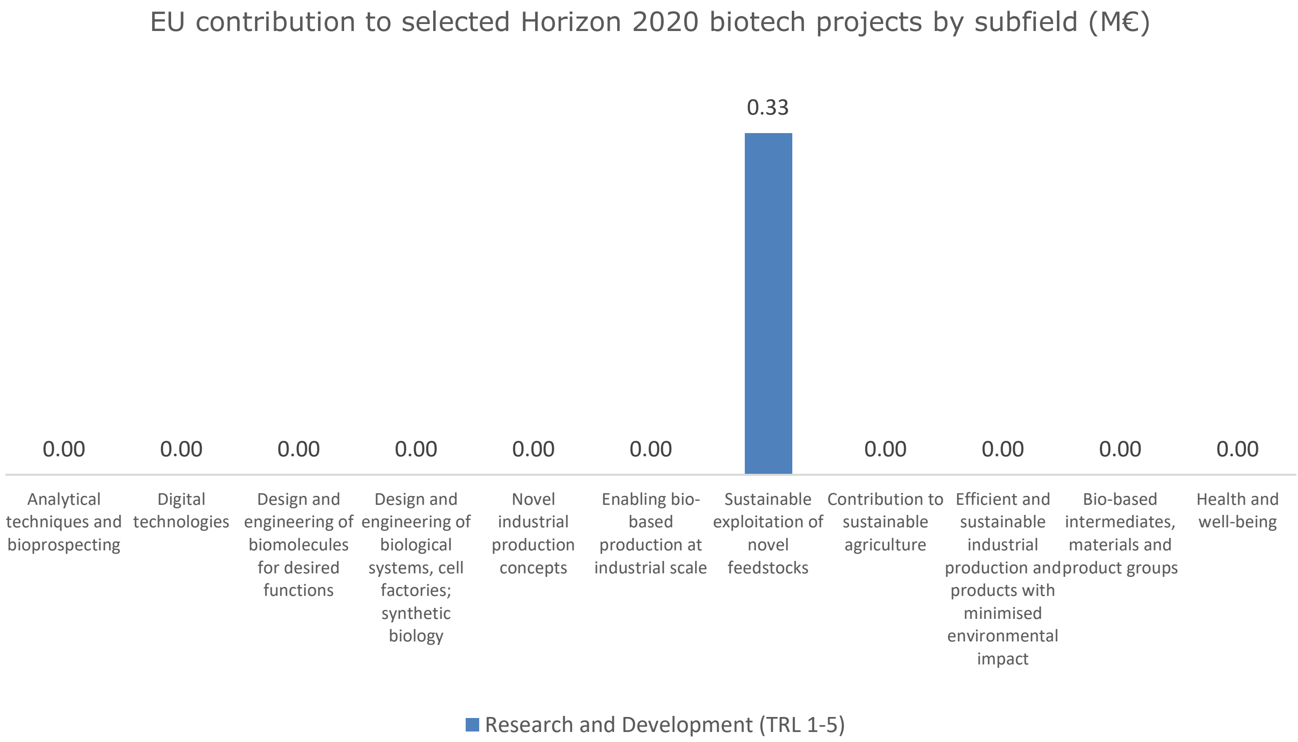
The EU and national level available research funding instruments are in place. The Latvian Bioeconomy Strategy 2030 has not yet been translated into dedicated action plan. Currently available funding opportunities are mostly on international level. Latvia itself has an extremely low research budget. **The Latvian Environment, Bioenergy and Biotechnology Competence centre** aims to facilitating the cooperation between research and industry sectors in the implementation of projects for industrial research, development of new products and technologies**. The Strategic Association on Bioeconomy Research** is a consortium of 15 national research institutes and universities dedicated to the development and realisation of a science based strategy for the bioeconomy in Latvia. **The Baltic Innovation Fund 2 (BIF2)** brings together funding from the governments of the Baltic States. In Latvia it is operated by ALTUM to boost innovation equity investments in Baltic SMEs. Between 2019 and 2024, the BIF is endowed by EUR 100 million exclusively for Latvia.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Latvia has received 328 thousand Euro of H2020 budget for biotech related projects, ranking 25th of all EU-27 countries plus UK, equalling 0.17 Euro/capita. 100% of that EU budget is allocated to a single research institute. Latvia took part in one project related to **sustainable exploitation of novel feedstocks**. More specifically, **supply and pre-treatment of novel feedstocks** is the only top 50 bio-based innovation that have received EU budget.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Lithuania

BIOECONOMY STRATEGY ✓	ACTION PLAN ✗	BIOSCIENCE RELATED POLICY ✓	NATIONAL SUPPORT MEASURES ✓

BIOECONOMY STRATEGY

In Lithuania, a dedicated bioeconomy strategy at national level is under development. In 2017 "Lithuanian Bioeconomy Development Feasibility Study" was presented that provided figures on the status of bioeconomy in Lithuania. The country participates in the Bioeconomy in the Baltic Sea Region initiative, and is part the BIOEAST initiative, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

By targeting a number of different sectors, such as agriculture, forestry, blue economy, food, wood, bio-based manufacturing significant progress is foreseen towards increasing the size of the Lithuanian bioeconomy as a whole. The Strategy does not explicitly mention any economic sector specific targets. The "Lithuanian Bioeconomy Development Feasibility Study", however, reveals several cross-sectoral themes that are vital in the development of bioeconomy in Lithuania:

- sustainable and strategically oriented development of bioeconomy
- efficient and sustainable biomass production and recycling
- bio-waste utilisation, including intensifying the development and implementation of prototypes of biotechnology
- increased demand & consumption of bioproducts.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

In Lithuania, biotechnology and life sciences have been included in different strategy documents. The government supports bioeconomy mainly in the area of biotechnology. For the period 2011 - 2013, the Government approved the "National Industrial Biotechnology Development Programme" that mainly focuses on technology development in order to process local biomass resources. Biotechnology is also considered a key area in Lithuania's "Innovation Development Programme" (2014-2020).

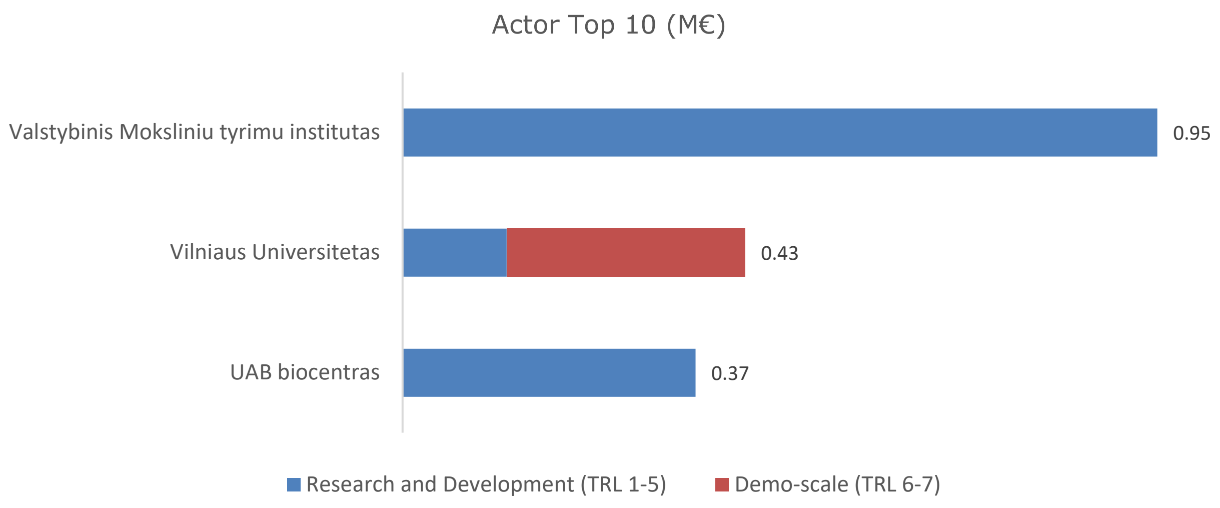
SUPPORT MEASURES

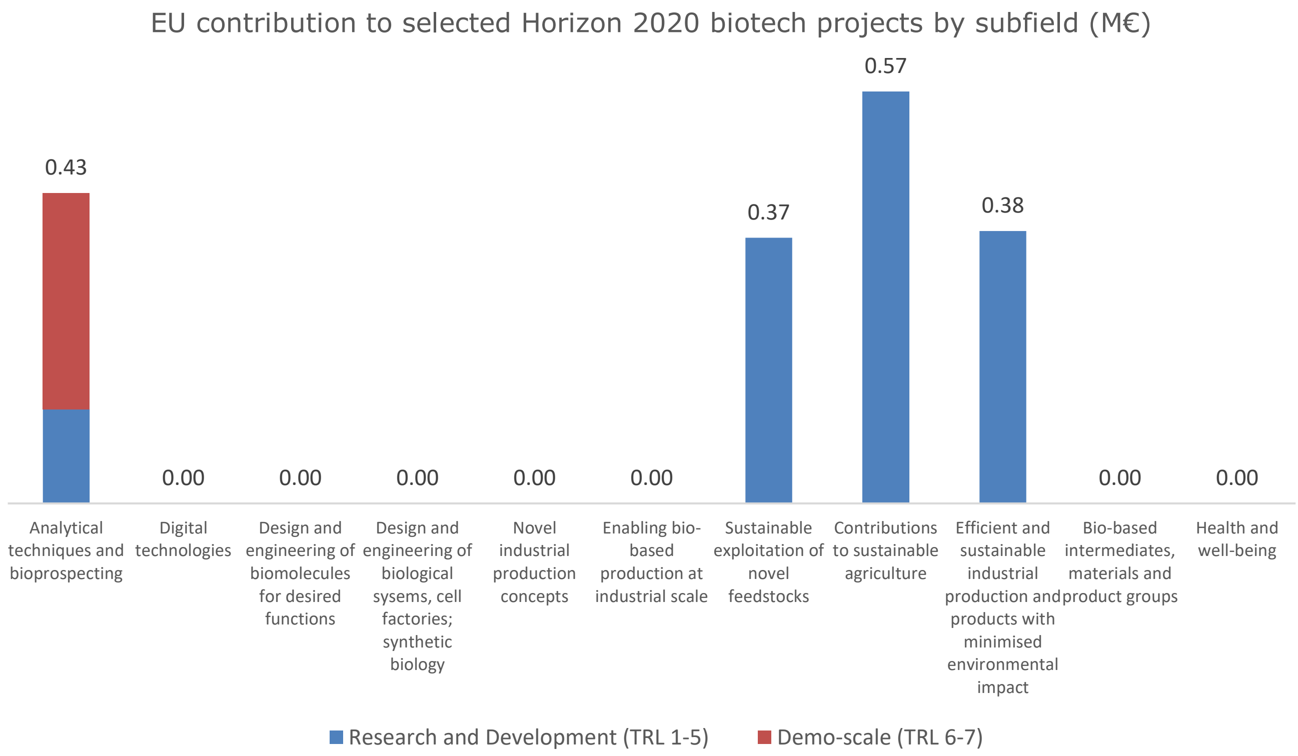
Next to the EU level available funding opportunities, national level support mechanisms exist. The Ministry of Economy has established a centralised innovation support infrastructure for bioeconomy, consisting of 4 industrial parks, 2 free economic zones, 9 science and technology parks (STPs) and 5 science, studies and business centres. The National level Lithuanian Industrial Biotechnology Development Program is set up to support biotechnology methods and processes and biological products for the chemical, plastics and pharmaceutical industries, agriculture and health. Until 2020, the support for the development and commercialization of innovative technologies, products, processes and methods is provided through the realisation of the Smart Specialisation programme for implementation of the priority areas of R&D, two of which, Health Technology and Biotechnology and Agro-Innovation and Food Technology - are directly linked to bioeconomy.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Lithuania has received 1.7 million Euro of H2020 budget for biotech related projects, ranking 20th of all EU-27 countries plus UK, equalling 0.63 Euro/capita. Approximately 24.6% of that EU budget is allocated to universities, 54.3% to research institutes, and 21.1% to the private sector. Lithuania shows a clear focus towards **contributions to sustainable agriculture**, consuming 33% of the total allocated budget. More specifically, **crop improvement targeting the genome and epigenome** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Luxembourg

✗ BIOECONOMY STRATEGY | ✗ ACTION PLAN | ✓ BIOSCIENCE RELATED POLICY | ✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Luxembourg does not have any national bioeconomy specific strategies. However, there are several strategic documents wherein the field is partly reflected, e.g. "National Action Plan on Renewable Energy" (2010), "2nd Action Plan for Reducing CO_2 Emissions", "National Plan for Smart, Sustainable and Inclusive Growth" and "Research and Innovation National Smart Specialization Strategy (RIS3)" both in 2017. In 2018 Luxembourg adopted the "3rd National Climate Plan 2021-2030" which covers a range of sectors including, the economy, energy supply, and agriculture and nutrition. At the beginning of 2020, "The National Research & Innovation Strategy" was presented.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The government demonstrates continuous support for climate change related challenges. Until now across different strategy documents energy, water and waste management (with a special focus on the construction and the wood sector) are the key sectors that have contribute the most to the bioeconomy development in Luxembourg.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Luxembourg does not have life science and/or biotechnology related strategies. However, in the recent "National Research & Innovation Strategy", biotechnology is listed as one of the priority sectors.

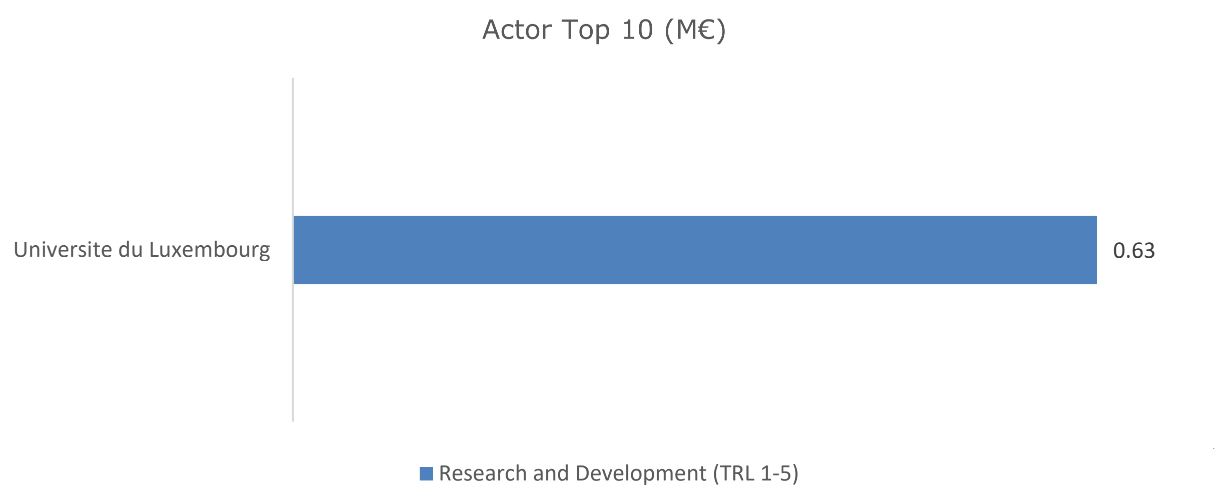
SUPPORT MEASURES

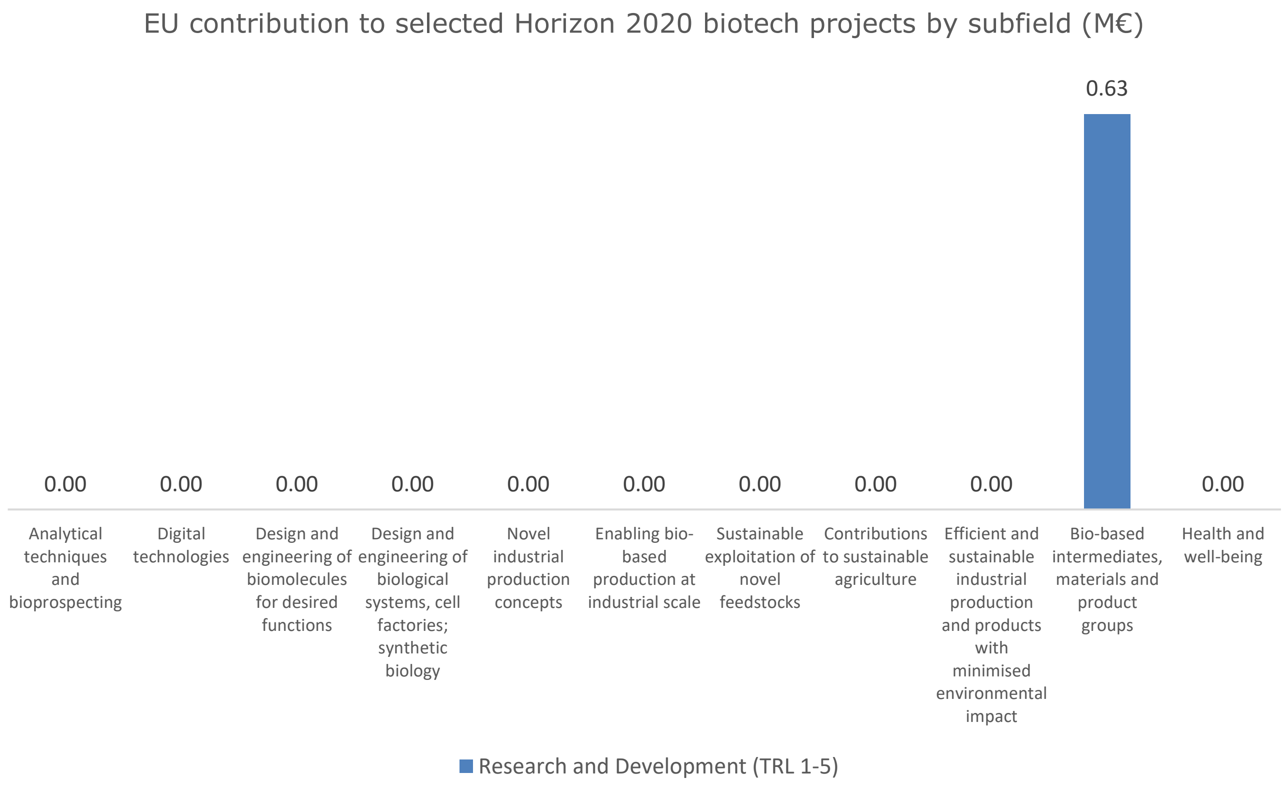
The national funding instruments are not specific to bioeconomy. Next to the EU funding, the key financial support measures for bioeconomy include **National Research Fund**, focus on research projects (mainly CORE) , PhDs and post-docs and public-private partnerships. **Luxembourg Ministry of the Economy** provides research-development and feasibility study aid, innovation aid for SMEs and young innovative enterprises, aid for process and organisational innovation, investment aid for research infrastructures and innovation clusters. **Société Nationale de Crédit et d'Investissement** provides direct R&D loans up to €250,000, indirect development loans up to €10,000,000 and loans for innovative start-ups up to €1,500,000. Managed by Luxinnovation, the Luxembourg HealthTech Cluster has been set up, with an aim to bring together national players involved in innovative health technologies.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Luxembourg has received 630 thousand Euro of H2020 budget for biotech related projects, ranking 22nd of all EU-27 countries plus UK, equalling 1.01 Euro/capita. 100% of that EU budget is allocated to a single university. Luxembourg took part in one project related to **bio-based intermediates, materials and product groups**. More specifically, **bio-based materials** is the only top 50 innovation that has received EU budget.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Malta

✗ BIOECONOMY STRATEGY	✗ ACTION PLAN	✗ BIOSCIENCE RELATED POLICY	✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Malta does not have a dedicated national bioeconomy strategy. However, there are some strategic documents developed wherein the field is partly reflected, e.g. a "National Energy and Climate Plan" Aquaculture Strategy for the Maltese Islands" (2014) and "National Strategy for Sustainable Development" (2006).

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

In a public consultation document "Towards a Smart Specialization Strategy 2021 - 2027", Maltese Government has provisionally identified five potential smart specialization areas. Among these, sustainable use of resources for climate change mitigation, sustainable manufacturing and marine & maritime technology, are also related to bioeconomy. The sector specific priorities are:

- sustainable manufacturing: transition towards more sustainable materials,
- sustainable use of resources for climate change mitigation: tailor-made solutions to enable Malta to meet international obligations on sustainability,
- marine & maritime technology: building on existing R&I capacity and explore how best to exploit current research results on different finfish species, shellfish and aquatic plants, as well as the non-fish farming side of aquaculture. Moreover, turning fish waste into a resource and producing innovative products.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Malta does not have life science and/or biotechnology related strategies.

SUPPORT MEASURES

Next to the EU level available funding instruments, national level support mechanisms exist. However, they are not specific to biotechnology neither to bioeconomy. The examples of the main financial support measures include on the EU-level available research funding schemes (e.g. ERA-NET Cofund) and on national level Science and Technology Cooperation Fund and Fusion programme (2014-2020) with a budget of EUR 2.2. million per year, among others.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Malta has received 0 Euro of H2020 budget for biotech related projects, ranking 28th of all EU-27 countries plus UK.

Netherlands

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The bioeconomy strategy (The position of the bioeconomy in the Netherlands) builds on the competency of its infrastructure and excellent research facilities. It also stresses the synergy between sustainable use and reuse (closing the loop). In addition, the strategy mentioned that a radical change is expected in the way biomass is used, through the application of the principle of 'cascading'.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The strategy does not explicitly mention any economic sectors to be targeted. It does, however, reveal eight themes that are vital in the **development of bioeconomic policy**. These eight themes address, among others, the principle of the circular economy, the sustainable use and production of biomass, and collaboration between sectors and value chains. According to the strategy, The Netherlands is committing itself to the following principles:

- Embracing the circular economy
- Mobilization of sustainable biomass
- Bridging gaps in innovation; encourage collaboration
- Increasing support via effective communication
- Developing market demand

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

The Netherlands does not have a separate life science and/or biotechnology related strategy. However, microbiological conversion (i.e. plant fractionation, biocatalytic conversion, bio-based materials and biochemical biofuels) is one of the main themes of the 'Research Agenda Biobased Economy 2015 – 2027'.

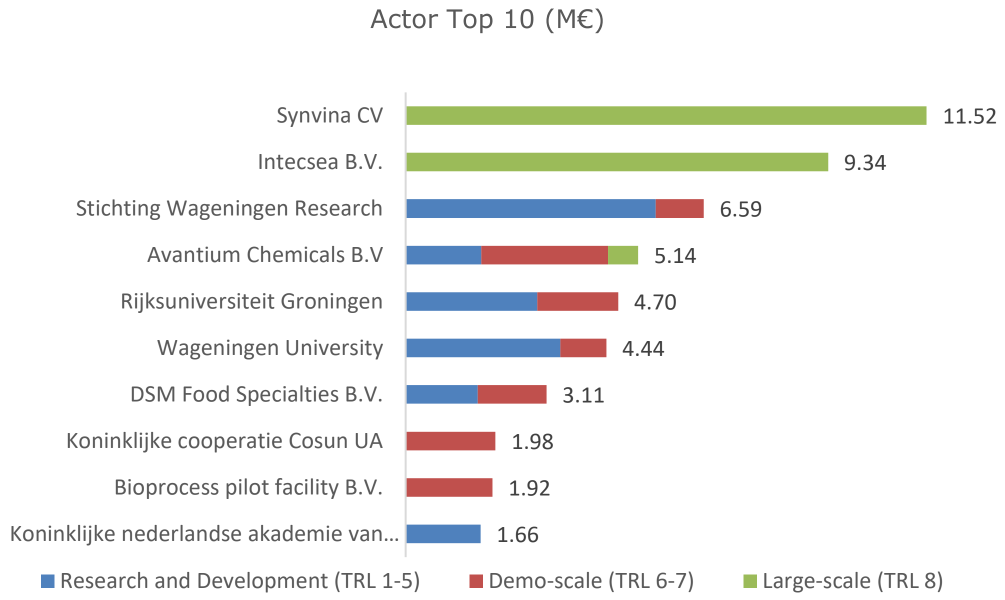
SUPPORT MEASURES

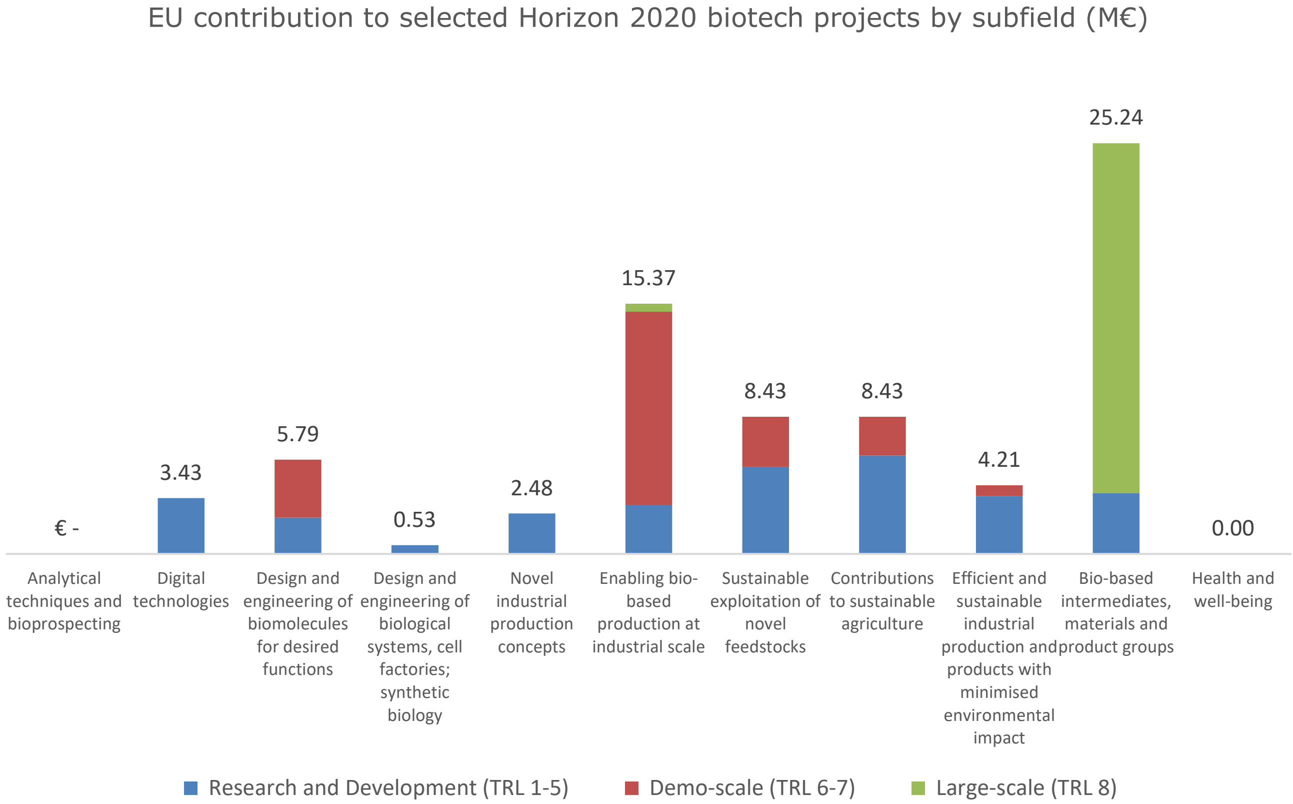
Top Sector Energy provides industrial research and experimental development subsidies for microbiological conversion under "Biobased Economy and Green Gas: Innovation Projects". Generic research funds like NWO are available as well.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

The Netherlands has received 73.9 million Euro of H2020 budget for biotech related projects, ranking 2nd of all EU-27 countries plus UK, equalling 4.25 Euro/capita. Approximately 28.4% of that EU budget is allocated to universities and 65.4% to the private sector. The Netherlands shows a clear focus towards **bio-based intermediates, materials and product groups**, consuming 34% of the total allocated budget. More specifically, **bio-based materials** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Poland

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

For bioeconomy, a specific strategy is currently under development. Several strategic documents already exist wherein the field is reflected, e.g. "Roadmaps Towards Circular Economy", the "Strategy for Innovation and Efficiency of the Economy", the "Strategy of Energy Safety and Environment" and the "Strategy for Sustainable Development of Agriculture, Rural Areas and Fisheries". Additionally, in 2014, a national working group on bioeconomy was set up by stakeholders with the Ministry of Agriculture. The country is also part the BIOEAST initiative, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

Poland's bioeconomy is based largely on traditional sectors, such as agriculture, forestry and food processing. Chemical and pharmaceutical industries have smaller, but also a sizeable role in the country's bioeconomy. Although, there is not yet a published bioeconomy strategy, the elements related to its individual sectors are reflected prominently in Poland’s Smart Specialisation Strategy, which is built around five axes that all address partly bioeconomy related aspects: 1) healthy society, 2) agro-food, forestry, environmental bioeconomy, 3) sustainable energy, 4) natural resources and waste management and 5) innovative technologies and industrial processes. . The government demonstrates continuous support for bioeconomy, by targeting all these different sectors and significant progress is foreseen towards increasing the size and role of the Polish bioeconomy as a whole.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Poland does not have a dedicated life science and/or biotechnology related strategies.

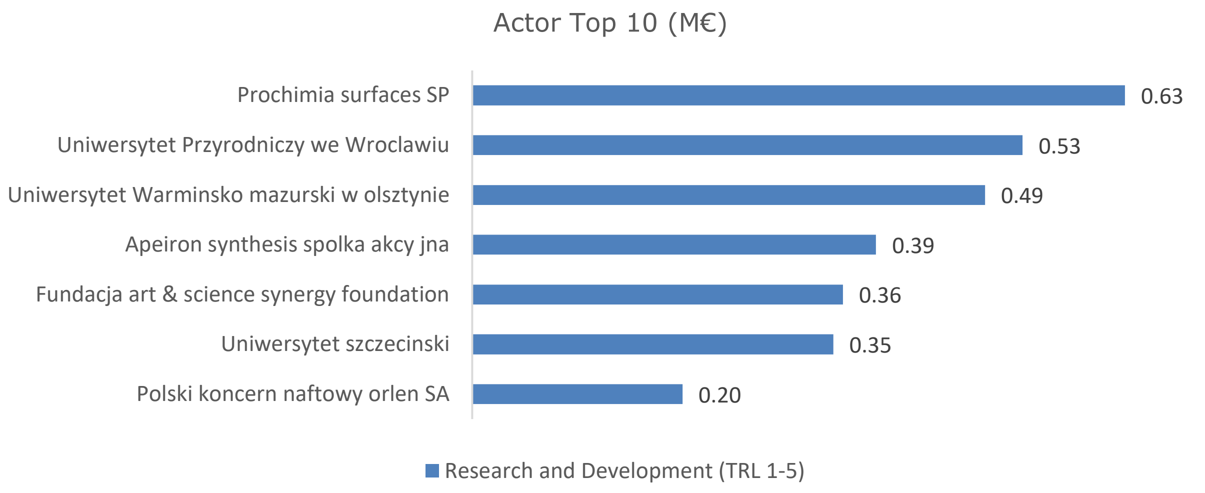
SUPPORT MEASURES

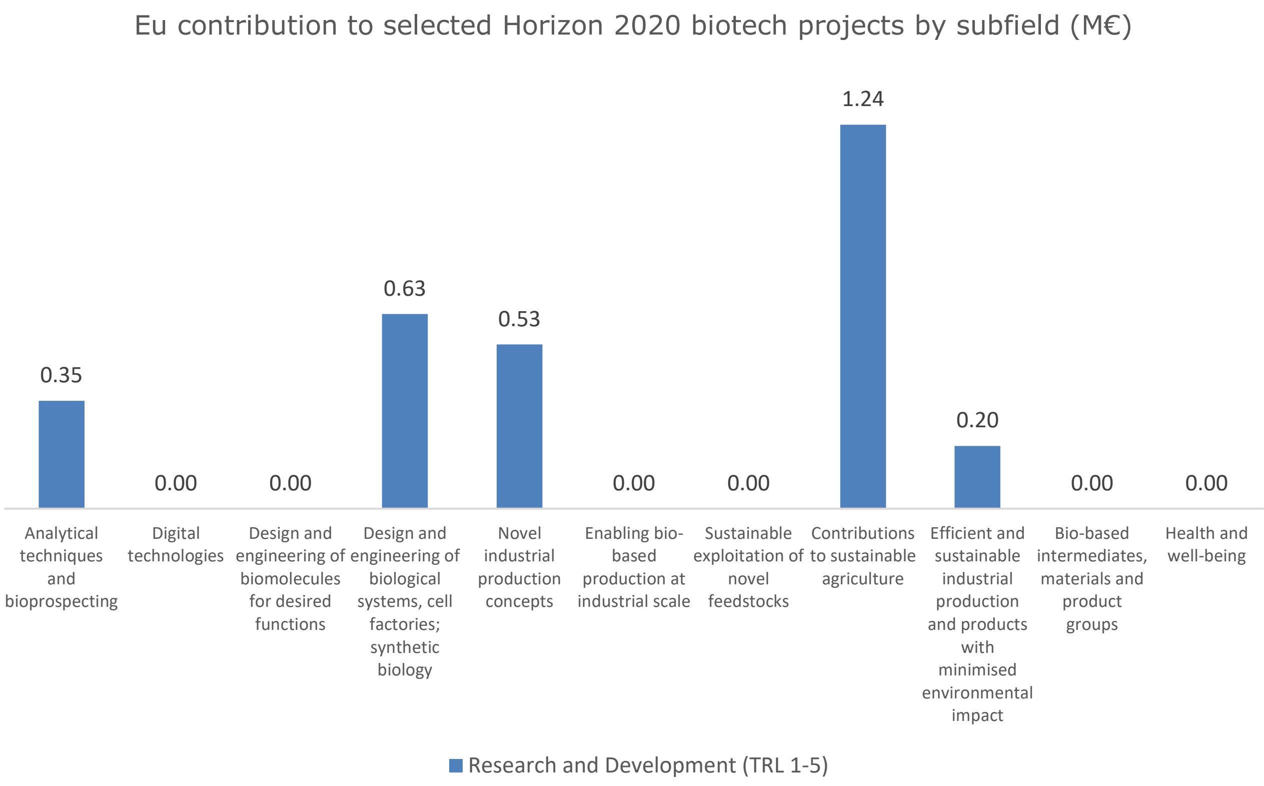
Poland is part of BIOEAST initiative. BIOEASTUP started in late 2019 that also aims to support the deployment of bioeconomy on national level in Central Eastern Countries. BioEcon is a research project aimed at the development of bioeconomy in Poland, financed under H2020. BIOSTRATEG is a national level strategic program of academic R&D with a goal to develop knowledge in programme areas (environment, agriculture and forestry) to stimulate the growth and innovation of the Polish economy. In September 2020, a new programme was announced by the Ministry of Funds and Regional Policy, that will provide grants and loans to SMEs to encourage innovative projects.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Poland has received 2.9 million Euro of H2020 budget for biotech related projects, ranking 17th of all EU-27 countries plus UK, equalling 0.08 Euro/capita. Approximately 52.9% of that EU budget is allocated to universities and 47.1% to the private sector. Poland shows a clear focus towards **contributions to sustainable** agriculture, consuming 42% of the total allocated budget. More specifically, **crop improvement targeting the genome and epigenome** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Portugal

✓ BIOECONOMY STRATEGY | ✗ ACTION PLAN | ✓ BIOSCIENCE RELATED POLICY | ✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The bioeconomy strategy is currently under development and expected to be finalised by the end of 2020. In the preparation process, a reflection process on the future "Strategy for the Bioeconomy in Portugal" was launched with the publication in March 2019 of the magazine dedicated to Bioeconomy - CULTIVAR 15. In May 2019, the "Portuguese Road map for the Bioeconomy Strategy" was presented. Other related strategies to bioeconomy include: "Agri-food & Forestry R&I Strategy 2014-2020", "Circular Economy Action Plan", "National Forest Strategy", "National Ocean Strategy 2013-2020", "Portuguese Strategy for Smart Specialization (RIS3)".

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The strategy recognizes the role of bioeconomy, as defined by the EU. Information on explicit economic sectors to be targeted is not yet available. Bioeconomy is currently considered of interest and embedded in several national strategies (green growth, agri-food, forests, oceans, food waste). In Portuguese context, bioeconomy is expected to strengthen market orientation and increase competitiveness, with a greater focus on R&D, technology and digitalisation; promote sustainable development, among other priorities.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Portugal does not have a dedicated life science and/or biotechnology related strategies. The key biotechnology areas in Portugal are pharmaceuticals and industrial biotechnology (i.e. applications in textiles, pulp & paper, food, plastics, chemicals and biofuels industries). In Portugal strategic R&I Agendas have been developed for the selected 14 thematic areas, where biotechnology is expected to play an important role.

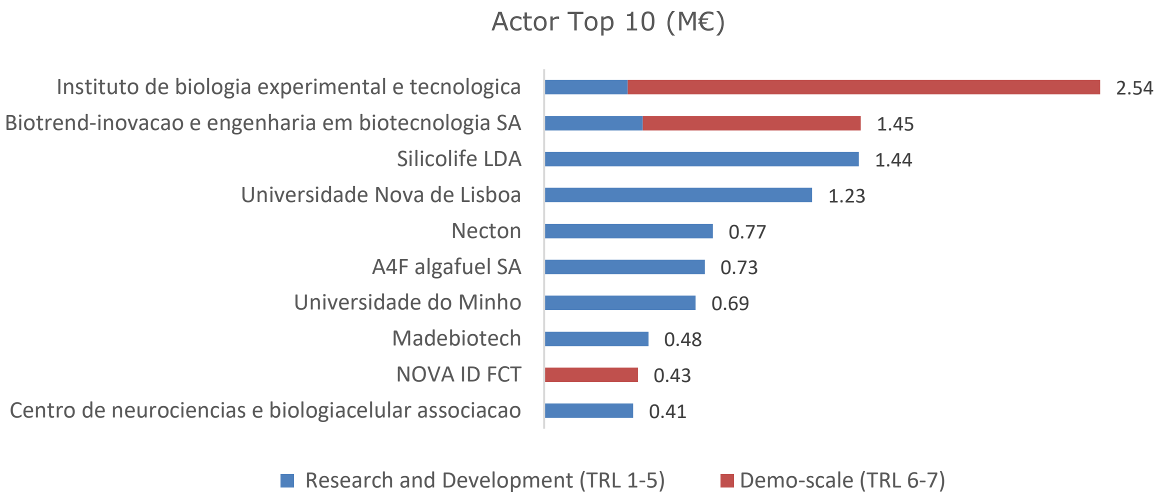
SUPPORT MEASURES

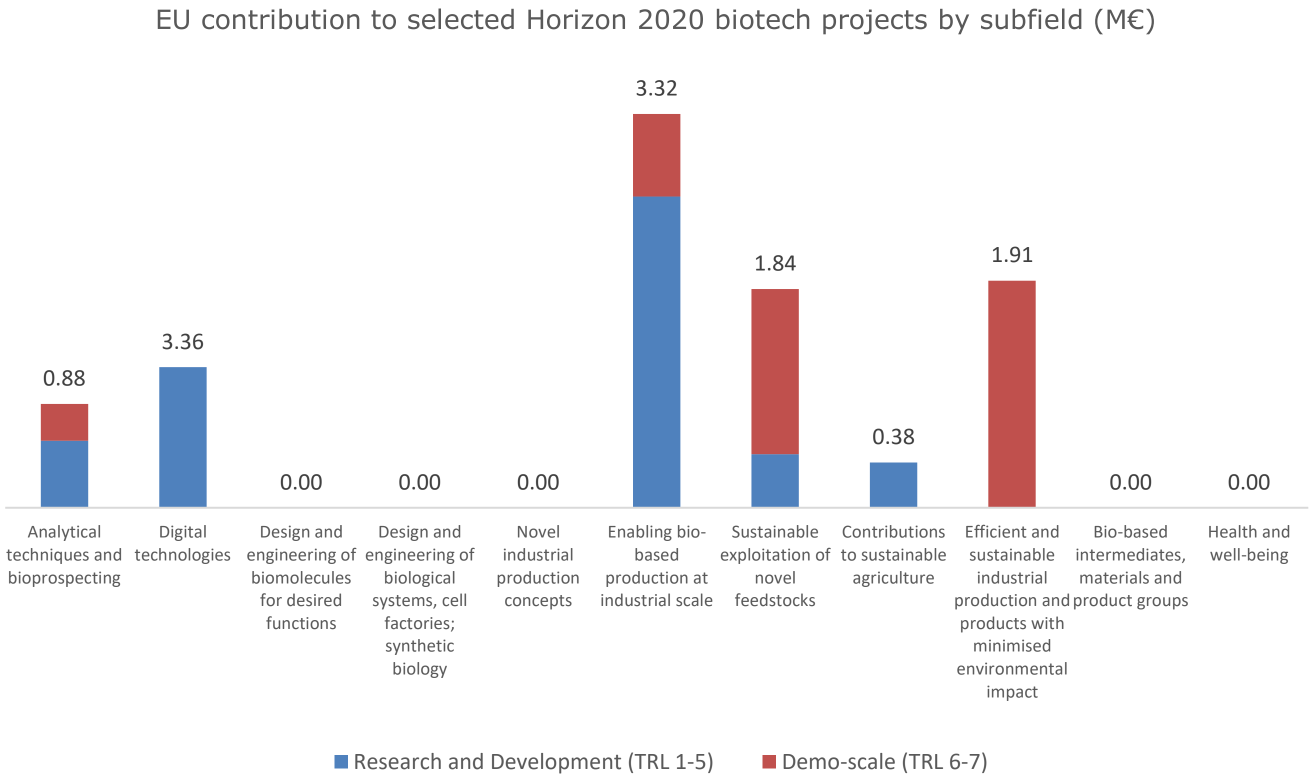
The main national funding agencies (FCT and ANI) have bottom-up programmes aligned with the National/regional RIS3 strategies, in which the involvement of the industrial sector is highly encouraged. In Lisbon and Tagus Valley, a working group to support Research Technologies and Health was created in 2015, that identified a number of investment needs of the sector, which resulted in EUR 67.6 Million funding over the following years. The Portuguese Association of Bio-industry Companies has launched a strategic plan in August 2020, with an aim to position Portugal as a centre of R&D in biotechnology and life sciences in the EU.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Portugal has received 11.7 million Euro of H2020 budget for biotech related projects, ranking 14th of all EU-27 countries plus UK, equalling 1.14 Euro/capita. Approximately 16.9% of that EU budget is allocated to universities, 32.7% to research institutes, and 50.4% to the private sector. Portugal shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 28% of the total allocated budget. More specifically, **biorefineries for new feedstocks** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Romania

BIOECONOMY STRATEGY	ACTION PLAN	BIOSCIENCE RELATED POLICY	NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Romania does not have a dedicated national bioeconomy strategy. However, there are several strategic documents, wherein the field is reflected, e.g. "Draft Integrated National Energy and Climate Change Plan for 2021-2030" (2018), "Smart Specialization Strategy" (2014), "Strategy for the Development of the Agri-food Sector on Average- and Long-term 2020-2030" (2015) and "Romanian RDI Strategy for 2014-2020" (2014). Romania is also part the BIOEAST initiative, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

Until now, agriculture sector (one of the largest in Europe) together with wood industry are the primary sectors that have contribute the most to the bioeconomy in Romania. Other sectors that play a smaller role are food processing, wood, paper and pulp industry. The country also has a strong (petro)chemical industry. Sector specific priorities have not been formulated. Several cross-sectoral themes that are vital in the development of bioeconomy include: 1) stimulating research and innovation, especially in the field of biotechnology, 2) promoting cross sectoral collaboration between different stakeholders, 3) prioritization of optimized use of biomass through the implementation of the "cascade" principle and the use of waste residue streams, 4) providing financial support for the development of biology-based activities.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

In its Smart Specialisation Strategy (2014) priority Axes have been formulated. Axis 4 include among others a number of topics relevant to biotechnology and life sciences. The examples include biotechnologies for agro-food, veterinary medicine, nano-biotechnology, environmental and industrial biotechnology, medical and pharmaceutical biotechnologies.

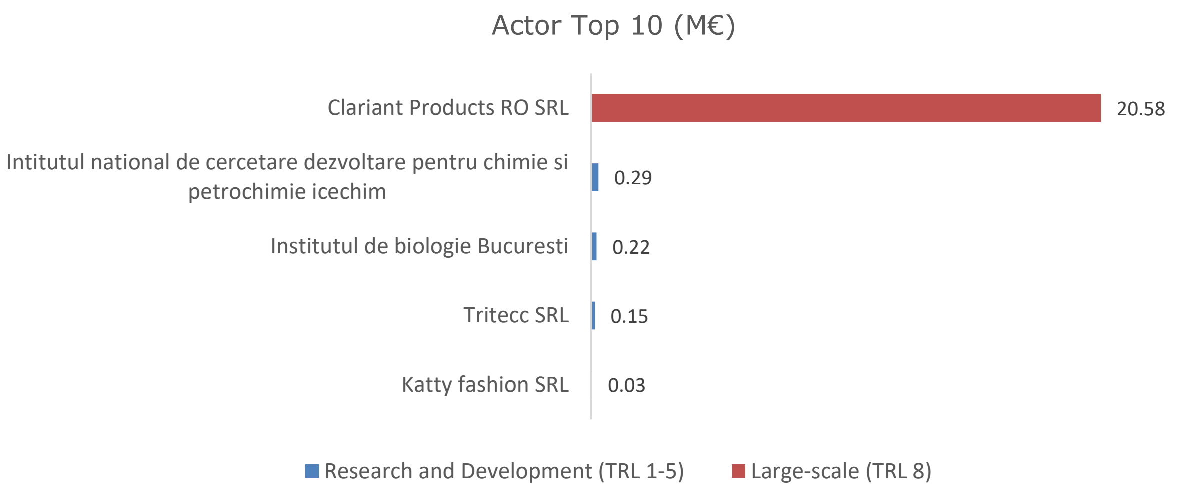
SUPPORT MEASURES

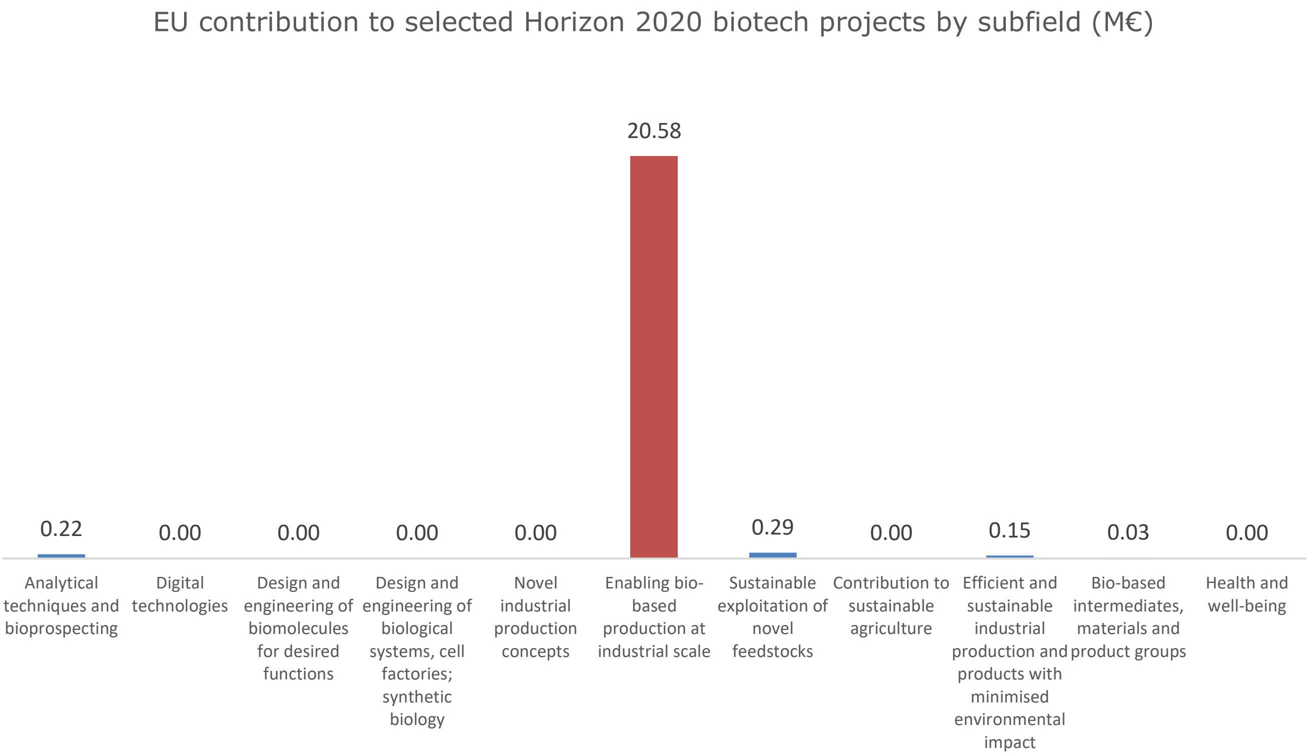
Next to the EU level available funding schemes, research is also supported on a national level within the National RDI Plan 2014-2020. A government-funded project performed by INCDSB (National Institute of Research and Development for Biological Sciences) is presently ongoing, committing itself at developing of bioeconomy in Romania for the period 2016-2030 by 1) assessing the R & D potential and the industrial potential in the bioeconomic field, 2) identifying priorities for the integration of national economic sub-systems into European bio-economic development and 3) establishing the main actions needed to achieve identified priorities. The Central-Eastern European Initiative for Knowledge-based Agriculture, Aquaculture and Forestry in the Bio-economy is promoting a strategic vision for bioeconomy development in Eastern European countries, as well as in South East European countries, including Romania. The BIOREGIO project (2014-2020) in Romania aims to promote innovation in private sector by supporting innovation and technology transfer in the areas of smart specialisation, such as "bioeconomy: developing circular economy".

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Romania has received 21.3 million Euro of H2020 budget for biotech related projects, ranking 10th of all EU-27 countries plus UK, equalling 1.10 Euro/capita. Approximately 1% of that EU budget is to research institutes and 99% to the private sector. Romania shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 97% of the total allocated budget. More specifically, **optimising biorefineries and production facilities** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Slovakia

✓ BIOECONOMY STRATEGY	✗ ACTION PLAN	✓ BIOSCIENCE RELATED POLICY	✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Slovakia does not have a dedicated national bioeconomy strategy. In 2019, the Ministry of Agriculture and Rural Development of Slovakia started developing a national bioeconomy strategy. Currently it is in the stage of data collection and further information is not yet available. Slovakia is also a member of a BIOEAST network, which brings together Central and Eastern European countries for the development of a knowledge-based bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The main sectors in Slovakia for bioeconomy are: agriculture, food, wood & furniture, forestry, bio-based textiles, paper, bio-based chemicals, pharmaceuticals and plastics. Sector specific goals are not yet defined, some cross-sectoral priorities for bioeconomy in Slovakia include increased collaboration between public and private sector, developing innovative ways for using domestic natural resources, supporting the conversation towards green technologies and biodegradable materials.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Slovakia does not have national life science and/or biotechnology strategy. It a country report of the Interreg project, the main priority areas of biotechnologies (in a pharmaceutical sector) in Slovakia are production of recombinant peptides and proteins, the construction of new microbial strains and organisms through modern methods of synthetic biology and genomics, the preparation of biocatalysts and bio-polymers. The same study lists the following priorities for industrial biotechnology: the scale up of fermentation processes for production of biologically active substances, the development of bioseparating processes for industrial technologies and the bio-catalysis of bio-transformation of products. In the Research and Innovation Strategy for Smart Specialisation, biotechnology is regarded as a priority topic for Slovakia.

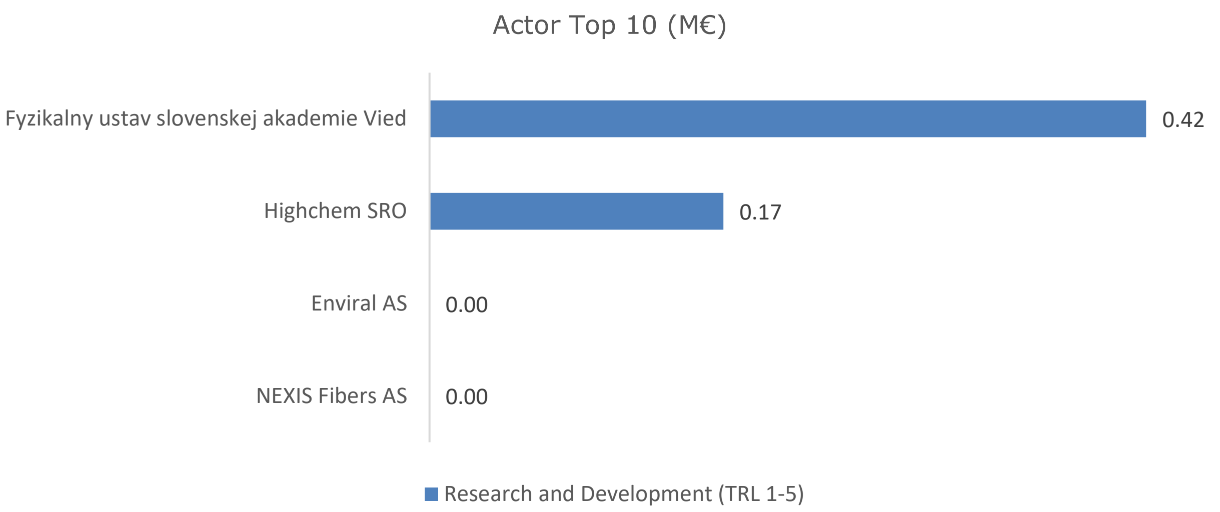
SUPPORT MEASURES

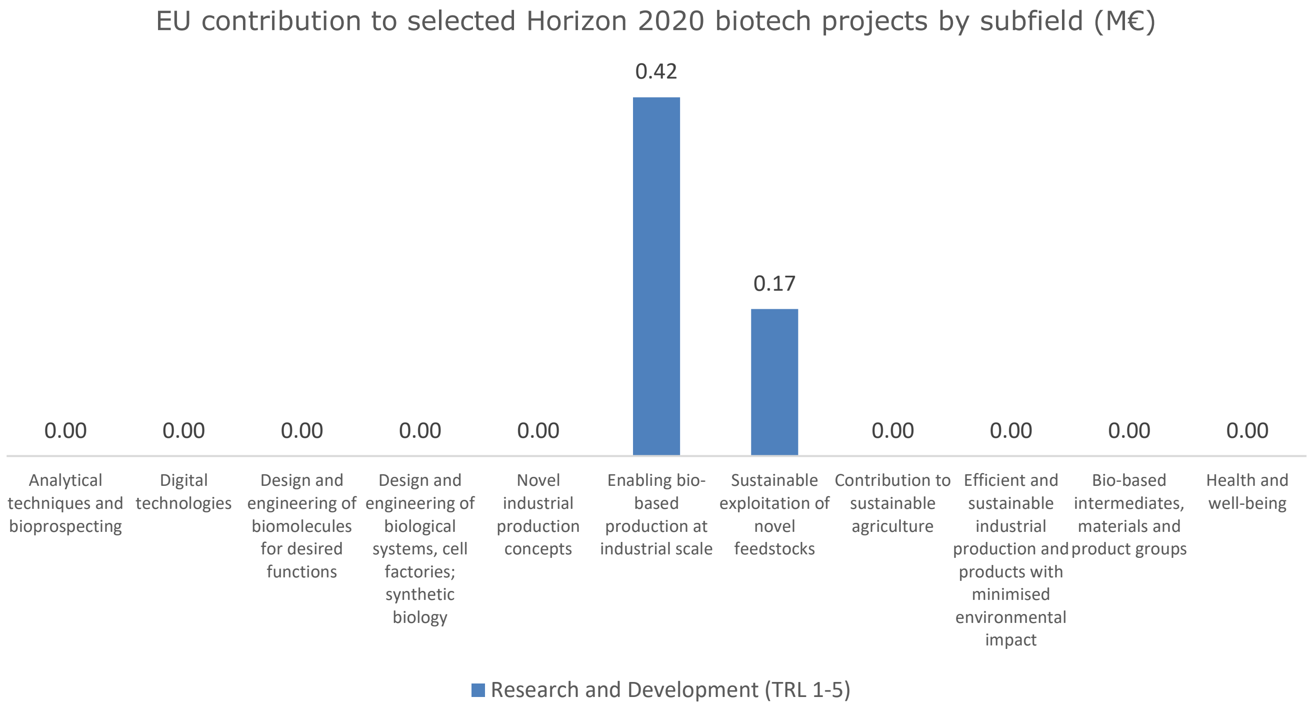
Biotechnology in Slovakia is supported through various policies, such as Operational Program Research and Innovation 2014-2020, in which biotechnology together with biomedicine are one of the three priority areas. Other relevant funding instruments are the Program of Rural Development 2014-2020, Envirofond, Operational Program Quality of Environment, Program of Waste Management 2016-2020 and Recycling Fund. Other strategies and concepts related to bioeconomy include: the Action Plan of the Biomass Exploitation, the Bio-waste Strategy, The Green report 2016, the Agricultural and Food Report, the Innovation Strategy of Agrobiotech, the Priority Area of Biomedicine and Biotechnology.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Slovakia has received 588 thousand Euro of H2020 budget for biotech related projects, ranking 24th of all EU-27 countries plus UK, equalling 0.11 Euro/capita. Approximately 70.9% of that EU budget is allocated to research institutes and 29.1% to the private sector. Slovakia took part in two projects related to **enabling bio-based production at industrial scale** and **sustainable exploitation of novel feedstocks**. More specifically, **biorefineries for new feedstocks** and **generating added value from downstream processing** are the only two top 50 bio-based innovations that have received EU budget.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Slovenia

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Slovenia does not have a dedicated national bioeconomy strategy. However, there are several strategic documents underway wherein the field will be reflected, in addition a national level ongoing research project, called Bridging Gaps in Bioeconomy in Slovenia (2018-2021) that all involve bioeconomy. Furthermore, Slovenia is a member of BIOEAST network, which is a Central and Eastern European Initiative for knowledge -based agriculture, aquaculture and forestry in the bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

By targeting a number of different sectors, such as:

- Forestry & Wood Processing Industry
- Pulp & Paper Industry
- Agriculture & Food Processing Industry
- Manufacturing Industry
- Fresh Water Aquaculture

significant progress is foreseen towards increasing the size of the Slovenian bioeconomy as a whole. Sector specific priorities are not yet defined. The government framework program for the transition to green Economy emphasizes green economy as an overall Slovenian long-term strategic direction to overcome the associated challenges on national and international level.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Slovenia does not have a dedicated national life science and/or biotechnology strategy. However, the S4 Slovenia's Smart Specialisation Strategy 2014-2020 establishes that the deployment of biotechnology in the different application areas of bioeconomy is a priority for Slovenian R&D. Furthermore, Slovenian Industry Policy 2014 - 2020 lists biotechnology as a priority technological field of the country.

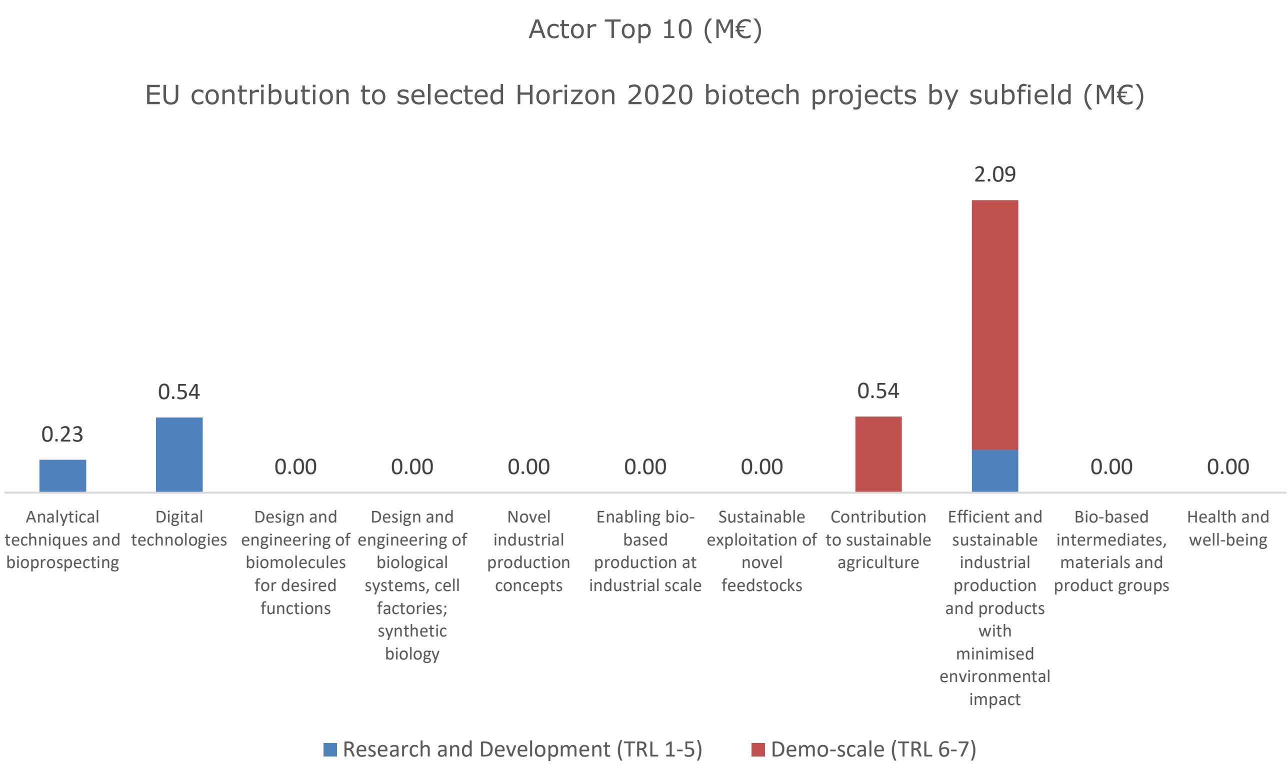
SUPPORT MEASURES

Even though, there is no bioeconomy dedicated policy in place, general conditions for the development of Slovenian bioeconomy are favorable. Next to on the EU level available funding instruments, on national level one of the main support instruments is the establishment of 9 Strategic Development Innovation Partnerships (SRIPs), which aims at supporting collaboration between different stakeholders in order to support the transition towards circular economy and set up a comprehensive innovation ecosystem.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Slovenia has received 3.4 million Euro of H2020 budget for biotech related projects, ranking 16th of all EU-27 countries plus UK, equalling 1.63 Euro/capita. Approximately 7% of that EU budget is allocated to universities, 9% to research institutes, and 68% to the private sector. Slovenia shows a clear focus towards **efficient and sustainable industrial production and products with minimised environmental impact**, consuming 61% of the total allocated budget. More specifically, **resource- and energy efficient bioprocesses** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS



Spain

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The bioeconomy strategy (The Spanish Bioeconomy Strategy: 2030 Horizon) is designed to encourage economic activity and sustainability of productive sectors by promoting the **generation of know-how** and its use in **developing and applying derived technologies**, via collaboration within the **science and technology system** and Spanish **public and private bodies.** The strategy is based on the science – economy – society triangle. Throughout the strategy document, developing and applying **new technologies** is central for the development of the Spanish bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

Agri-food: New technologies and innovation to improve efficiency of productive, organizational and logistics processes. Example: Cropping systems should be improved by sustainable intensification practices and "omics" technologies as well as precision farming tools.

Forestry: Implementation of sustainable resource management systems. Prolonging the end-of-life of wood products by using genetics and genomics as technology.

Industrial bioproducts: Efficient and sustainable use of biomass from various sources (e.g. agri-food and forestry residues or urban waste) to produce a wide range of bioproducts through the development of biorefineries. Great potential has also been attributed to the development of the blue bioeconomy and the use of non-conventional feedstock (e.g. algae and micro-organisms) to obtain bioproducts.

Bioenergy: Advances are anticipated by developing new ways of synthesizing biofuels through the use of thermochemical or biochemical technologies and of using alternative feedstocks (e.g. organic waste and residues).

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

Spain issued the Spanish Strategy on Science, Technology and Innovation Plan in 2012. This plan emphasizes the promotion of essential enabling technologies which includes biotechnology. The objective of the strategy is to guide the RDI activities towards the eight great (societal) challenges. Biotechnology plays a key role within two challenges including, **Health, demographic change and well-being,** and **Food safety and quality; productive and sustainable activity; sustainability of natural resources, marine and maritime research.**

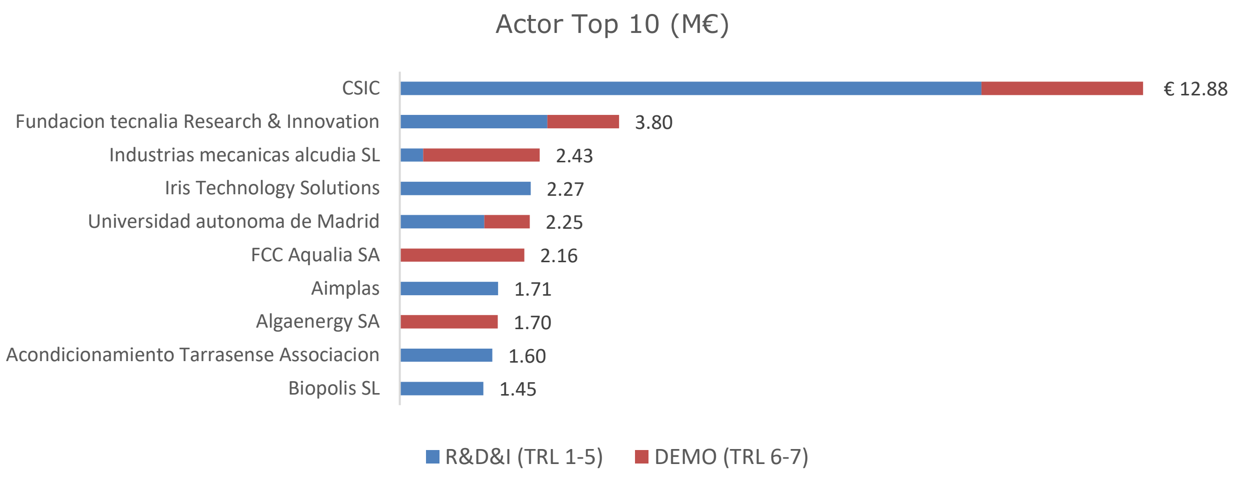
SUPPORT MEASURES

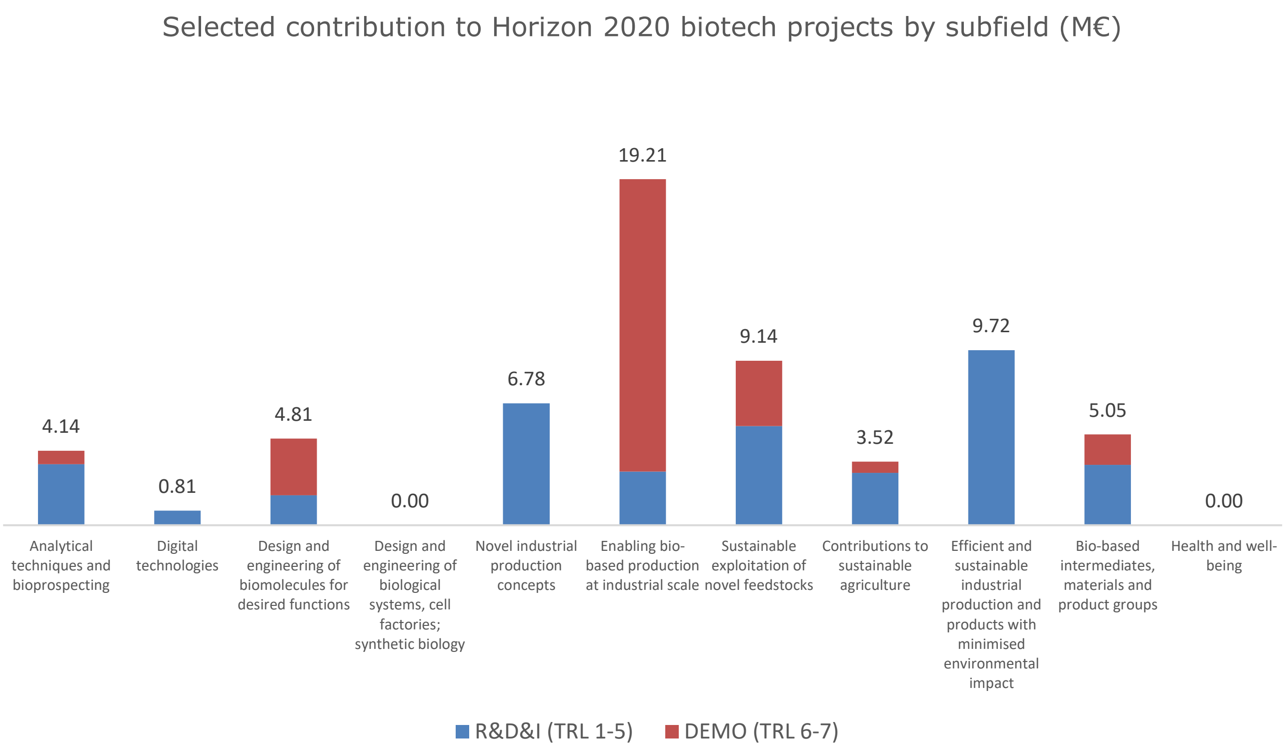
The Spanish Bioeconomy Strategy developed the First Annual Action Plan in 2016. It provides general measures such as **the promotion of public and private research and company investment in innovation** through research funds and programs, in the field of **market development and competitiveness** particularly within the field of food and agriculture and organic waste, and in the field of **developing demand for new products**. The action plan further elaborates on the possibilities for financing R&D projects composed of European Union funds (H2020), General State Administration Funds and Regional Administration Funds. A total of 230 million euros of available funds has been foreseen.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Spain has received 63.2 million Euro of H2020 budget for biotech related projects, ranking 3rd of all EU-27 countries plus UK, equalling 1.33 Euro/capita. Approximately 18% of that EU budget is allocated to universities, 46.1% to research institutes, and 35.2% to the private sector. Spain shows a clear focus towards **enabling bio-based production at industrial scale**, consuming 30% of the total allocated budget. More specifically, **biorefineries for new feedstocks** has received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





Sweden

BIOECONOMY STRATEGY | ACTION PLAN | BIOSCIENCE RELATED POLICY | NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

Swedish Government published its national bioeconomy strategy, the "Swedish Research and Innovation Strategy for a Biobased Economy" in 2012. Opportunities provided by green growth are high on the political agenda in Sweden, alongside with the climate-related targets. Sweden aims to reach zero greenhouse gas emissions by 2050.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

By targeting a number of different sectors, such as agriculture, forestry, transport, automotive, construction and chemical industries, significant progress is foreseen towards increasing the size of the Swedish bioeconomy as a whole.

The priorities as outlined in the Strategy are:

1) the replacement of fossil-based resources with bio-based ones: production of fuels, plastics, pharmaceuticals, new sources of protein, foodstuff,

2) smarter/innovative use of raw materials: health promoting food products, more efficient use of by-products and fibres, recycling,

3) change of consumption habits: new products and services, new forms of foodstuff,

4) prioritisation & choice of measures: governing policies, socio-economic and environmental consequences.

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

The Swedish government released its national life science strategy at the end of 2019, focused on red biotechnology. In the bioeconomy strategy, technological research within the area of biotechnology is considered as one of the key elements to facilitate a successful transition process to a bioeconomy.

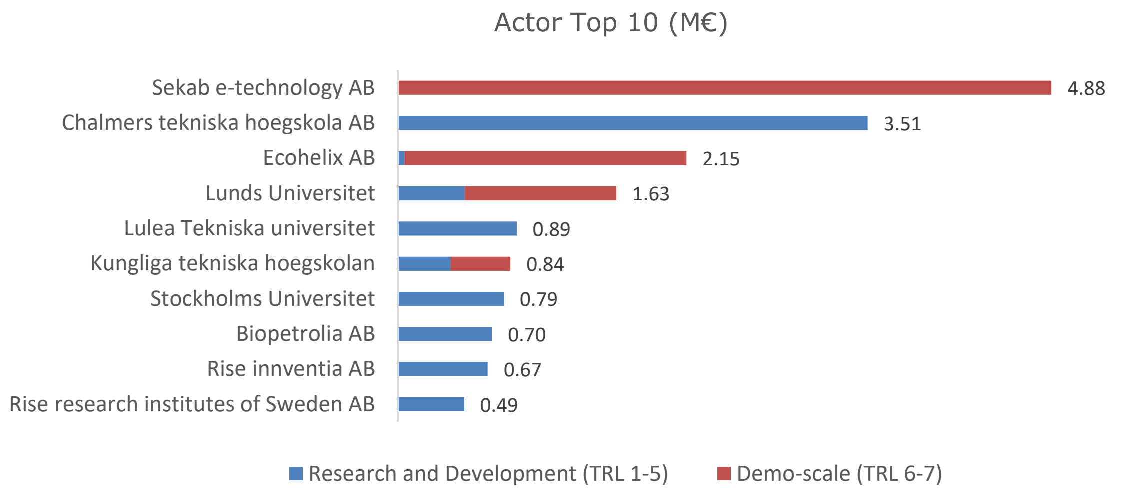
SUPPORT MEASURES

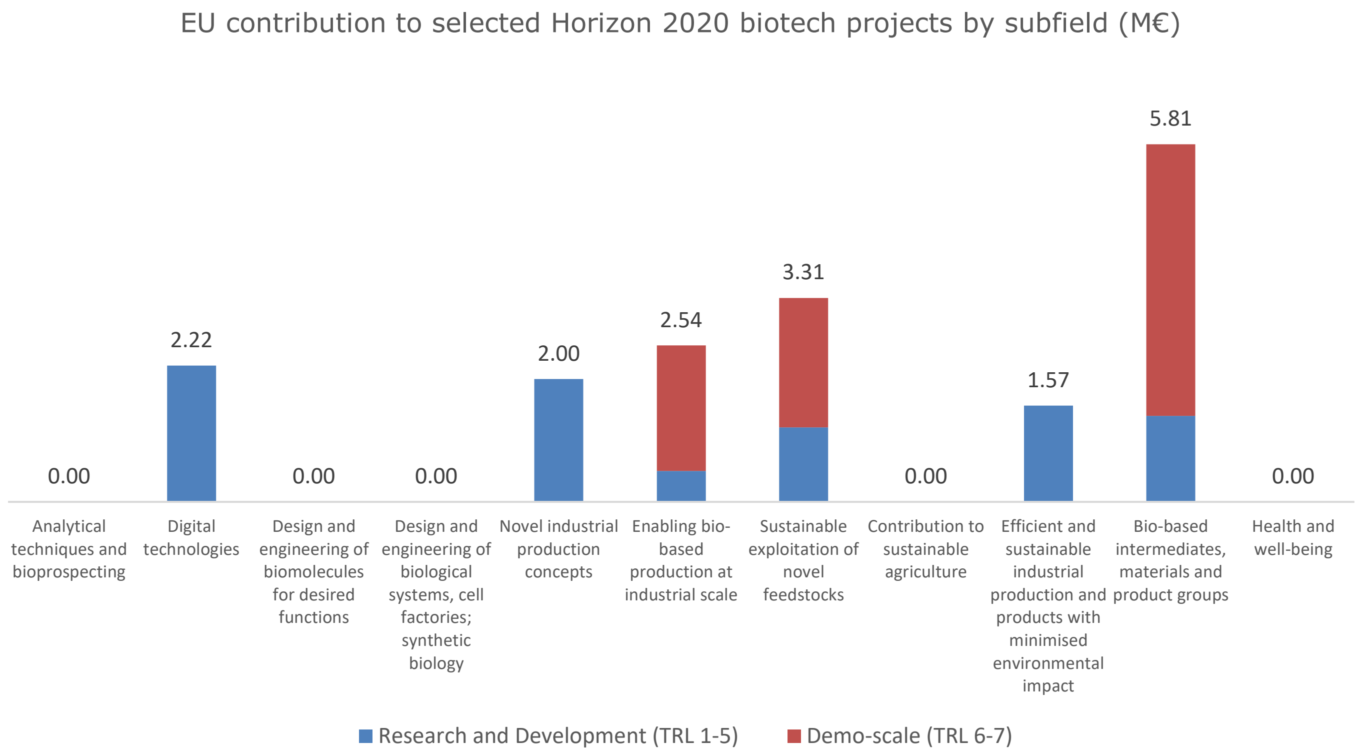
Besides EU and national level available research funds, other support measures exist. The Swedish Government recently has set up a delegation for bioeconomy at the Swedish Growth Agency to serve as a knowledge centre for the transition towards circular and bioeconomy. BioInnovation Strategic Innovation Programme financed by the public sector and the participating organisations aims to connect organisations from different industries and sectors and supports them in creating innovation projects on bioeconomy. RE:Source is a strategic innovation programme, financed by governmental bodies, with the aim of turning Sweden into a world leader in waste management and exploiting value from waste. Formas, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning Formas has allocated 2 500 000 EUR for years 2021 - 2023 to fund projects on sustainable and competitive food systems.

POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

Sweden has received 17.4 million Euro of H2020 budget for biotech related projects, ranking 11th of all EU-27 countries plus UK, equalling 1.69 Euro/capita. Approximately 43.9% of that EU budget is allocated to universities, 6.7% to research institutes, and 49.4% to the private sector. Sweden shows a clear focus towards **bio-based intermediates, materials and product groups**, consuming 35% of the total allocated budget. More specifically, **bio-based chemicals** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS





United Kingdom

✓ BIOECONOMY STRATEGY | ✓ ACTION PLAN | ✓ BIOSCIENCE RELATED POLICY | ✓ NATIONAL SUPPORT MEASURES

BIOECONOMY STRATEGY

The bioeconomy strategy (Growing the bioeconomy: a national bioeconomy strategy to 2030) aims to create the right supportive environment in the UK to help double the size of the impact of the bioeconomy (from £220bn to £440bn in 2030). Their approach is to strongly build on the **collaboration between government, industry and the research community** to transform the UK economy through the power of **bioscience and biotechnology**. Building further on their **expertise in synthetic biology and industrial biotechnology**, new businesses and solutions can be created which in turn support and enable the transformation across the bioeconomy.

TARGETED ECONOMIC SECTORS WITH THEIR CORRESPONDING PRIORITIES

The strategy set out a long-term vision for the bioeconomy which is underpinned by five strategic priorities:

- Capitalize on their great strength in RDI capability and **experience in synthetic biology and industrial biotechnology**; strengthen the way in which research is translated into commercial success.
- Maintaining and improving the highly skilled bioeconomy workforce.
- Realizing full potential of existing UK bioeconomy assets with a great emphasis on infrastructure and (sustainable use of) natural resources.
- Create the right societal and market conditions to allow novel bio-based products and services to thrive.
- Delivering benefits right across the country (i.e. coastal, rural, and urban communities).

HOW IS LIFE SCIENCE AND/OR BIOTECHNOLOGY ADDRESSED?

The United Kingdom adopted the **National Industrial Biotechnology Strategy to 2030**, developed by the Industrial Biotechnology Leadership Forum (IBLF). It becomes clear that the UK recognizes industrial biotechnology (IB) as a critical enabling technology to address major societal challenges and that the employment of an IB strategy is necessary to unlock the full potential of its IB research base. The strategy is drafted to provide policy certainty, access to finance and knowledge exchange to maximize the chances of success. Reducing CO_2, exploiting waste & reducing reliance on fossil fuels, growth in the agri-food sector, improvements in medicine manufacturing, microbiomes, green chemistry, and developing bio-based materials and fuels are priority areas for IB. In addition, the UK has adopted the **UK Synthetic biology Strategy Plan "Biodesign for the Bioeconomy"** in 2016. It is based on the Synthetic Biology Roadmap of 2012, in which **synthetic biology** is recognized as one of the "eight great technologies" of the future. It does not replace but rather build directly upon the original roadmap, seeking to accelerate commercial translation towards the delivery of products and services of clear public benefit. The synthetic biology plan fosters the transition towards **digital biology** and **laboratory automation** to unleash a new business sector of **biodesign**, and fosters the development of **platform technologies** that form much of the basis of industrial translation in synthetic biology benefits. The Scottish Industrial Biotechnology Development Group (SIBDG) has developed both the **National Plan for Industrial Biotechnology** and **The Biorefinery Roadmap** for Scotland. Furthermore, Scotland has updated its strategy for the Life Sciences sector in Scotland called **Life Sciences Strategy for Scotland 2025 Vision**.

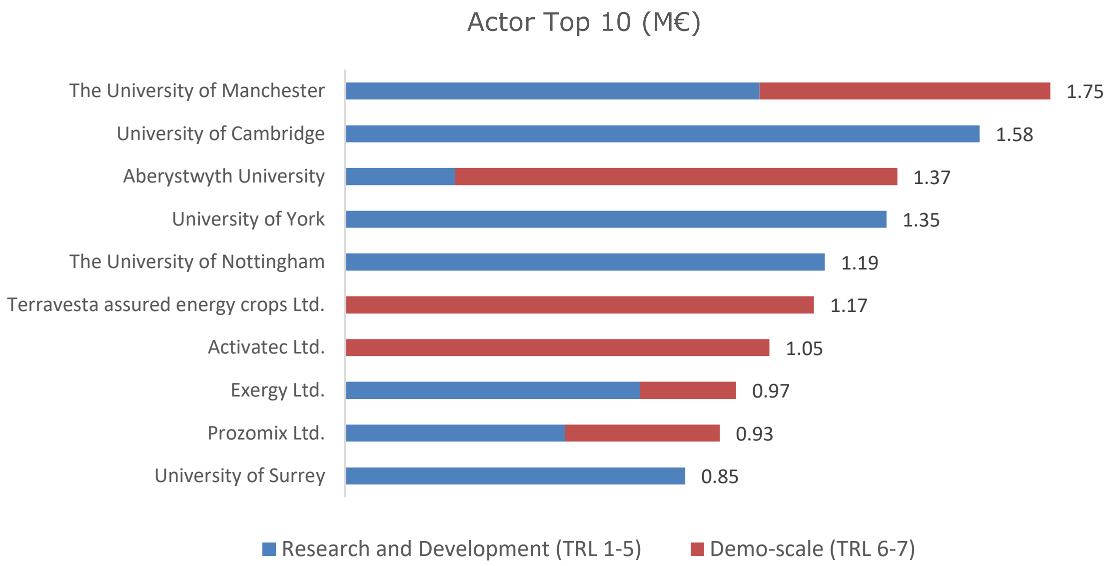
SUPPORT MEASURES

The bioeconomy strategy sets out 15 specific actions that are currently being elaborated on in a delivery plan which will have further specific outputs. The strategy already indicated an additional £4.7bn funding for research and development over the period 2018-2022. More explicitly, £1bn is intended for a range of innovation areas such as healthcare and medicine, robotics and artificial intelligence, and materials of the future. In addition, up to £60m is committed to producing smart sustainable plastic packaging.

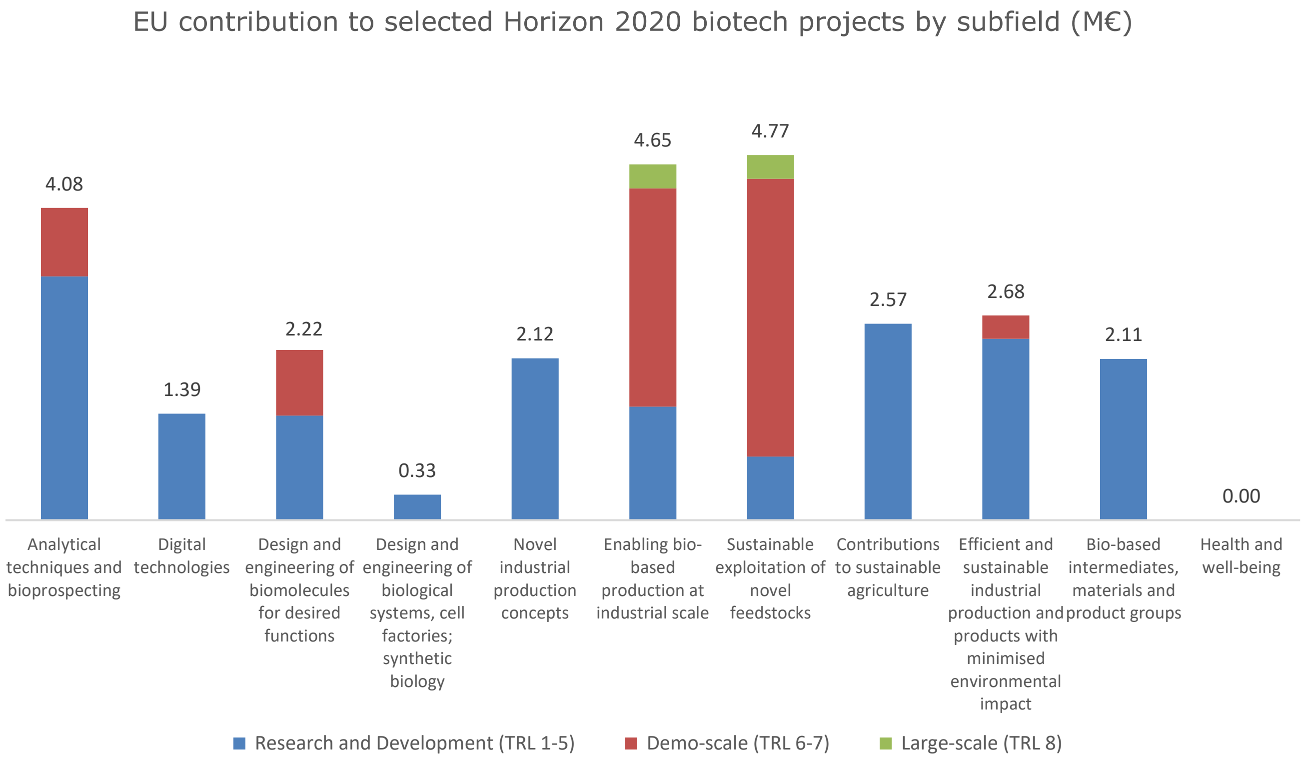
POSITION IN HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS

The UK has received 26.9 million Euro of H2020 budget for biotech related projects, ranking 7th of all EU-27 countries plus the UK itself, equalling 0.40 Euro/capita. Approximately 56.4% of that EU budget is allocated to universities, 5.5% to research institutes, and 38.1% to the private sector. The UK shows a clear focus towards **enabling bio-based production at industrial scale** and **sustainable exploitation of novel feedstocks**, consuming 35% of the total allocated budget. More specifically, **biorefineries for new feedstocks** and **crop improvement targeting the genome and epigenome** have received the largest share of the top 50 bio-based innovations.

EU CONTRIBUTION TO HORIZON 2020 BIOTECH PROJECTS LINKED TO THE TOP50 BIO-BASED INNOVATIONS



Annex VI: Innovation Factsheet



Each of the top 50 bio-based innovations is characterised by a factsheet. In Table 28 the elements of the fact sheet are explained.

Table 28. Explanation of fact sheet elements

Element of the fact sheet	Explanation
Subfield	Gives the information to which of the 11 subfields the innovation has been assigned
No.	Number of the innovation, range 1 - 50
Title	Title of the innovation
Innovation description	Gives a short description of the innovation, based on scientific literature
Illustrative example	Gives an example for the innovation to illustrate it, based on scientific literature
Priority issues	Gives in information on issues which must be addressed with priority to overcome existing hurdles for this innovation. Information sources are the EU-wide online expert survey (question 7), expert interviews and scientific literature
Icons in title line	The icons represent the application areas for which the innovation is most relevant; assessment by project team. Application areas are Environmental biotechnology; Industrial biotechnology; Marine biotechnology; Plant biotechnology
International comparison	Gives information on the EU position in international comparison. Data source EU-wide online expert survey (question 6). %-values give the share of respondents who assessed that the EU would be in a leading or average position, or lagging behind in this innovation. The EU flag marks the calculated mean of the responses. If the EU flag is above the average, it means that the EU is globally among the leaders. If the EU flag is below the average, it means that the EU is lagging behind other world regions in this innovation.
Maturity level 2020/2030	Gives information of the maturity level of the innovation in 2020 and the expected maturity level in 2030. Data source EU-wide online expert survey (questions 4 and 5). The bars show the percentage of respondents who assessed that the innovation is on the maturity level of lab scale research, pilot scale, demonstration, market introduction or in broad use. The higher the bars, the more experts are of opinion that this maturity level is achieved.
Expected impact	Gives information on the expected impact of this innovation on knowledge base, economy, environment and society. Data source EU-wide online expert survey (question 8). The bars show the percentage of experts who assessed whether the impact in the respective impact category is positive, neutral or negative.
Impact on industrial sectors	Gives information which industrial sectors will benefit to a large extent from this innovation. Data source EU-wide online expert survey (question 9). Colours on the bar indicate which share of experts are of opinion that the respective sector will benefit to a large extent.
Contribution to SDGs	The icons represent the SDGs for which the innovation is most relevant; assessment by project team
References	References with additional information on the innovation

01 Screening biodiversity

INNOVATION DESCRIPTION

In order to detect novel organisms, variants of biomolecules, biomaterials and metabolic pathways with interesting properties fast and efficiently, novel sources of biodiversity are sampled and screened with advanced technologies, using various detection methods and machine and deep learning algorithms. Novel sources are e.g. marine environments, microbiota, endosymbionts, in silico bioprospecting of databases. Technologies comprise e.g. high-throughput screening, cell-free expression systems, microfluidics. Detection methods are e.g. fluorescence activated cell sorting, mass spectrometry, nuclear magnetic resonance, colorimetric assays.

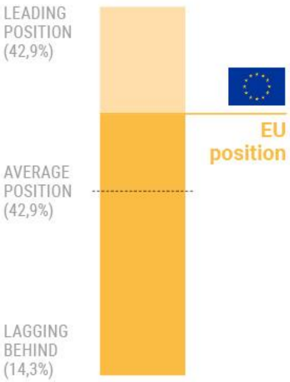
ILLUSTRATIVE EXAMPLE

Advanced high-throughput screening strategies are applied to discover e.g. new enzymes which can convert a given chemical substance: Microfluidic chips are used to generate thousands of droplets of picoliter volume per second. Each droplet functions as a reaction chamber and contains an enzyme variant and substrates. If an enzyme variant can convert the substrate, this is indicated by fluorescence or colour of the reaction product. Fluorescing or coloured droplets are sorted, and the enzyme contained in each coloured droplet is characterised further. More than 100 million enzyme variants can be screened per day in this way.

PRIORITY ISSUES

R&D in interdisciplinary cooperation is required to develop novel detection methods, not relying on fluorescence or colour, to implement screening systems with real-life selection conditions, and to use machine and deep learning. Especially sampling of extreme environments requires costly expeditions and equipment.

INTERNATIONAL COMPARISON



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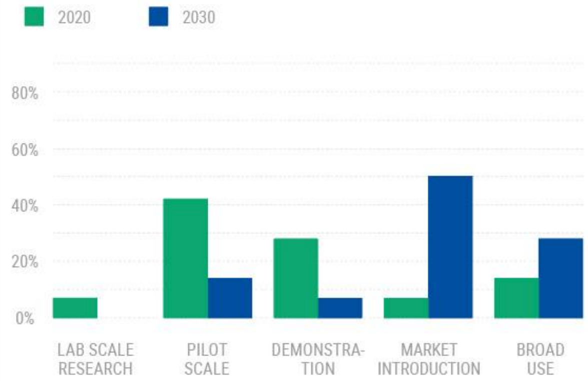

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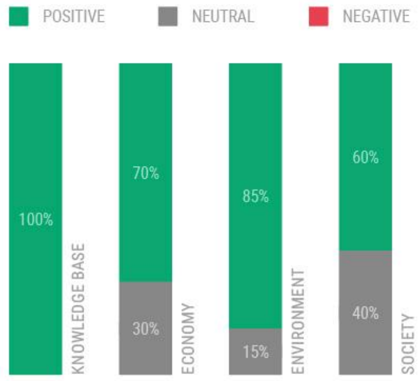
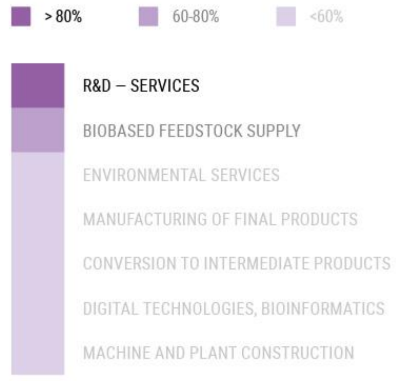


IMPACT ON INDUSTRIAL SECTORS



CONTRIBUTION TO SDGs

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02 -omics technologies

INNOVATION DESCRIPTION

With high throughput technologies ("-omics technologies", such as next generation DNA sequencing) all genes (genomics), transcripts (transcriptomics), proteins (proteomics), metabolites (metabolomics), organisms in a given environment (microbiomics) can be analysed. The enormous amount of data which is generated in this way is interpreted with bioinformatic and artificial intelligence tools. This makes biosciences data driven sciences.

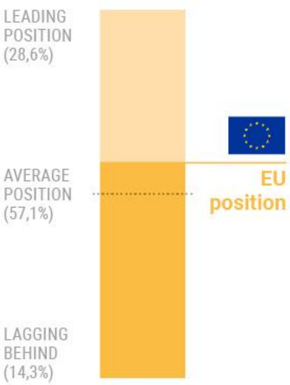
ILLUSTRATIVE EXAMPLE

The "-omics era" started with the international Human Genome Project (1991-2003) in which the entire sequence of the human genome was determined. Today, also all transcripts, proteins, metabolites of an organism, or all microorganisms in a given environment can be analysed by high throughput technologies. The results of -omics analyses can be used to e.g. better understand which properties of organisms are inherited and how they are influenced by their environment. They are also the basis for metabolic and genome engineering approaches.

PRIORITY ISSUES

Priority issues are innovation financing, due to costly equipment and consumables, and (international) cooperation, as well as staff highly qualified in interdisciplinary cooperation.

INTERNATIONAL COMPARISON



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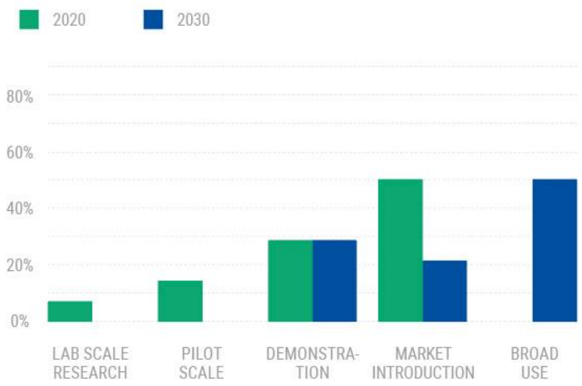

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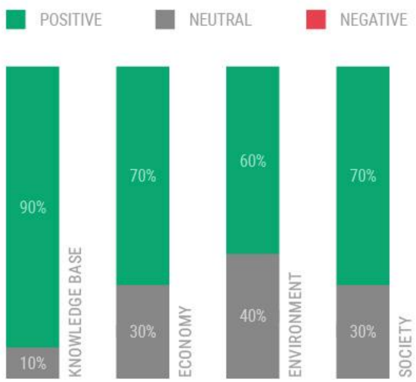

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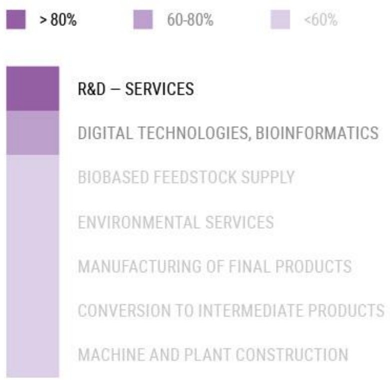

CONTRIBUTION TO SDGs

REFERENCES

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03 Analysing microbial consortia

INNOVATION DESCRIPTION

Microbiomes, i.e. complex microbial communities, can now be analysed due to advanced analytical technologies: they comprise -omics technologies, imaging, reporter systems to assess and quantify function and 3D organization of microbial communities, microfluidics, bioinformatics. With these technologies, composition, dynamics and functions of complex microbial communities (microbiomes) can be analysed qualitatively and quantitatively. This provides the knowledge base for targeted manipulation of microbiomes or engineering of microbial communities with tailored functions.

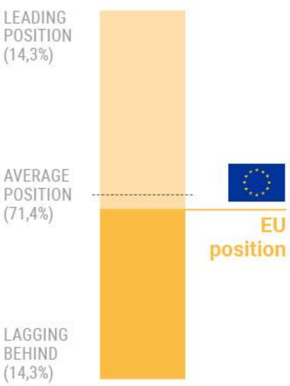
ILLUSTRATIVE EXAMPLE

By analysing the bacteria which live in the human gut ("human gut microbiome") it was not only discovered that the gut bacteria outnumber the cells which make the human body by a factor of 10. It was also established that these bacteria play a crucial role in human health and a large number of different diseases, opening new ways to prevent and treat these diseases. Brain degenerative diseases like Alzheimer and Parkinson are, for example, now considered to be linked to abnormalities in the functioning of the human gut microbiome.

PRIORITY ISSUES

R&D is the priority issue in microbiome research, to be carried out in interdisciplinary cooperation.

INTERNATIONAL COMPARISON



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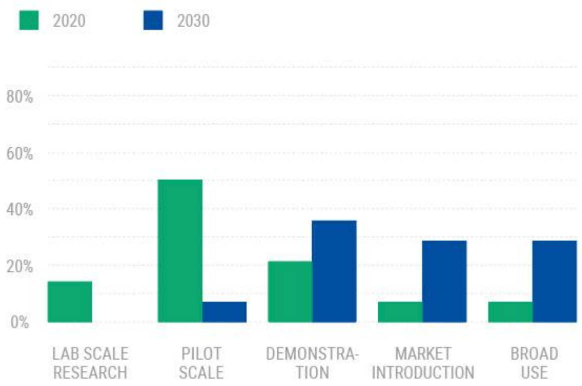

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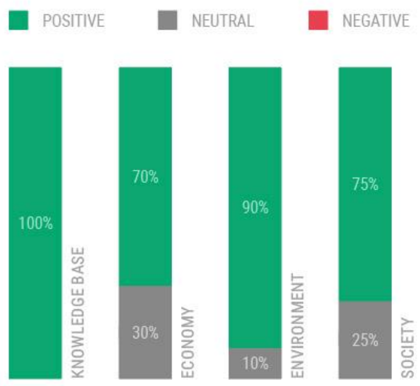

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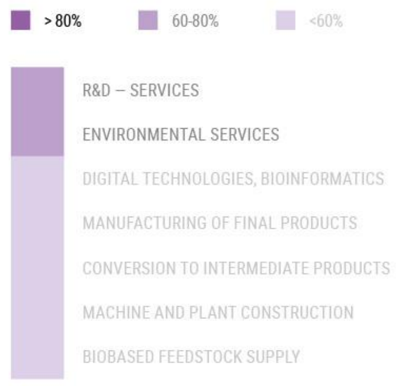

CONTRIBUTION TO SDGs

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04 Lab-on-a-chip

INNOVATION DESCRIPTION

Labs-on-a-chip (LoC) are fully automated, integrated analytical portable devices which shrink the laboratory to the size of a chip. Their specific strengths are complex analytical assays which can be performed even if no laboratory infrastructures and qualified staff are available and/or very quick results are required. LoCs can detect e.g. chemicals, antibodies or cell surface molecules, hormones or DNA sequences. Advanced systems are capable of multi-parameter measurements or even complex analytical reactions like DNA or RNA sequencing.

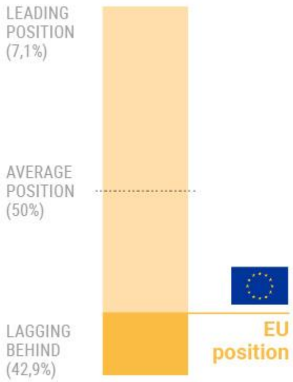
ILLUSTRATIVE EXAMPLE

Labs-on-a-chip are used e.g. in emergency medicine when there is no time to wait for the result of a laboratory analysis; in rapidly identifying infected persons in case of infectious diseases or epidemics; in process and quality control, e.g. to detect pathogens in food or drinking water; for detecting environmental contamination; for home monitoring of chronic diseases.

PRIORITY ISSUES

In order to harness the very broad application potential of labs-on-a-chip, R&D, application-specific cooperation and innovation financing are the priority issues to be addressed. Moreover, it must be proven that mobile, decentralised analyses have clear benefits over laboratory analyses.

INTERNATIONAL COMPARISON



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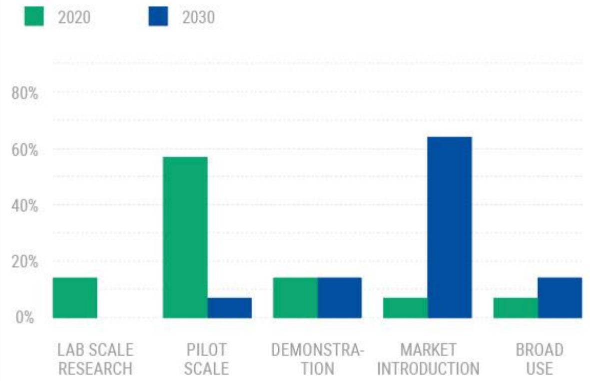

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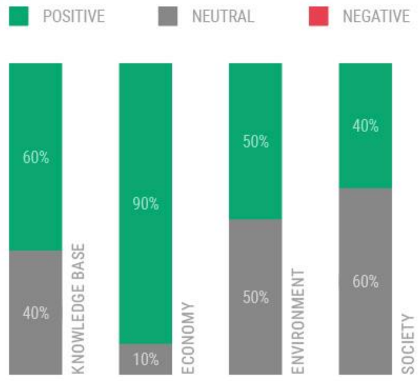

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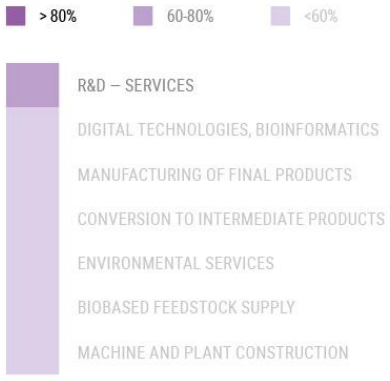

CONTRIBUTION TO SDGs

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05 Biosensing

INNOVATION DESCRIPTION

Biosensing exploits the highly specific and selective interaction of biological recognition units with analytes of interest to produce a measurable (qualitative or quantitative) signal. Its high versatility stems from

1. the broad range of biological recognition units (e.g. peptides, antibodies, enzymes, nucleic acids, aptamers, CRISPR-Cas, cell components or even whole cells or tissues), which can be further engineered for desired functions,
2. the large diversity of analytes which can be specifically and selectively measured even in complex samples, and
3. the integration into assays, stationary or portable devices, opening up applications in research, diagnostics, health and environmental monitoring, agricultural and bioproduction applications.

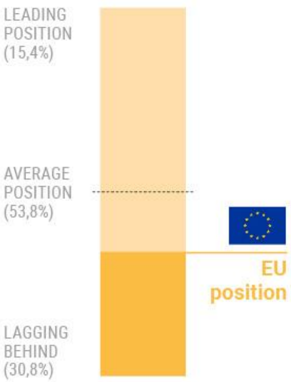
ILLUSTRATIVE EXAMPLE

Broadly used biosensors are blood-glucose tests for persons with diabetes, and pregnancy tests for home use. Gas biosensors can detect odours and smells: Olfactory receptors and odorant-binding proteins of human and animal origin are now engineered and functionally integrated into such biosensors. Odour and smell detection with biosensors holds promise e.g. in detecting food spoilage, in early diagnosis of disease, security, agriculture, and environmental monitoring.

PRIORITY ISSUES

In order to harness the very broad application potential of biosensing, R&D must address and improve the long-term stability and functionality of the biomolecules, as well as the reproducibility of measurements, and the functional integration of biosensors into assays and devices.

INTERNATIONAL COMPARISON



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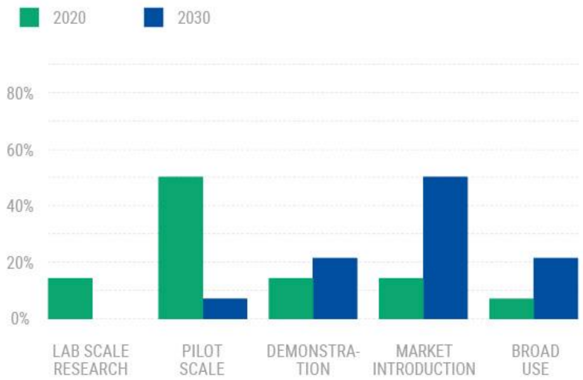

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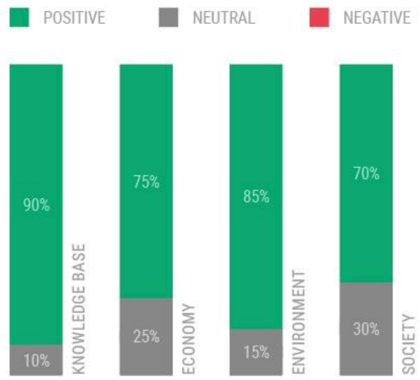

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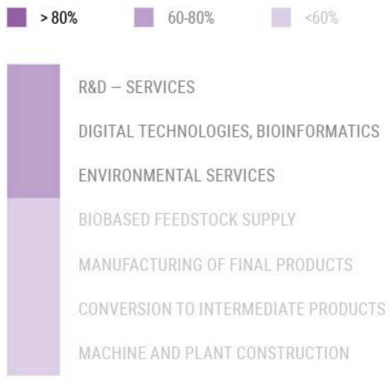

CONTRIBUTION TO SDGs

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06 Macromolecular design

INNOVATION DESCRIPTION

Computational design and directed evolution are two complementary approaches which enable the design and engineering of biological macromolecules such as proteins, DNA and RNA, and are the basis for synthetic biology, cell factory and biomaterials engineering. Functions of interest to be tailored are catalysis, binding, sensing, and regulation. Scientific-technological innovations aim at increasing the number of design and engineering experiments that can be run in parallel, at broadening the scope of functions that can be designed and engineered, at increasing the success rate and achieving superior functions (as compared to natural ones), and at designing non-natural macromolecules.

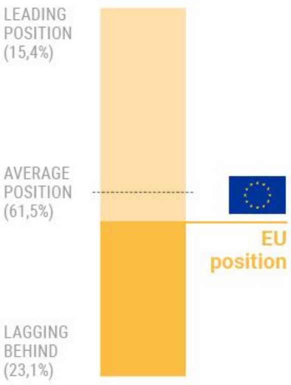
ILLUSTRATIVE EXAMPLE

Macromolecular design plays an important role in tailoring CRISPR-Cas molecules which are the tools for genome editing. With specifically designed CRISPR-Cas systems, precision genome editing simultaneously at multiple sites of the genome with no off-target effects can be achieved.

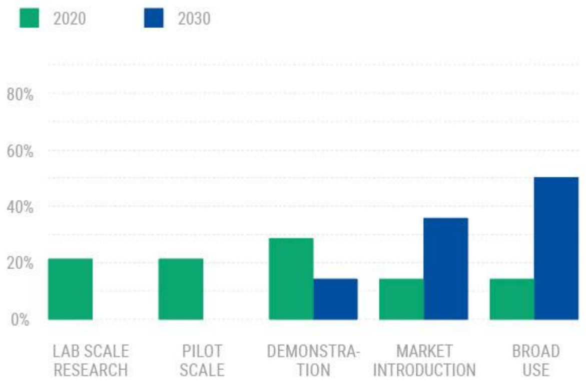
PRIORITY ISSUES

R&D both in interdisciplinary and in academia-industry cooperation should aim at improving success rates of macromolecular design for desired functions and at reducing its costs, in order to achieve broad adoption.

INTERNATIONAL COMPARISON



MATURITY LEVEL 2020/2030



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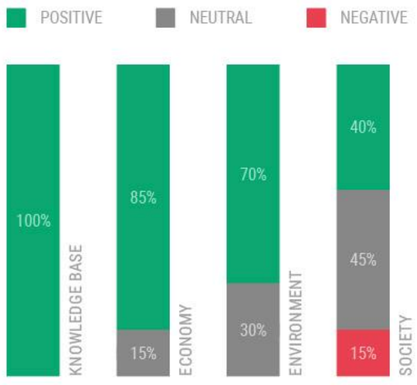
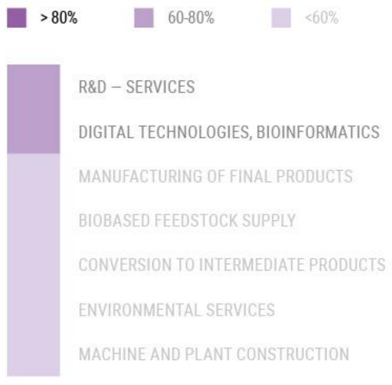


IMPACT ON INDUSTRIAL SECTORS



CONTRIBUTION TO SDGs

REFERENCES

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07 **Multi-enzyme biocatalysis**

INNOVATION DESCRIPTION

Complex reactions require the coordinated action of several enzymes. Multi-enzyme biocatalysis aims at carrying out these complex reactions as one-pot synthesis. Either, several enzymes are automatically added separately in a predefined subsequent manner to the reaction chamber, or artificial multi-enzyme complexes are created. They can be constructed by physically linking the enzymes with linking molecules, or by fusing their genes. Such multi-enzyme biocatalysis approaches can avoid several separation and purification steps, increase the yield, and cofactor regeneration can be simplified.

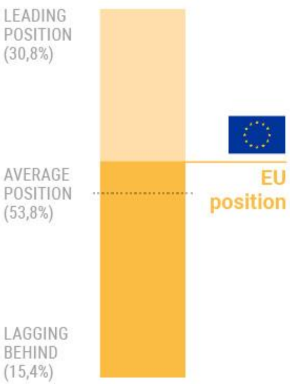
ILLUSTRATIVE EXAMPLE

In enzyme fusion, two or more enzymes are physically linked by a bridging molecule. This technique is often used for the mere simplification of multienzyme reactions. But in some cases, the fused enzymes perform better, compared to adding the enzymes separately. This has been attributed to the phenomenon of substrate channelling: the product of the first enzyme is directly channelled to the active site of the second enzyme. This is faster than random migration of the product from one enzyme to the other through the bulk solution. The pairing of two enzymes provides an advantage in terms of the production of the enzymes within the cells, their catalytic activity, and stability. This is especially the case in cascade reactions which require the regeneration of cofactors (such as NAD(P)H, $FADH_2$).

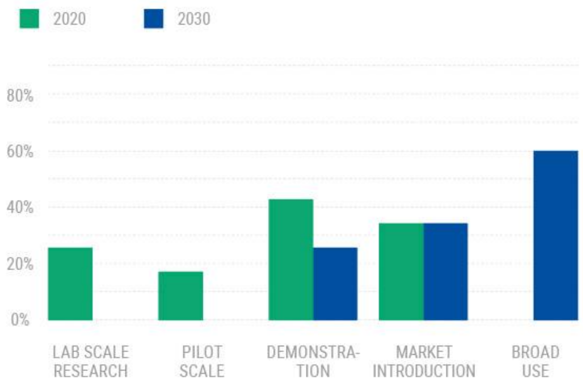
PRIORITY ISSUES

Innovation financing for more systematic, rational approaches in academia-industry cooperation is a priority issue.

INTERNATIONAL COMPARISON



MATURITY LEVEL 2020/2030



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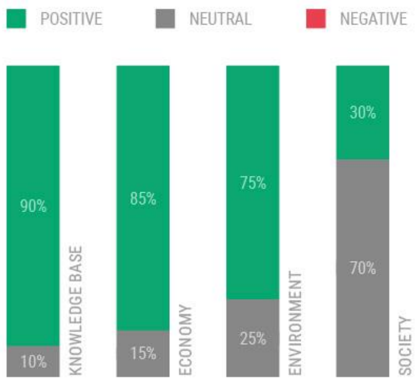
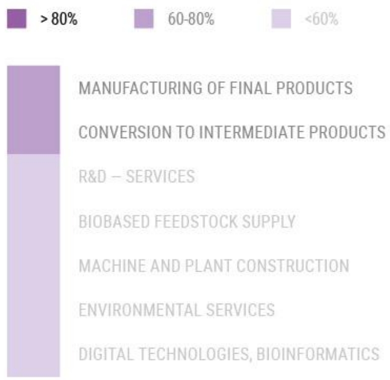


IMPACT ON INDUSTRIAL SECTORS



CONTRIBUTION TO SDGs

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08 New enzymes

INNOVATION DESCRIPTION

The spectrum of industrially relevant enzymes is broadened by discovery of new enzymes, or by designing or tailoring enzymes for specific purposes, including reactions not found in nature. Broadening the pool of enzymes will enable chemical conversions that are challenging or impossible using traditional organic chemistry (e.g. creation of new carbon-carbon bonds, regio- and stereoselective conversions, conversion of feedstock under mild conditions), enable new production processes and products, increase energy efficiency and reduce overall environmental impact of production processes.

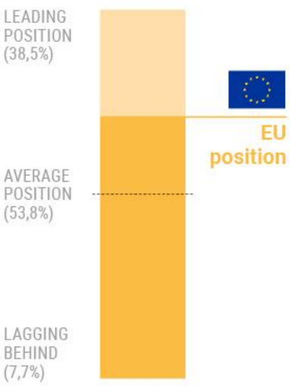
ILLUSTRATIVE EXAMPLE

Industrial enzymes have been used for decades in industries which convert biological materials, e.g. in food and beverage manufacture and processing, in the dairy-, textile-, pulp- and leather industries, but also in chemical, biofuel and pharmaceuticals production. Many consumer products contain enzymes, e.g. detergents and personal care products. More recent applications of enzymes are e.g. the recovery of precious metals from waste, or the degradation of plastics.

PRIORITY ISSUES

Enzymes are a European strength. Developing new enzymes and new applications requires both academia-industry cooperation as well as industry cooperation between enzyme providers and potential users.

INTERNATIONAL COMPARISON



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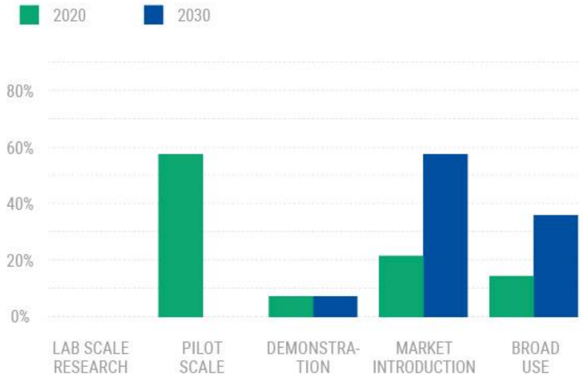

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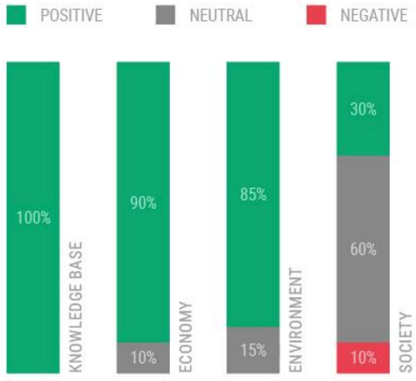

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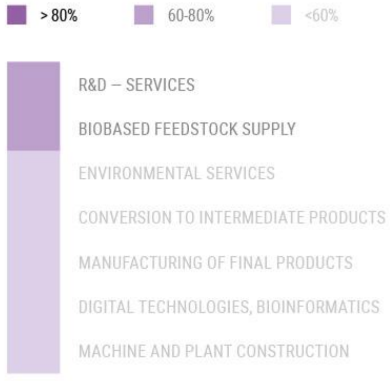

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09 Precision genome editing

INNOVATION DESCRIPTION

The CRISPR Cas based technology for genome editing is a versatile platform for intentional, direct, precise and efficient alterations of DNA and genomes. It can be applied in all important organism groups (e.g. microorganisms, crop plants, animals, humans). Innovations in the CRISPR Cas genome editing toolbox comprise increased efficiency of DNA modification and base editing, reduced off-target effects, simultaneous genome editing at multiple sites for large-scale genome modification ("multiplexing"), improved delivery of the editing system into cells, and reduced toxicity and immunogenicity.

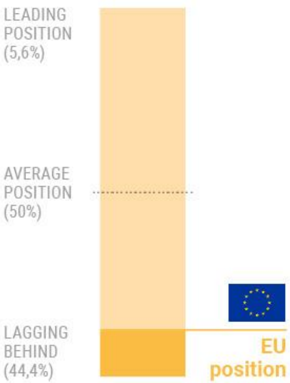
ILLUSTRATIVE EXAMPLE

The CRISPR–Cas systems enable the rapid and flexible manipulation of genomes in both targeted and large-scale experiments as well as in numerous applications. They can mainly be applied in three different ways:
to create defined alterations of specific building blocks of the genetic material on demand ("base editing");
to insert defined pieces DNA into the genetic material on demand, or delete them, respectively;
to guide functional proteins to specific sites in the genetic material, in order to regulate the function of these sites.

PRIORITY ISSUES

Regulation is seen as a top priority due to the unsettled controversy whether genome editing should fall under the genetic engineering regulation. Many survey participants from academia and industry perceive the present regulation as a disadvantage of the EU in international comparison, especially in crop plant breeding, and also as a hindrance to exploiting the innovation potential of this technology.

INTERNATIONAL COMPARISON



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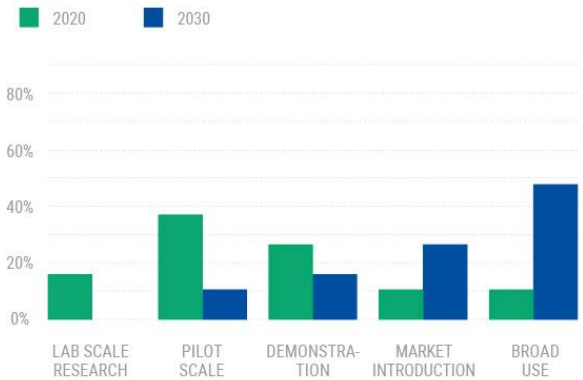

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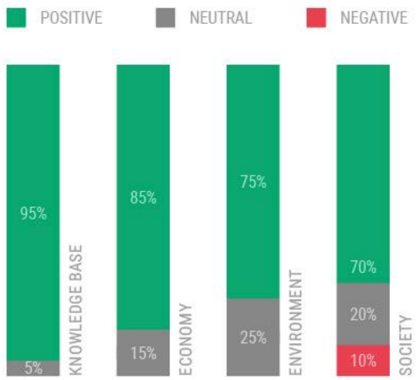

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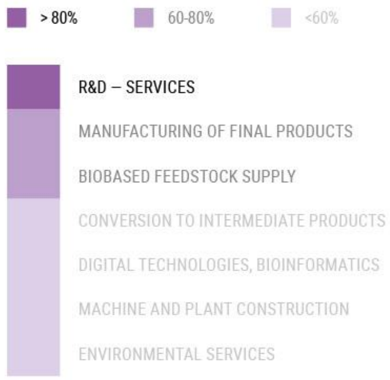

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10 Synthesis and assembly of long DNA fragments

INNOVATION DESCRIPTION

The cornerstone of engineering biology is the capability to both "read" genetic information (by next generation sequencing and genomics) and "write" genetic information on demand. Synthetic DNA fragments with designed sequences are produced at scale by chemical synthesis and assembled into longer DNA constructs. Their function can then be tested in organisms. Innovations in the synthesis of longer oligonucleotides and in the assembly of these DNA fragments with high fidelity at lower cost make it possible to rationally engineer larger parts of genomes or to even synthetize entire genomes de novo rapidly.

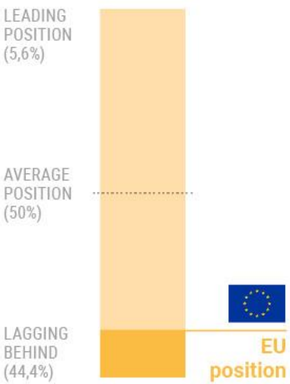
ILLUSTRATIVE EXAMPLE

The mycoplasms have the smallest genomes for cells which are capable of autonomous growth and can be found in nature. Nevertheless, even this genome contains genes which are not required for cell growth in the laboratory. In 2016, researchers wanted to find out whether it is possible to produce a minimal cell that is simpler than any natural cell. They successfully applied the technologies of synthetic DNA synthesis and assembly to produce a minimal, viable cell that is simpler than any natural one. This minimal variant of the mycoplasm Mycoplasma genitalium is used in research to determine the molecular and biological function of every gene.

PRIORITY ISSUES

Improving the technology further, especially with respect to fidelity and cost reduction, and applying it requires R&D, carried out in interdisciplinary cooperation.

INTERNATIONAL COMPARISON



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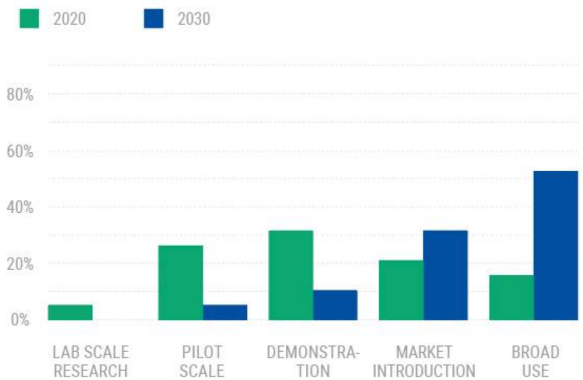

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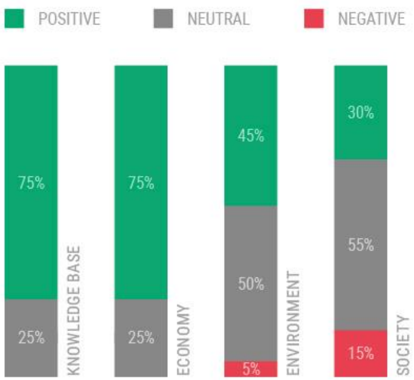

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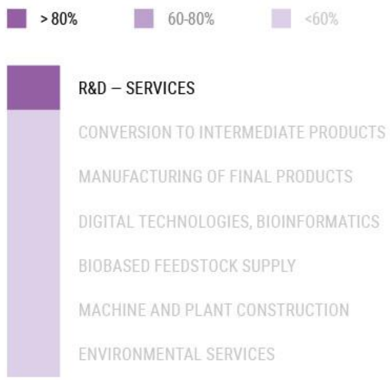

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11 Modular cloning systems

INNOVATION DESCRIPTION

Modular cloning systems facilitate the construction of complex genetic constructs. They allow for the systematic assembly of genes from basic pre-made standardized modules. Modular cloning systems make various steps from the classical cloning methods obsolete and therefore reduce time and costs required for the construction of complex genetic constructs.

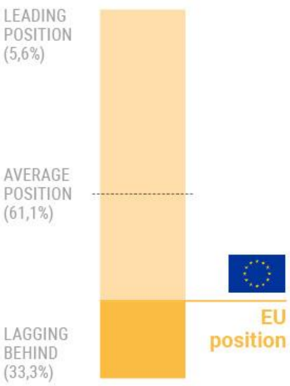
ILLUSTRATIVE EXAMPLE

Researchers wanted to study the ability of a bacterium to convert atmospheric nitrogen fixation to ammonia by investigating many different variants of the key enzyme nitrogenase and the corresponding metabolic and regulatory pathways. The overall aim was to find genetic constructs which confer the ability to fix nitrogen to a new host, e.g. a crop plant or a soil microorganism. For this purpose, a specific modular cloning system was developed and applied. It made it possible to design and synthetize in a combinatorial manner many different DNA constructs for the nitrogen fixing trait. This averted the need to design each construct individually by manually combining DNA parts. The resulting variants were then tested for the most efficient one.

PRIORITY ISSUES

Improving the technology further and applying it requires R&D, carried out in interdisciplinary cooperation.

INTERNATIONAL COMPARISON



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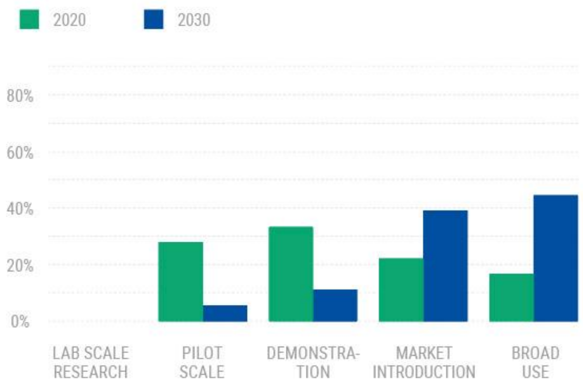

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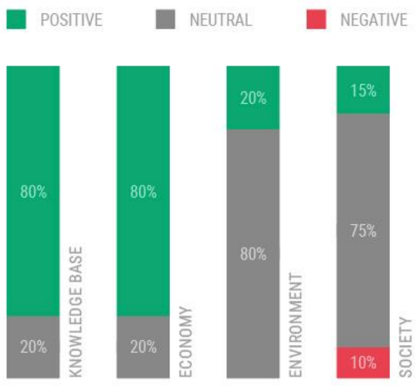

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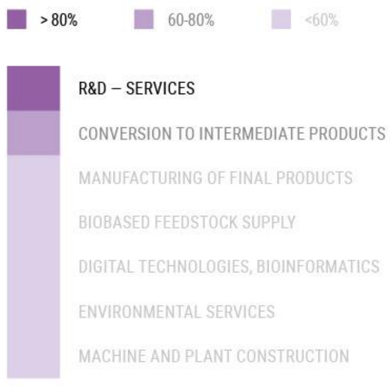

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Casini, Arturo; Storch, Marko; Baldwin, Geoffrey S.; Ellis, Tom (2015): Bricks and blueprints: methods and standards for DNA assembly. In Nature reviews. Molecular cell biology 16 (9), pp. 568–576. DOI: 10.1038/nrm4014. | Smanski, Michael J.; Bhatia, Swapnil; Zhao, Dehua et al. (2014): Functional optimization of gene clusters by combinatorial design and assembly. In Nature biotechnology 32 (12), pp. 1241–1249.DOI: 10.1038/nbt.3063.

12 **Minimal cells**

INNOVATION DESCRIPTION

Minimal cells are natural or synthetic organisms that contain only the bare minimum of genetic information needed to survive. They could function as a chassis for universal production platforms. These platforms could be tailored to the efficient production of a specific product by equipping the chassis with the respective biosynthetic pathways. Efficiency of product formation in a minimal cell should be higher compared to conventional production organisms because competition for energy and substrates between product formation and other metabolic pathways is minimized.

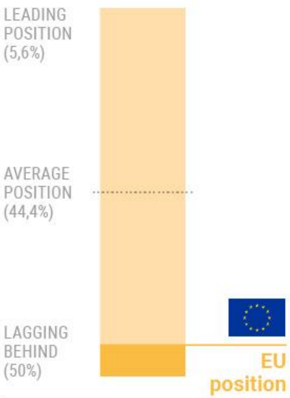
ILLUSTRATIVE EXAMPLE

Streptomyces chattanoogensis L10 is the industrial producer of natamycin, a preservative and fungicide. The goal was to develop this organism as a versatile cell factory for the production of related bioactive substances (so called polyketides) of economic importance. By multiple computational approaches, researchers identified large non-essential genomic regions, deleted them and after subsequent fine-tuning, a genome-reduced industrial Streptomyces chassis was obtained. It can serve as cell factory for high-efficient production of valuable polyketides.

PRIORITY ISSUES

The construction and application of industrially relevant minimal cells still requires substantial collaborative R&D efforts. Appropriate regulation should be developed in due time.

INTERNATIONAL COMPARISON



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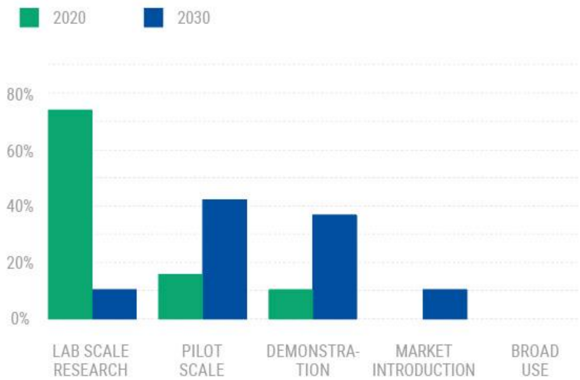

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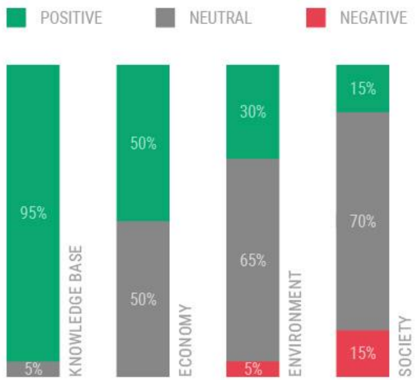

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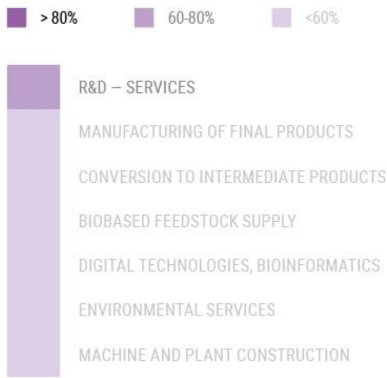

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13 Expansion of the genetic code

INNOVATION DESCRIPTION

An expanded genetic code is an artificially modified genetic code in which specific codons encode unnatural ("non-canonical") amino acids. In in vitro systems as well as in specifically engineered microorganisms, the unnatural amino acid(s) can be incorporated at any site in the protein of interest with high efficiency and fidelity. This results in proteins with interesting properties for research, catalysis, therapeutics and materials. Expanded genetic codes can also be used as biocontainment strategy so that organisms with an expanded genetic code cannot survive in natural environments.

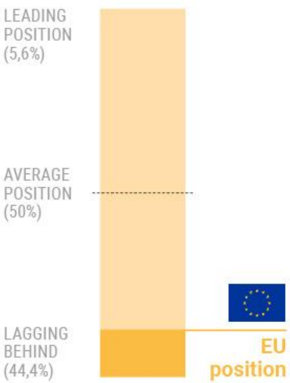
ILLUSTRATIVE EXAMPLE

A major application of organisms with modified genetic codes is the production of designer proteins with unique properties such as metal binding, having a fluorescent tag at specific protein sites, or linking them specifically with therapeutics. The genome of the organism is redesigned in a way that it incorporates an entirely synthetic, unnatural amino acid in a specific protein. Once engineered, these microbes are a self-replicating factory for continuous production of designer proteins which are used e.g. as research tools, therapeutics, biomaterials, or commodity chemicals.

PRIORITY ISSUES

Improving the technology further and applying it still requires substantial collaborative R&D efforts. Appropriate regulation should be developed in due time.

INTERNATIONAL COMPARISON



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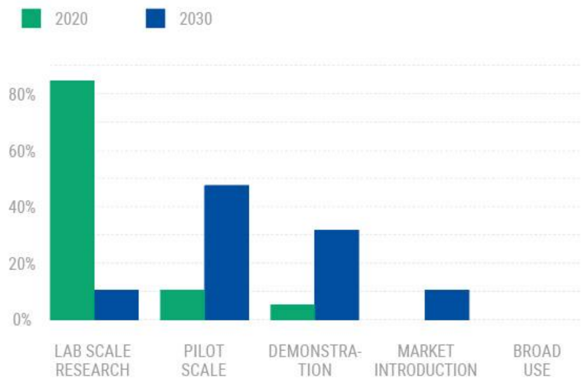

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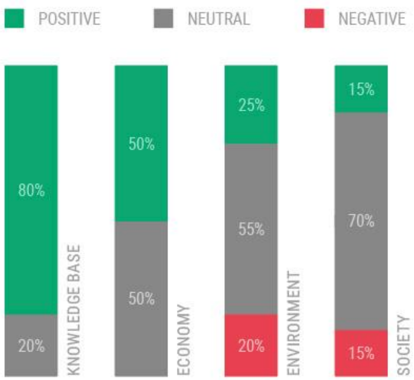

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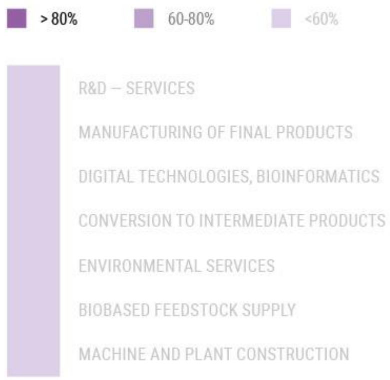

CONTRIBUTION TO SDGs

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Ostrov, Nili; Nyerges, Akos; Chiappino-Pepe, Anush; Rudolph, Alexandra; Baas-Thomas, Maximilien; Church, George M. (2020): Synthetic genomes with altered genetic codes. In Current Opinion in Systems Biology 24, pp. 32–40. DOI: 10.1016/j.coisb.2020.09.007. | Diwo, Christian; Budisa, Nediljko (2019): Alternative Biochemistries for Alien Life: Basic Concepts and Requirements for the Design of a Robust Biocontainment System in Genetic Isolation. In Genes 10 (1). DOI: 10.3390/genes10010017.

14 FAIR principle for databases

INNOVATION DESCRIPTION

Databases are set up and maintained in a way that they comply with the FAIR principle, which means findable, accessible, interoperable, reusable. Access to high quality data is the essential prerequisite for realising the full potential of bioinformatics and artificial intelligence uses in the life sciences.

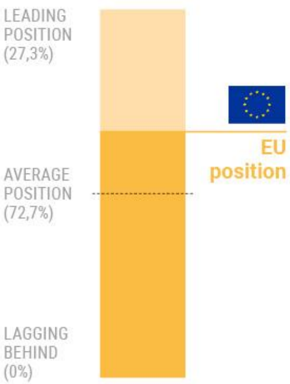
ILLUSTRATIVE EXAMPLE

A researcher wants to compare his own experimental data with findings from other researchers. The following questions could be easily answered if the databases comply with the FAIR principles: In which repositories can the required data be found? What search tools should be used? Is the relevant search information ('metadata') captured by the repositories? Can the data be downloaded in a format that can be easily integrated with private in-house data as well as other data publications from third-parties? Can this integration be done automatically to save time and avoid copy/paste errors? Does the researcher have permission to use the data from these third-party researchers, under what license conditions, and who should be cited if a data-point is re-used?

PRIORITY ISSUES

International adoption of the FAIR principles is required in order to exploit the potentials of -omics technologies in a data economy. This may require solutions to intellectual property issues and for benefit sharing.

INTERNATIONAL COMPARISON



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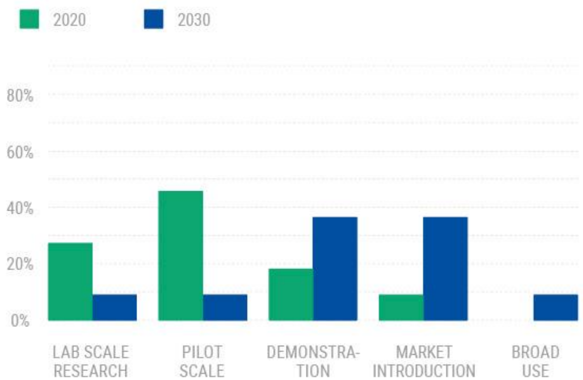

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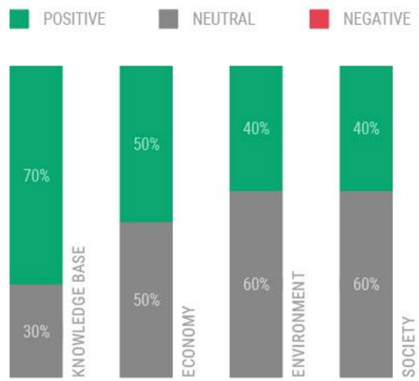

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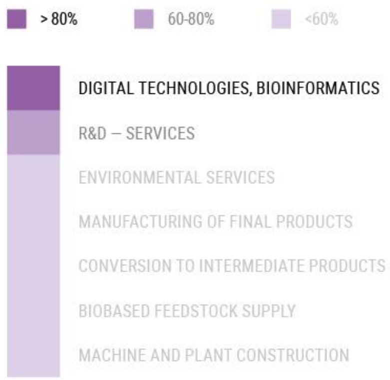

CONTRIBUTION TO SDGs

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15 Deep Learning

INNOVATION DESCRIPTION

-omics approaches yield very large data sets which require novel tools for analysis and for extracting meaning from the data, such as algorithms based on machine learning and deep learning.

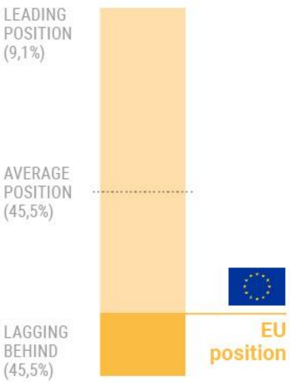
ILLUSTRATIVE EXAMPLE

The plant breeding process could be significantly accelerated and its success rate increased, if it were possible to predict the crop phenotype (i.e. its relevant properties, e.g. drought tolerance) directly from genome data. However, it is often not known how many and which genes contribute to the desired trait, so that conventional statistical correlations between plant genotype and phenotype are of limited predictive accuracy. It has been shown that deep learning can be successfully applied to increase the accuracy of predicting the phenotype from genome data.

PRIORITY ISSUES

Substantial R&D efforts are required to improve the quality and validity of results of applying deep learning in the life and biological sciences. Exploitation of the huge, largely untapped potential of artificial intelligence and deep learning in the life sciences requires intensive cooperation between technology companies, specialised in artificial intelligence, and life and biological sciences and technology actors. Lack of qualified staff is also an important issue.

INTERNATIONAL COMPARISON



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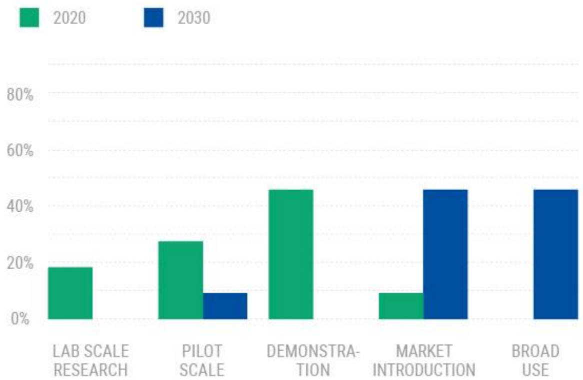

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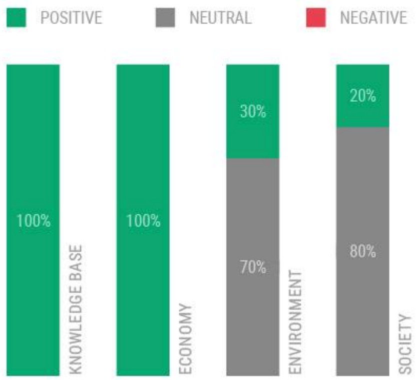

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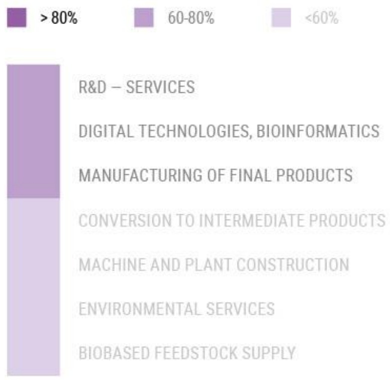

CONTRIBUTION TO SDGs

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16 Computational protein design

INNOVATION DESCRIPTION

Computational protein design aims at providing specific amino acid sequences that convey the desired three-dimensional protein shapes or functions (e.g. enzyme activity). By predicting functions from sequences, likely functional (and non-functional) proteins can be identified in silico without producing and directly testing them. Computational protein design thus complements directed evolution approaches and bears the potential to speed up design-build-test-learn cycles in protein engineering.

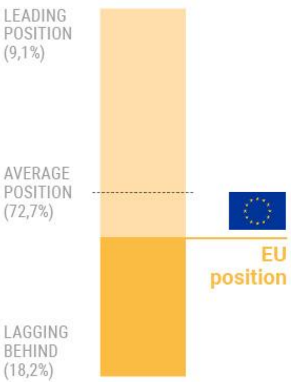
ILLUSTRATIVE EXAMPLE

Computational protein design is applied to e.g. enzymes, biopharmaceuticals and antibodies. Information can be gleaned how the protein should be engineered to achieve improved enzymatic or physiological activity, improved stability, or improved selectivity and specificity for the target (e.g. substrate, antigen).

PRIORITY ISSUES

While computational protein design broadens the toolbox for protein design and optimisation, collaborative R&D by academia and industry must improve the success rate, quality and validity of design efforts to achieve a broad adoption. Moreover, the potential to design proteins not found in nature should be exploited.

INTERNATIONAL COMPARISON



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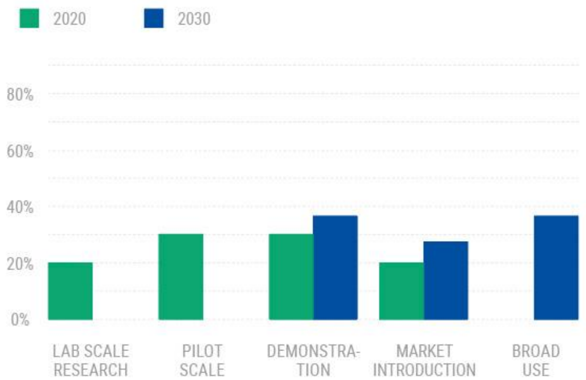

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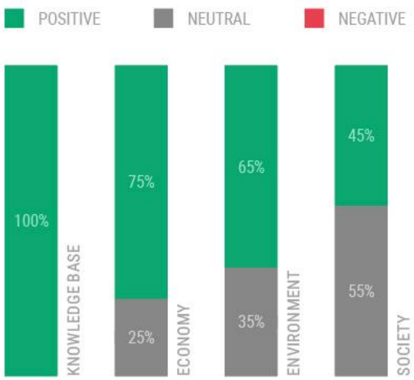
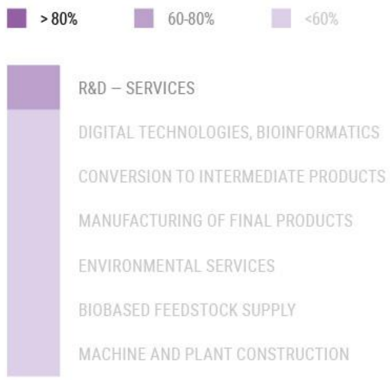


IMPACT ON INDUSTRIAL SECTORS



CONTRIBUTION TO SDGs

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17 Computational cell factory engineering

INNOVATION DESCRIPTION

Computational tools support the engineering of cell factories: they are used to identify suitable genes, enzymes and regulatory elements and to suggest best sets of these elements for metabolic and regulatory networks. By combining multi-omics data with computational models and machine learning, hypotheses for functional metabolic pathways can be derived, which help to guide experimental optimisation of the cell factory, diagnose failures, and predict which elements must be changed to better meet design goals. This increases the efficiency of design-build-test-learn-cycles in cell factory engineering.

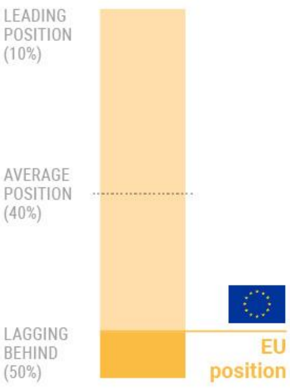
ILLUSTRATIVE EXAMPLE

Researchers wanted to design a completely novel metabolic pathway for the use of atmospheric CO_2 as carbon source which had theoretical higher efficiency than the known natural CO_2 fixation pathways. Building on profound chemical knowledge, they searched enzyme data bases for known enzymes from different organisms which could be combined to the novel pathway. Computational models were then applied to identify the best combinations of these enzymes. Moreover, further optimisation of the enzymes by protein engineering was required. It was shown that CO_2 could successfully be fixed via the artificial pathway in vitro.

PRIORITY ISSUES

While tools for metabolic engineering and gene regulatory network engineering, based on high-throughput, data-driven workflows are well-developed for industrially relevant unicellular microorganisms, collaborative R&D by academia and industry should aim at broadening the tools for more organisms, especially microbiomes, more metabolic and regulatory pathways and for integration of multi-omics with other biological data.

INTERNATIONAL COMPARISON



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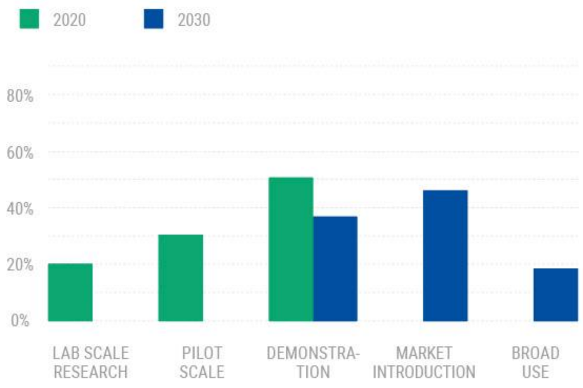

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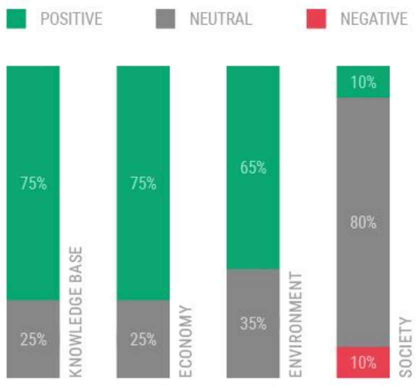

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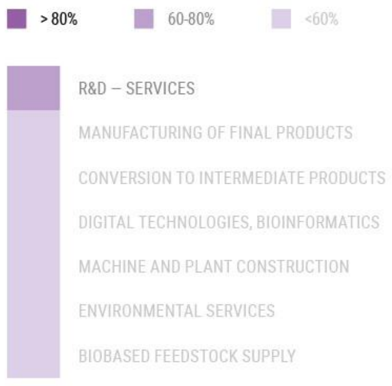

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Presnell, Kristin V.; Alper, Hal S. (2019): Systems Metabolic Engineering Meets Machine Learning: A New Era for Data-Driven Metabolic Engineering. In Biotechnology journal 14 (9), e1800416. DOI: 10.1002/biot.201800416.

18 **Process models**

INNOVATION DESCRIPTION

Process models are important elements for the digitalisation of the bioprocess industry. In bioprocess development, they support bioprocess optimization, design of experiments, and scale-up/-down. In bioprocess monitoring and control, they support proactive real-time decision-making, stringent quality control, and optimal automated operation. Data generation, analysis and interpretation require sensor technology, computational power, data management solutions, and data analytics techniques.

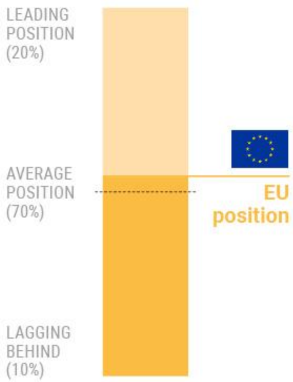
ILLUSTRATIVE EXAMPLE

One application of process models is process control. Conventional process control often relies on measuring only a few parameters (e.g. temperature, pH, dissolved oxygen) at-line or off-line and feeding of substrates and nutrients without exact knowledge of the actual process state. Advanced process models are dynamic and adapt the control strategy in real time by feedback loops. These models contribute to more consistent product quantity and quality and support the staff in decision-making how to operate the process.

PRIORITY ISSUES

Cooperation between academia, providing expertise in process modelling, and industry providing the bio-production relevant data for the models, is the key issue in advancing the digitisation of the bioprocess industry.

INTERNATIONAL COMPARISON



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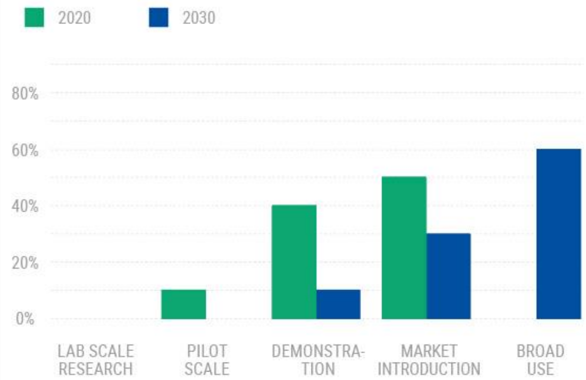

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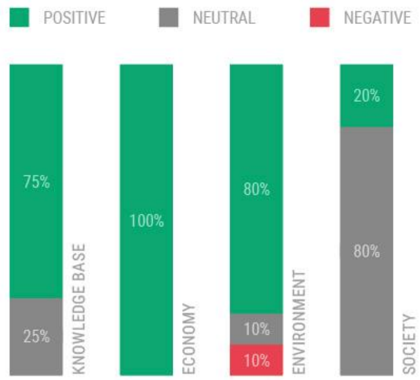

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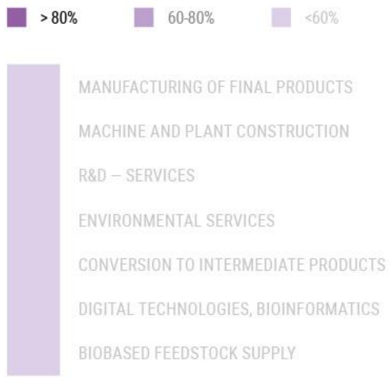

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19 Novel microbial cell factories

INNOVATION DESCRIPTION

In addition to "traditional" industrial cell factories (e.g. E. coli, yeast, Bacillus), a broader range of microorganisms and microbial communities is established as production platforms, making use of their specific capabilities: e.g. utilization of CO_2 or non-sugar feedstocks (methane, lignocellulose) as carbon source; using sunlight, hydrogen or electricity as energy source; more efficient production and secretion of complex macromolecules.

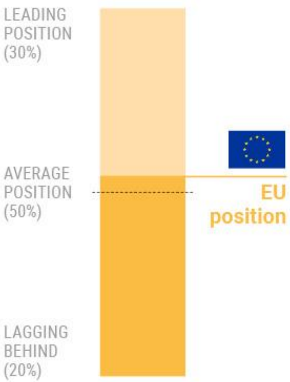
ILLUSTRATIVE EXAMPLE

Traditional industrial cell factories require sugars as carbon and energy source for growth and bioproduction. By contrast, autotrophic organisms like microalgae or photosynthetic bacteria use CO_2 as carbon and sunlight as energy source. If these autotrophic organisms were used as industrial cell factories, this could enable increased industrial bioproduction without increasing its demand for biomass and land. Moreover, autotrophic production is potentially carbon-neutral and potentially more energy efficient than using traditional industrial cell factories.

PRIORITY ISSUES

Substantial interdisciplinary, collaborative R&D efforts are required to develop readily applicable molecular biology tools and computational engineering tools for systemic optimisation of novel microbial cell factories. Yield and productivity need to be improved substantially.

INTERNATIONAL COMPARISON



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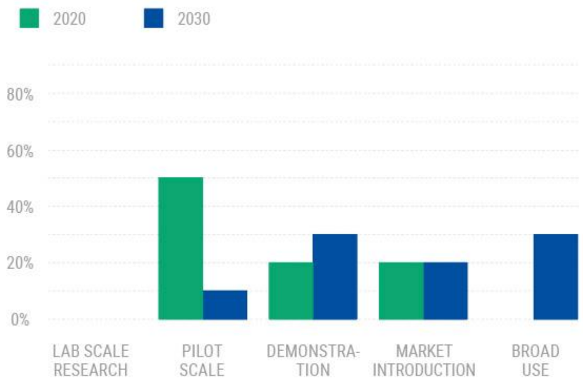

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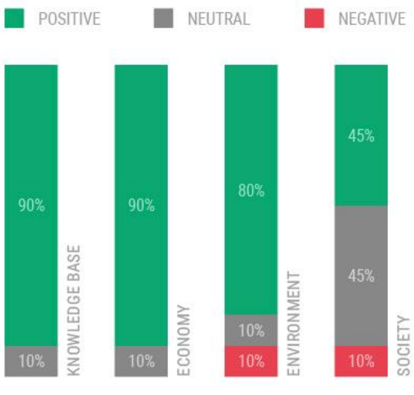

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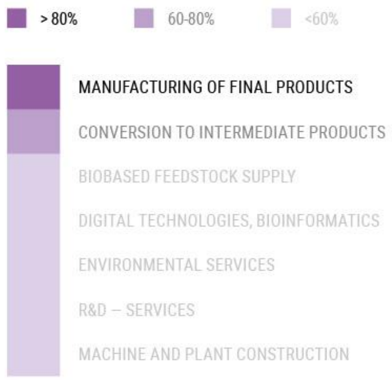

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Claassens, Nico J.; Sousa, Diana Z.; Dos Santos, Vitor A. P. Martins; Vos, Willem M. de; van der Oost, John (2016): Harnessing the power of microbial autotrophy. In Nature reviews. Microbiology 14 (11), pp. 692–706. DOI: 10.1038/nrmicro.2016.130.

20 Engineering microbial consortia

INNOVATION DESCRIPTION

Microbial consortia (microbiota) - either as biofilms or in suspension - are exploited as novel cell factories for bioproduction: complex metabolic tasks are synergistically partitioned between different organisms. In order to establish stable bioprocesses, research into the composition, architecture of 3-dimensional microbiota, dynamics and metabolism as well as the modelling and engineering of such consortia is required. Applications comprise, among others, synthetic chemistry (ranging from specialty to bulk chemicals), bioenergy, biologics and the food industry.

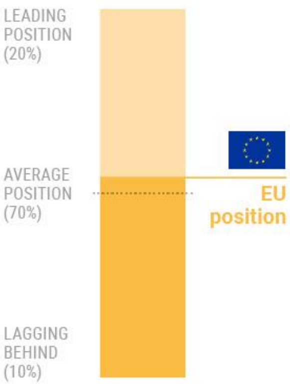
ILLUSTRATIVE EXAMPLE

Bacteria with different carbon source preferences are combined and engineered in a way that the resulting microbiome can degrade complex mixtures of carbon sources and feedstocks and more efficiently utilize substrates without releasing carbon dioxide. Microbiome biofilms are engineered to produce antimicrobial compounds (e.g., antibiotics, antibacterial peptides) in the presence of contaminating microbes. By mitigating contaminations in this way, wider use of non-aseptic fermentation facilities could become possible.

PRIORITY ISSUES

While proof of concepts have shown a large potential of microbial consortia for industrial biotechnology, substantial collaborative R&D efforts, ranging from basic to industrial implementation research, are still required.

INTERNATIONAL COMPARISON



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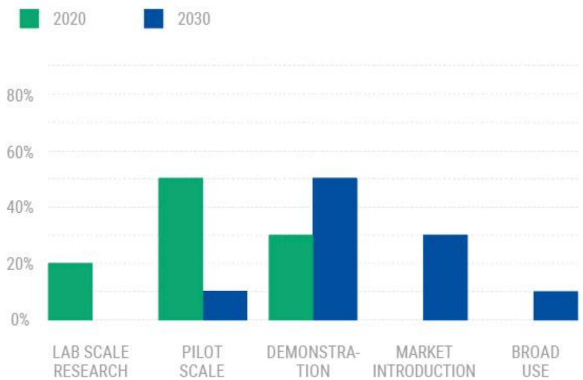

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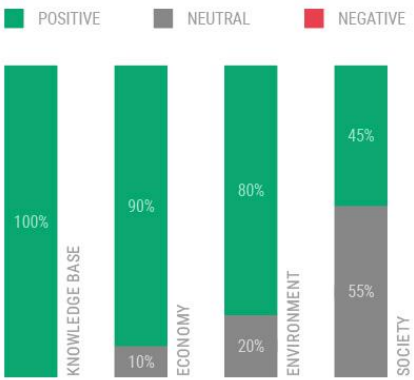

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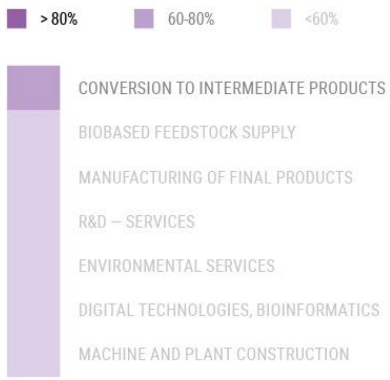

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21 Microbial Electrosynthesis

INNOVATION DESCRIPTION

Microbial electrosynthesis is a biotechnological production system in which electrical power is the energy source for the biosynthesis of the desired products. The bioreactor is equipped with electrodes. Electrons are either transferred directly or via mediator compounds between the electrodes and the microorganisms. With microbial electrosynthesis, even energetically unfavourable reactions, e.g. the reduction of carbon dioxide to organic molecules, can be performed with high efficiencies. Novel bioreactor concepts are required which enable surface interactions between electrodes and bacteria. Alternative options aim at coupling effective electrochemical reactions (e.g. electrolytic reduction of carbon dioxide (CO_2) to carbon monoxide or ethanol; electrolytic hydrogen production) with subsequent fermentation processes.

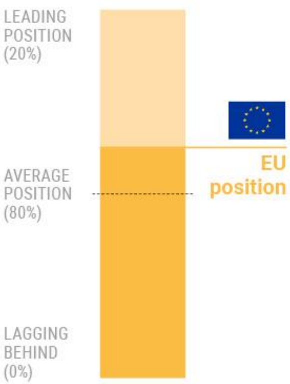
ILLUSTRATIVE EXAMPLE

The bioelectrosynthetic reduction of CO_2 to industrially relevant chemicals has attracted most interest due to its scientific novelty, possible societal and ecological impact if "green" electricity is used. It has been shown in the laboratory that industrially relevant chemical commodities such as organic acids (acetic acid, butyric acid) and alcohols (ethanol, isopropanol, butanol, and isobutanol) can be produced by microbial electrosynthesis.

PRIORITY ISSUES

Proof of concepts have shown a large potential of microbial electrosynthesis for highly efficient bioproduction without relying on organic carbon and energy sources. However, substantial collaborative and interdisciplinary R&D efforts, ranging from basic research via bioreactor development to scale-up and industrial implementation research, are still required.

INTERNATIONAL COMPARISON



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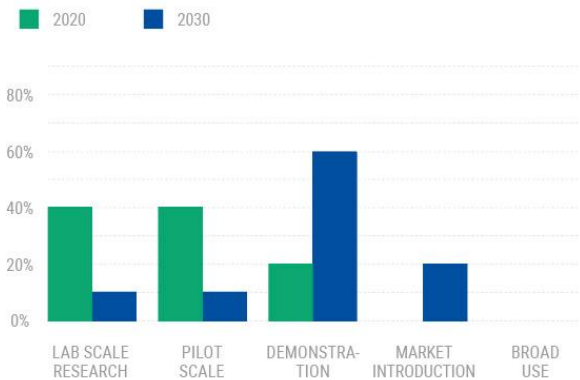

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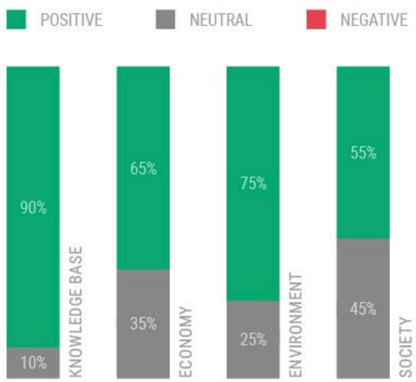

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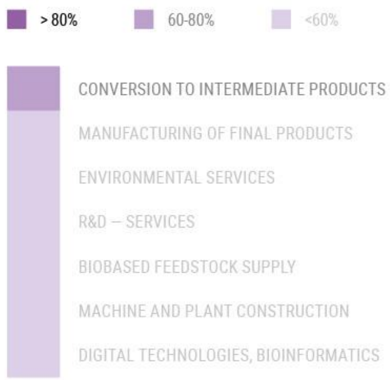

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Prévoteau, Antonin; Carvajal-Arroyo, Jose M.; Ganigué, Ramon; Rabaey, Korneel (2020): Microbial electrosynthesis from CO_2: forever a promise? In: Current opinion in biotechnology 62, S. 48–57. DOI: 10.1016/j.copbio.2019.08.014.

22 Optimising biorefineries

INNOVATION DESCRIPTION

The process and product spectra of established biorefineries and biobased production facilities are broadened by innovative technologies, processes and products. Pretreatment, conversion, and downstream processing become fully integrated and are optimised, in order to convert biomass efficiently at a large scale, to deliver high product quality consistently, to reach zero waste and to compete with the fossil-based industry at higher energy efficiency and sustainability standards.

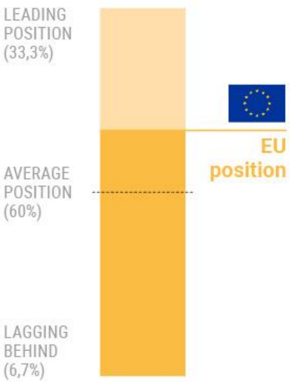
ILLUSTRATIVE EXAMPLE

The pulp and paper industry runs biorefineries which process wood. Microfibrillated cellulose (MFC) is an innovative product of pulp and paper biorefineries. It serves as an example how the product portfolio of these biorefineries can be broadened. MFC can be obtained by enzymatic pretreatment of wood pulp followed by a mechanical production step. By mixing a small amount of MFC into the wood pulp, paperboard is obtained with the same strength, opacity and brightness but lower fibre use. The large surface area of MFC allows for stronger composites, saving weight and material. Paperboard enhanced with MFC has been commercialised e.g. in milk cartons for the dairy industry.

PRIORITY ISSUES

Measures are required which increase the competitiveness of biorefinery products: this comprises investments into more efficient processes, facilities and infrastructures of biorefineries as well as demand-side policy measures aiming at market creation.

INTERNATIONAL COMPARISON



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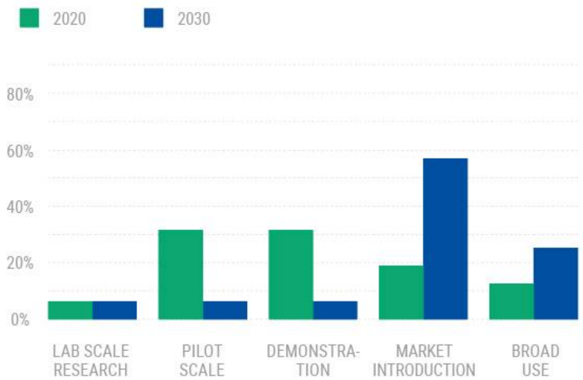

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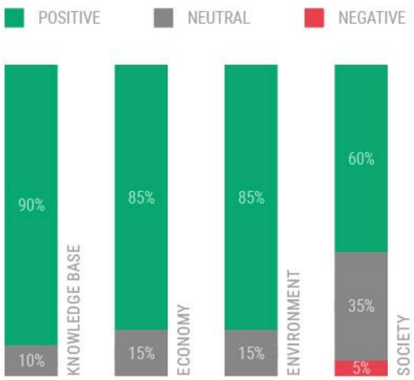

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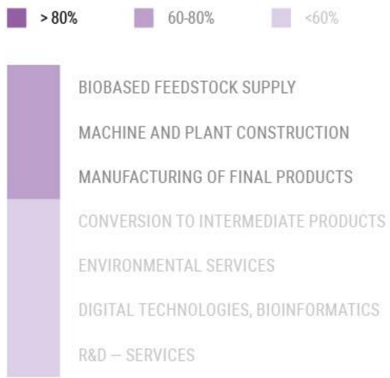


CONTRIBUTION TO SDGs

REFERENCES

Wagemann, Kurt; Tippkötter, Nils (Eds.) (2019): Biorefineries. Cham: Springer International Publishing.

23 Biorefineries for new feedstocks

INNOVATION DESCRIPTION

Biorefineries are developed and optimised for the conversion of currently underexploited non-food biomass feedstocks, such as grass, algae and organic municipal waste. They can process multiple feedstocks, by deploying a range of mechanical, physicochemical and enzymatic pretreatment and fractionation techniques combined with chemical, enzymatic or microbial conversion processes. A diversity of value-added products is generated. Biorefineries for new feedstocks complement existing biorefineries and make a large amount of new, non-food feedstock available for the bioeconomy.

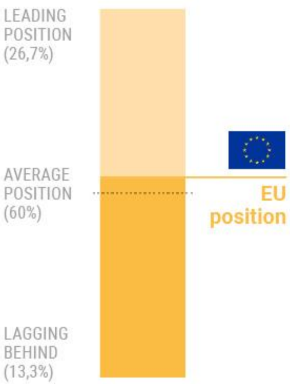
ILLUSTRATIVE EXAMPLE

A macro-algae biorefinery integrates algae biomass production, harvesting and refining. A key issue is reducing energy demand and waste in processing marine biomass. While the current focus is on the optimisation of processing known algae and on near shore aquaculture, in the longer term the inclusion of new species and new culturing regimes (offshore, deep sea aquaculture) will become more relevant.

PRIORITY ISSUES

Substantial R&D efforts as well as financing of pilot and demonstration facilities are required to develop, scale-up and implement biorefineries for novel feedstocks. Cross-sector cooperation between feedstock-providing and feedstock-converting industries is important.

INTERNATIONAL COMPARISON



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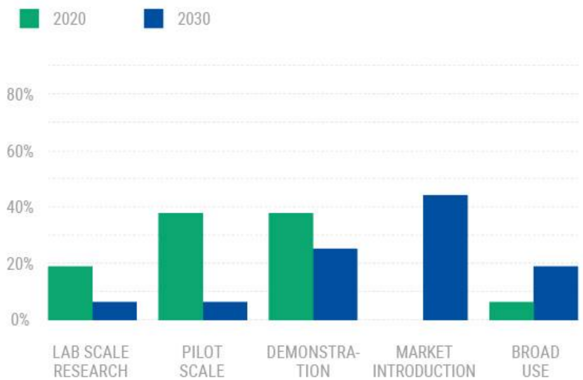

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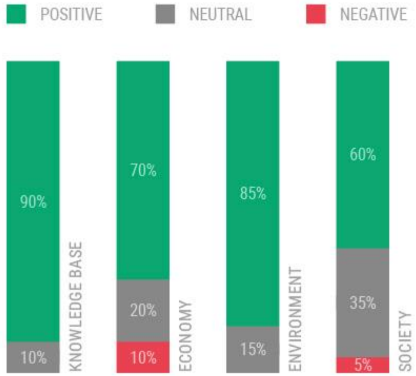

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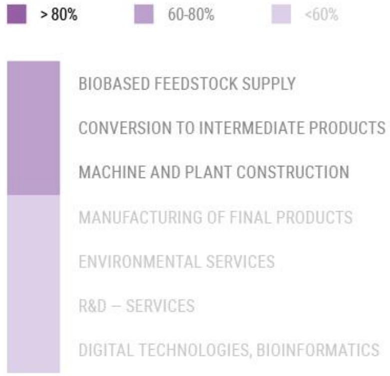

CONTRIBUTION TO SDGs

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24 Reactor design and process monitoring

INNOVATION DESCRIPTION

New bioreactor designs and process analytical technologies (PAT) are required for novel microbial cell factories (e.g. photosynthetic microorganisms, microbiomes) and bioprocesses (e.g. electrobiosynthesis). By collaboratively and synergistically integrating reactor design, process design and monitoring design, robust processes and high and consistent product quality can be achieved.

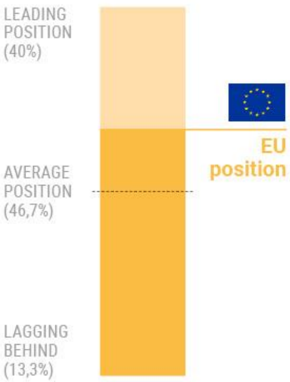
ILLUSTRATIVE EXAMPLE

Many different types of reactors have been developed for innovative biotechnological processes, such as microbioreactors, photobioreactors, industrial continuous culture reactors, single-use reactors, and reactors for electrobiosynthesis. Innovations in PAT comprise e.g. novel analytical techniques, previously mainly used in laboratories, but not in manufacturing, real-time continuous measurements instead of at line, discontinuous analyses, automation, and decision support by bioinformatics and artificial intelligence interpretation of process data.

PRIORITY ISSUES

Financing for the development, scale-up, piloting and demonstration of novel reactor and process monitoring concepts is a key issue to be addressed to achieve their industrial implementation..

INTERNATIONAL COMPARISON



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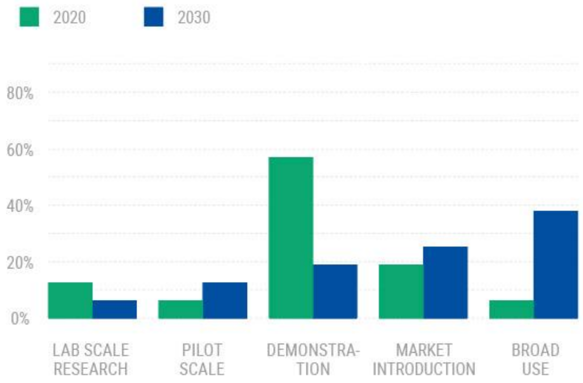

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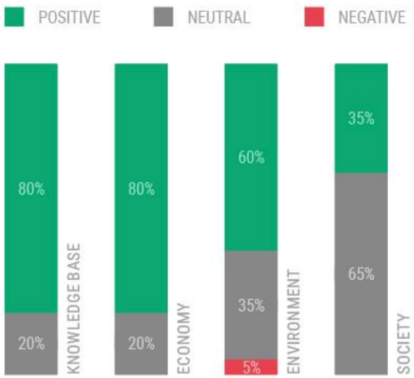

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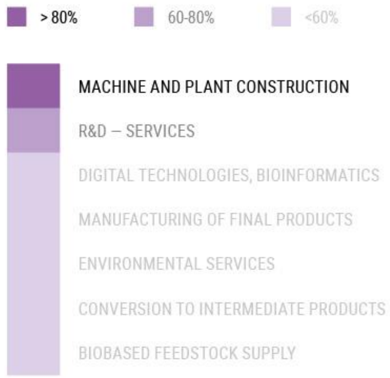

CONTRIBUTION TO SDGs

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Cooney, C. L. (2019): Bioreactors: Design and operation. In Philip H. Abelson (Ed.): Biotechnology and Biological Frontiers: Routledge, pp. 242–253.

25 Cell heterogenity

INNOVATION DESCRIPTION

The heterogenic metabolic activity of cells in fermentation processes is a new target for optimisation of production organisms and cell lines. The metabolic activity of seemingly uniform cultures used for industrial production can be studied at single-cell resolution, enabled by e.g. flow cytometry, droplet microfluidics or microfluidic single-cell cultivation. It can be shown that the cultures consist of both high- and low-performance variants. Low-performance variants may consume nutrients without efficiently synthesizing products, thus reducing overall yield and production rate. By contrast, continuous enrichment of high-performance variants should result in more reproducible bioprocesses with higher yields and lower production costs.

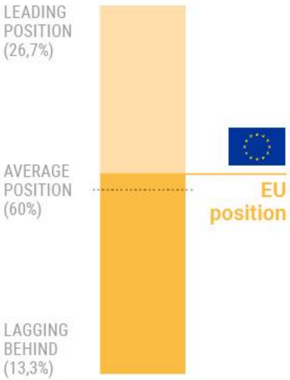
ILLUSTRATIVE EXAMPLE

Cell-to-cell heterogeneity is being studied in mammalian cell cultures used for the production of biopharmaceuticals. It was shown that certain subpopulations became dominant which were responsible for process variability, reduced reproducibility or even process failure. In microbial fermentations to produce fatty acids, when high-performing microorganisms were substantially enriched by a special selection procedure, very high production titres and production rates could be achieved.

PRIORITY ISSUES

R&D, in close cooperation of academia and industry, should focus on real-life conditions in single cell analytical systems (e.g. shear stress, gradients), in order to better understand the mechanisms which underlie cell heterogeneity. On this knowledge base, engineering strategies can be developed to overcome cell heterogeneity.

INTERNATIONAL COMPARISON



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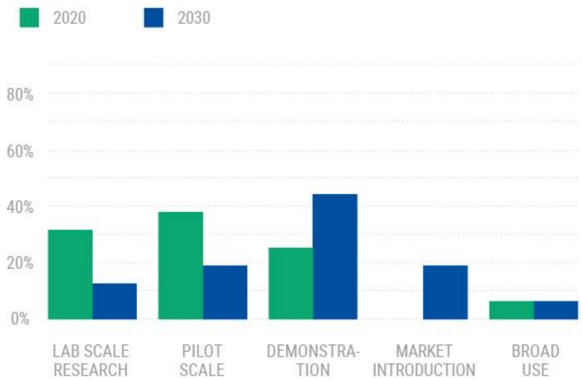

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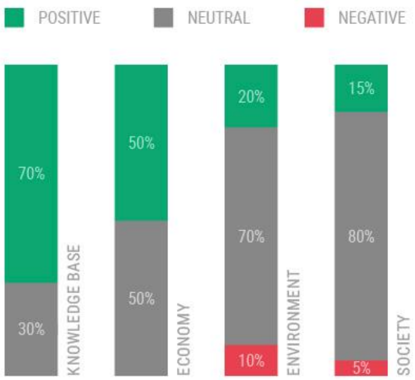

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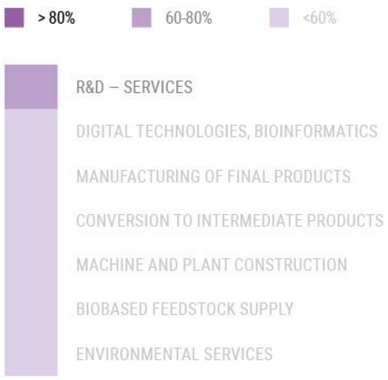

CONTRIBUTION TO SDGs

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26 Stress-tolerant production organisms

INNOVATION DESCRIPTION

The stress tolerance of microbial production platforms against harsh production conditions (e.g. fluctuations in pH, osmolarity, temperature, oxygen, bacteriophage infections) is enhanced by systematically selecting stress-tolerant strains, by systems metabolic and genetic engineering, and synergistic integration with bioprocess design. This leads to higher productivity, process stability and product quality.

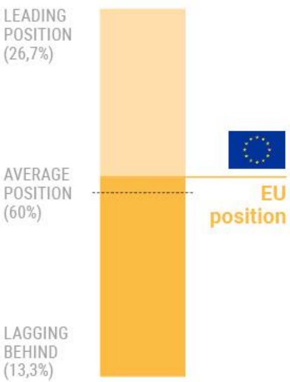
ILLUSTRATIVE EXAMPLE

When producing ethanol from lignocellulose, the ethanol-producing yeast is inhibited by components in the lignocellulose hydrolysate, e.g. furfural and phenols. Although the inhibitor concentration in the hydrolysate can be lowered by several process modifications, higher tolerance towards these inhibitors must be achieved in the yeast to make the process cost-competitive.

PRIORITY ISSUES

R&D, in close cooperation of academia and industry, should focus on the mechanisms which underlie stress tolerance and should synergistically integrate engineering of stress tolerance in production organisms with bioprocess design.

INTERNATIONAL COMPARISON



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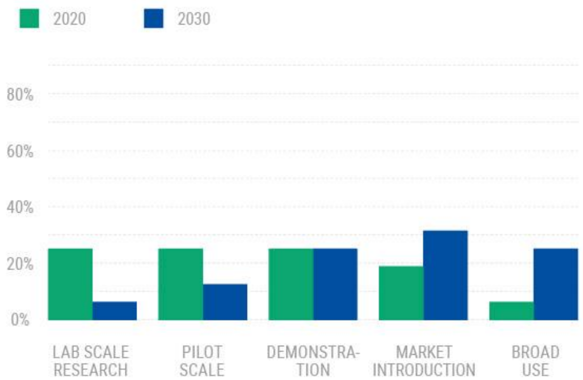

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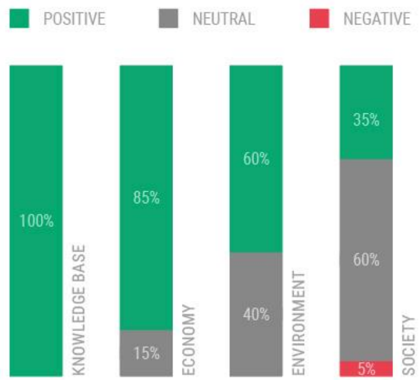
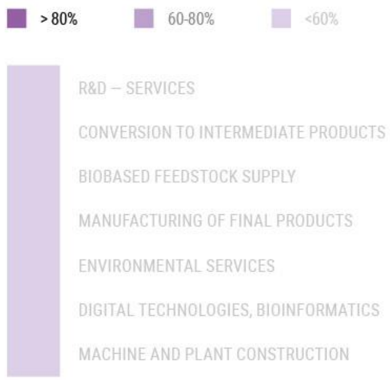


IMPACT ON INDUSTRIAL SECTORS



CONTRIBUTION TO SDGs

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27 Novel feedstocks

INNOVATION DESCRIPTION

The feedstock range for the bioeconomy is broadened: Novel feedstocks comprise non-food feedstocks from forestry, agriculture, horticulture and fisheries; side and waste streams from industries (e.g. feed, food and drink, aquatic-based industries); municipal bio-waste; and methane and carbon dioxide emissions from various industries and the atmosphere. In addition to new feedstock converting processes, new partnerships between feedstock-providing and feedstock-converting industries and companies must be established for the valorisation of these feedstocks.

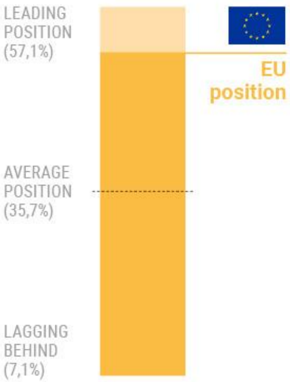
ILLUSTRATIVE EXAMPLE

There are many valuable carbon containing components in municipal and bio-waste. However, the production, separation and purification of bio-based products from these waste streams are still at an early stage. Partnerships with municipalities in order to align the waste management and the bio-based production processes will exploit the potential and improve the availability of these renewable carbon streams for bio-based production processes.

PRIORITY ISSUES

Priority issues for using gases, waste and side streams as substrates more widely are regulations, innovation financing and market creation, highlighting the need to create appropriate regulatory frame conditions, to give (financial) incentives and to support investments into infrastructures and logistics .

INTERNATIONAL COMPARISON



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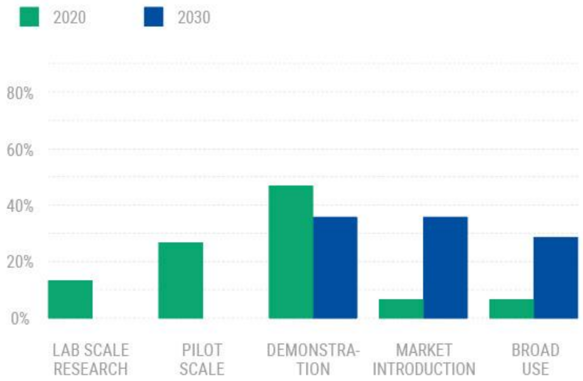

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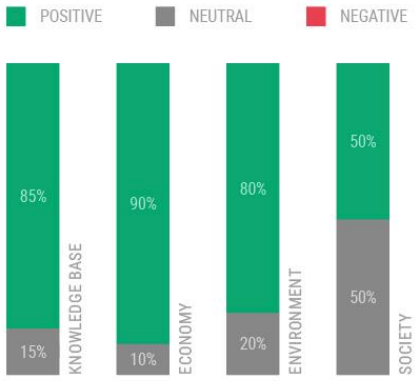

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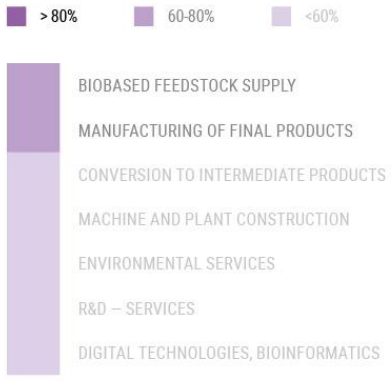

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28 Using side and waste streams

INNOVATION DESCRIPTION

In order to close material cycles and to realise a circular economy, side and waste streams of primary production, industries and municipalities are used as novel feedstocks for the bioeconomy to produce useful products. This shifts the focus from processing and discarding waste to cascading and recycling bio-carbon to its full potential.

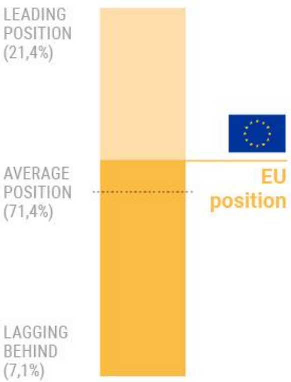
ILLUSTRATIVE EXAMPLE

There are many waste streams that can be utilised in a biorefinery approach, with one example being marine waste streams. The directive on compulsory landing of fish by-catch will lead to significant amounts of available and accessible fish feedstocks, with huge potential for biotechnological valorisation. Together with waste from the fish processing industries, this can be used to obtain high added value products, e.g.. food ingredients, flame retardants, edible or barrier coatings etc.

PRIORITY ISSUES

Priority issues for using waste and side streams as substrates more widely are cross-company and cross-sector cooperations between waste providers and waste converters, regulations and standards which support the valorisation of waste, as well as innovation financing to support investments into infrastructures and logistics .

INTERNATIONAL COMPARISON



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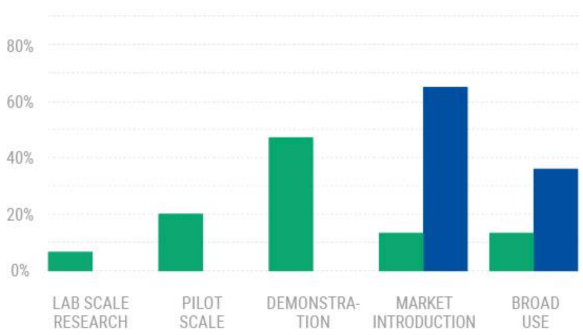

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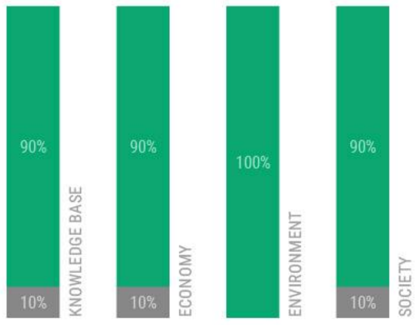

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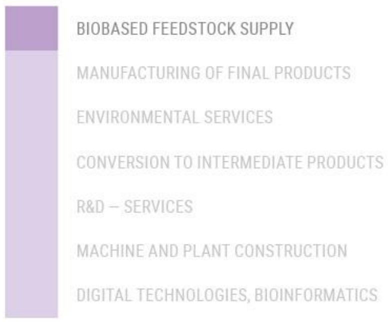

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29 Supply and pretreatment of novel feedstocks

INNOVATION DESCRIPTION

To exploit the full range of feedstocks for bioprocesses, pretreatment processes for novel feedstocks (e.g. lignocelluloses, waste and side streams, algae) are developed which make all fractions of the feedstock available for conversion. Locally distributed pretreatment facilities as well as logistic concepts are developed which ensure feedstock supply that matches the demand of the bioproduction facility.

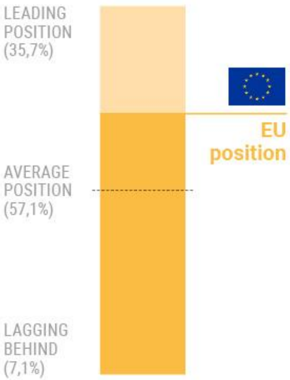
ILLUSTRATIVE EXAMPLE

Lignocellulose is a difficult material to process, due to the structural differences of its main components lignin, cellulose and hemi-cellulose. Moreover, these components are intertwined in the biomass and difficult to separate. The conversion of these three components require different processes. Therefore, the three components would ideally be separated by a new pretreatment process. Many innovations using biotechnological techniques have been developed to enable this separation. An example is the combination of pretreatment methods. For example, a dilute alkali pretreatment makes the material more susceptible to subsequent enzymatic hydrolysis.

PRIORITY ISSUES

Priority issues for supply and pretreatment of novel feedstocks are cross-company and cross-sector cooperations between feedstock providers and feedstock converters, regulations and standards which support the valorisation of novel feedstocks, as well as supporting investments into infrastructures, logistics and treatment facilities.

INTERNATIONAL COMPARISON



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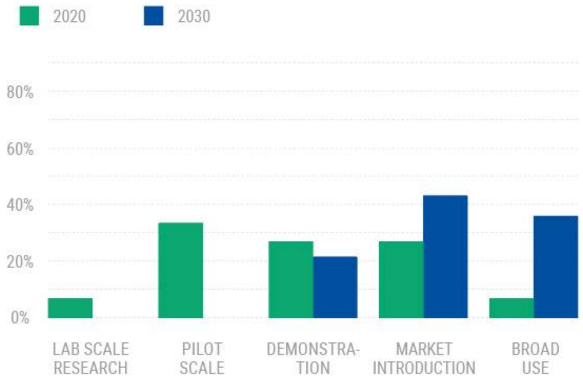

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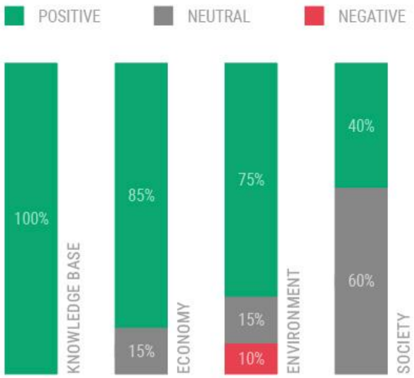

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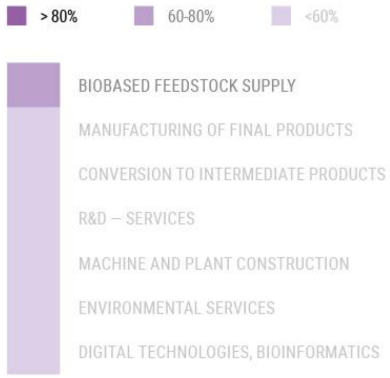

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30 Resource- and energy efficient bioprocesses

INNOVATION DESCRIPTION

The resource and energy efficiency of biomass conversion, process aids and energy is optimised through e.g. biocatalysis, cascading approaches, the valorisation of side and waste streams, recovery of biocatalysts, closing water cycles. The aim is to reach a zero waste bioproduction system that utilises all inputs in a smart and effective manner.

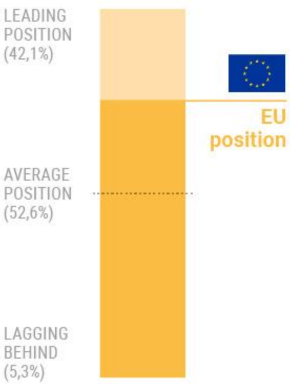
ILLUSTRATIVE EXAMPLE

A large part of enzymatic conversions are performed in aqueous solutions. Here, complete isolation and recovery of enzymes, products and side products leads to a pure and high quality water stream. This water can then be safely reused or fed back into its source, with both options leading to a preservation of the water balance and an important contribution to a circular economy.

PRIORITY ISSUES

Priority issue for harnessing the potentials for increased resource- and energy-efficient bioprocesses is innovation financing for the improvement of industrial production facilities.

INTERNATIONAL COMPARISON



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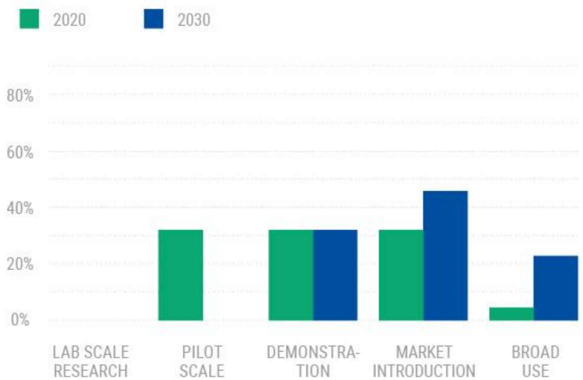

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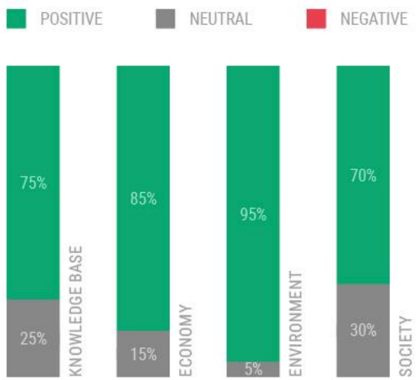

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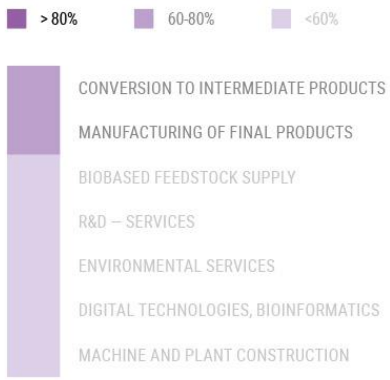

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31 Carbon-neutral bioprocesses

INNOVATION DESCRIPTION

In order to minimize emission of greenhouse gases and avoid the loss of biogenic carbon, bio-based industrial processes apply "carbon capture and use" (CCU): Carbon dioxide (CO_2) or methane (CH_4) emitted from bio-based processes are used as feedstock for production processes of valuable substances. Moreover, durable bio-based products (e.g. construction materials) are used as long-term carbon sinks. This will result in carbon-neutral or even carbon-negative processes and products.

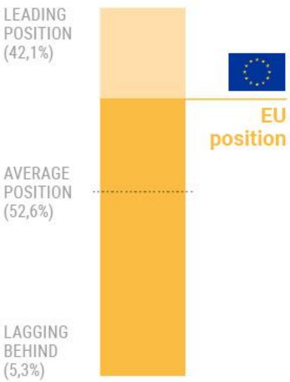
ILLUSTRATIVE EXAMPLE

Several biotechnological processes use CO_2 as substrate for the production of value-added products, e.g. photosynthetic processes with algae, biogas production and subsequent upgrading to biomethane, gas fermentations of industrial flue gases, and electrobiosynthetic conversion of CO_2.

PRIORITY ISSUES

Priority issue for harnessing the potentials of carbon-neutral bioprocesses is innovation financing for the implementation and improvement of industrial production facilities.

INTERNATIONAL COMPARISON



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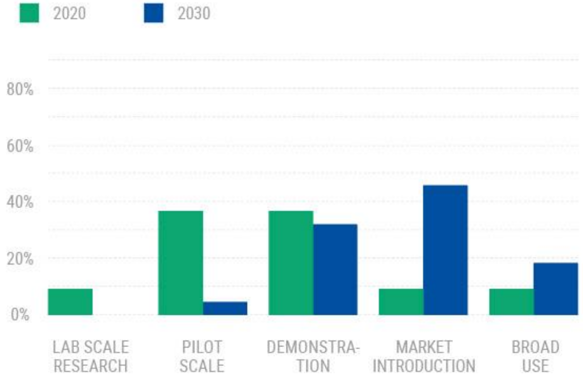

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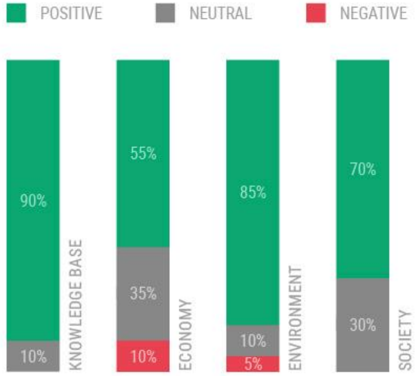

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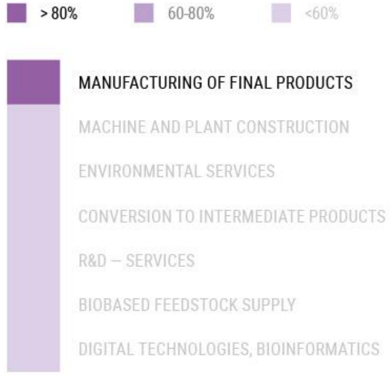

CONTRIBUTION TO SDGs

REFERENCES

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32 CO_2-based chemicals

INNOVATION DESCRIPTION

Carbon dioxide (CO_2), a greenhouse gas, from flue gases or from the atmosphere is used as major feedstock for the microbial bioconversion to industrially relevant chemicals. Suitable organisms are microalgae, archaea, or CO_2-converting microorganisms which additionally need hydrogen (H_2), carbon monoxide (CO) and/or electrons for CO_2 bioconversion. Relevant intermediate products synthesized from CO_2 are CO, methane and various organic acids and alcohols.

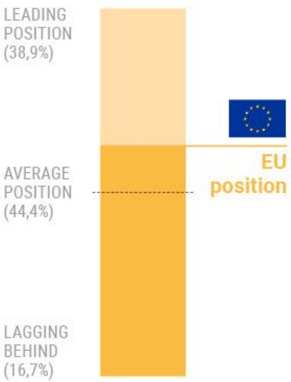
ILLUSTRATIVE EXAMPLE

Flue gases from steel mills contain high amounts of CO_2, H_2, and CO. A process using anaerobic bacteria was developed to produce ethanol from flue gases of steel mills thereby reducing the CO_2 emissions. This process has been commercialized.

PRIORITY ISSUES

Priority issues are improvements in market conditions for CO2-based chemicals to achieve competitiveness with fossil-based chemicals and power-to-X-technologies, as well as innovation financing for industrial implementation of pilot-, demonstration- and production plants. Interdisciplinary and cross-sector cooperation of CO_2-emitting industries with specialists in industrial biotechnology, electrolysis, and green H_2 production are mandatory.

INTERNATIONAL COMPARISON



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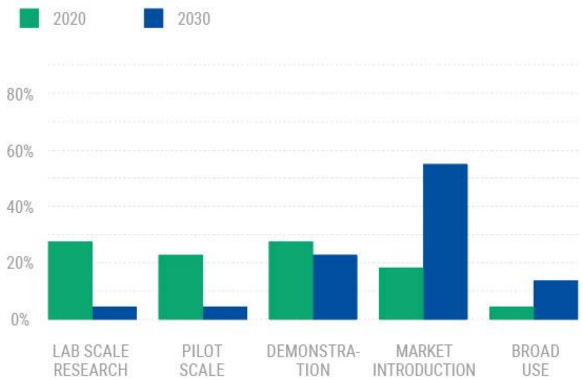

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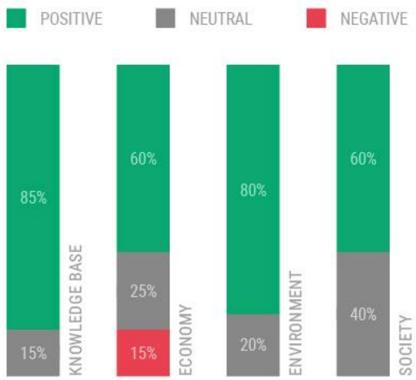

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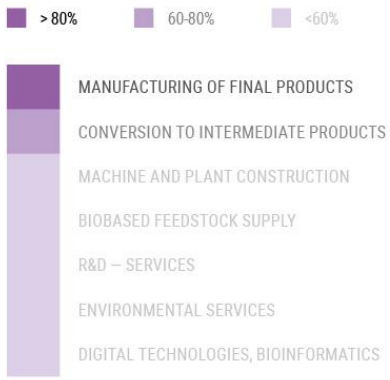

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33 Climate-gas mitigation of microbial activities

INNOVATION DESCRIPTION

Several natural microbial processes contribute significantly to greenhouse gas emissions, e.g. anaerobic and aerobic degradation of organic matter, releasing carbon dioxide (CO_2) and methane; nitrogen dioxide (NO_2) emissions from soils, microbially produced by the process of denitrification; methane produced by intestinal microbes in ruminants. Novel climate-gas mitigation strategies target these microbial communities and processes: they aim at redirecting carbon and nitrogen fluxes away from greenhouse gas production towards target products (e.g. meat, milk, biomass) while maintaining stability and productivity of the system. Reducing carbon and nitrogen losses are also desirable from an economic point of view.

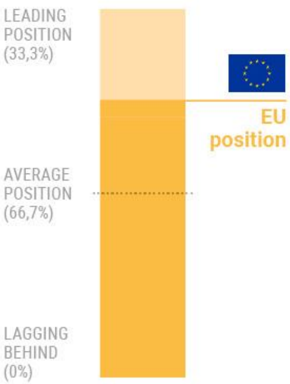
ILLUSTRATIVE EXAMPLE

Plant-based feed additives for ruminants have been commercialised which stimulate the microbiome in the digestive tract of milk cows in a way that the number of methane-producing bacteria is reduced. As less feed intake is lost to methane formation, milk yield increases. Thus, the methane-reducing feed additives contribute to reduced greenhouse gas emissions and a more efficient use of feed.

PRIORITY ISSUES

Due to the high price sensitivity of the livestock sector, innovation financing is a priority issue. Cooperations along the value chain from primary agro-food production to customers are required.

INTERNATIONAL COMPARISON



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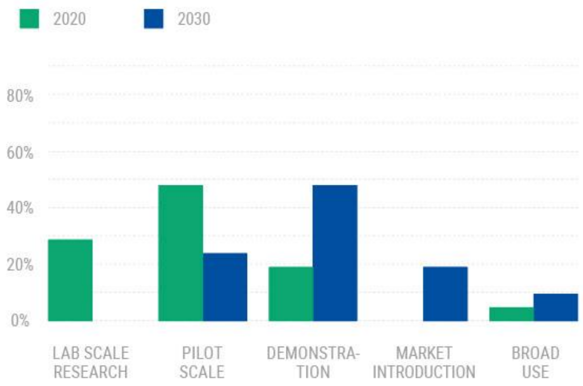

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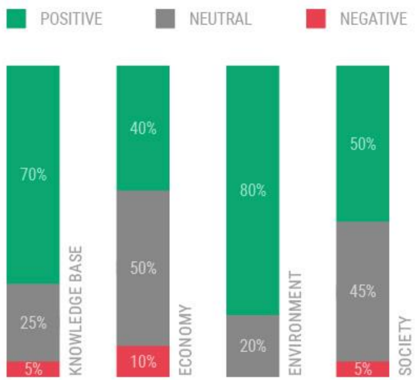

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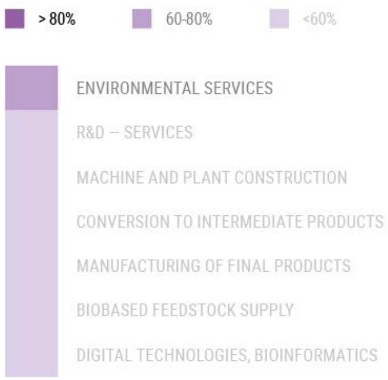

CONTRIBUTION TO SDGs

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34 Biodegradable plastics

INNOVATION DESCRIPTION

Bio-based and at the same time bio-degradable plastics are plastics that - under proper conditions - degrade over time, either via home composting or industrial composting. Increasing the pool of available biodegradable bio-based plastics complements other end-of-life solutions for plastic products, such as reuse and recycling, and contributes to the substitution of fossil-based plastics.

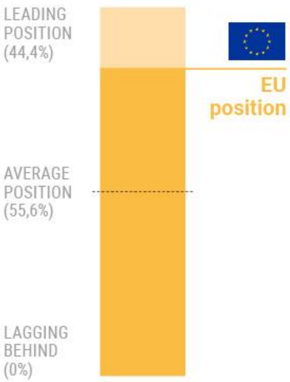
ILLUSTRATIVE EXAMPLE

Bio-based and biodegradable plastics which are already on the market are cellulose or starch based polymers, as well as polylactic acid (PLA). Several others are in development, e.g. polyhydroxyalkanoates (PHA). Other plastics such as polybutylene succinate (PBS) and polybutylene-adipate-co-terephthalate (PBAT), are biodegradable, but currently fossil-based. R&D efforts aim at producing PBS and PBAT no longer from fossil, but from bio-based resources.

PRIORITY ISSUES

In order to achieve competitiveness with conventional plastics, innovation financing and marketing cooperations with brand owners are priority issues, flanked by standards and regulations which create market and recycling opportunities for biodegradable bio-based plastics.

INTERNATIONAL COMPARISON



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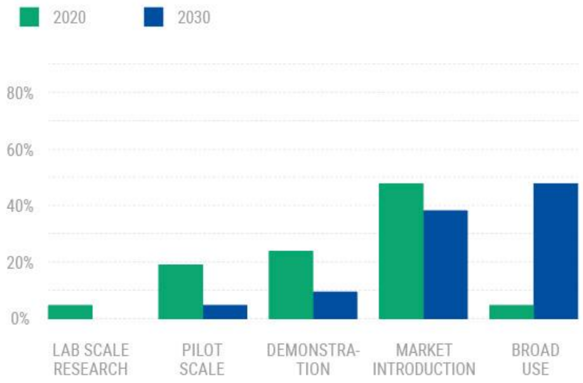

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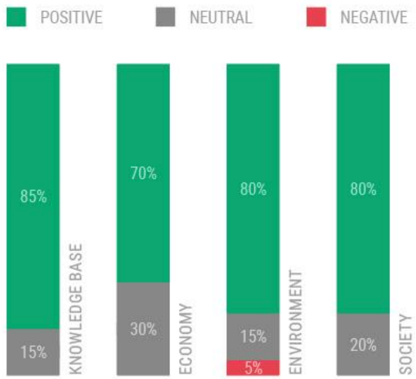

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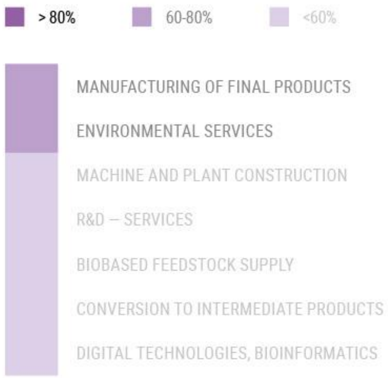

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Polman, Emma M.N.; Gruter, Gert-Jan M.; Parsons, John R.; Tietema, Albert (2021): Comparison of the aerobic biodegradation of biopolymers and the corresponding bioplastics: A review. In Science of The Total Environment 753, p. 141953. DOI: 10.1016/j.scitotenv.2020.141953

35 Plastic degrading enzymes

INNOVATION DESCRIPTION

Enzymes which can break down non-biodegradable plastics to their building blocks are optimised for their use in recycling plastic waste. The resulting building blocks can be used to produce new plastic products which have the same properties as the virgin material. Enzymatic recycling could circumvent problems of thermal recycling and downcycling, where the material can only be recycled once or a limited number of times. The knowledge gleaned from the biodegradation of plastics is also used in early design phases of novel plastics: not only the production process for the new polymer is considered, but also sustainable and circular end-of-life options.

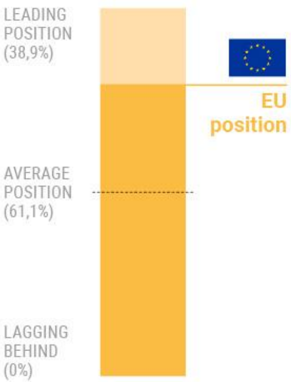
ILLUSTRATIVE EXAMPLE

The plastic polyethylene terephthalate (PET) is a polyester formed from the two building blocks terephthalic acid (TPA) and ethylene glycol. It is widely used in packing materials, beverage bottles and the textile industry. A severe limitation of current recycling of PET is that the recycled PET material has slightly worse properties ("downcycling"). An enzymatic recycling process has been developed which combines two enzymes that are capable of breaking down PET to its two building blocks. PET recycled by this enzymatic process has identical properties to newly produced PET. In vitro and in silico protein engineering is now applied to optimize the enzyme function further. There is a strong market pull for this technology, which is therefore expected to be fully implemented in 2022 - 2025.

PRIORITY ISSUES

R&D is required to achieve higher efficacies of enzymatic plastic degradation. Cooperations between academia, enzyme companies and the waste management sector as well as support in innovation financing are crucial in order to establish functional plastic recycling and reuse value chains.

INTERNATIONAL COMPARISON



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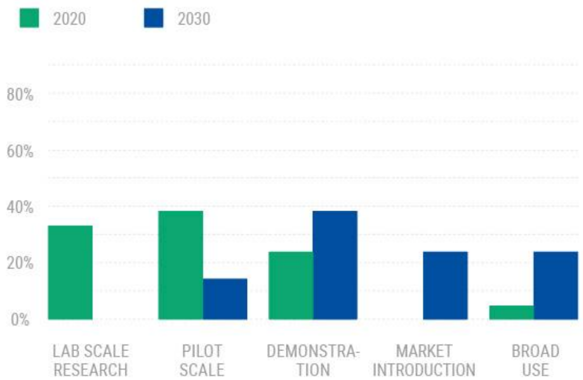
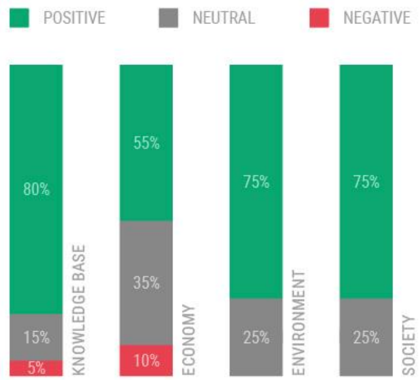
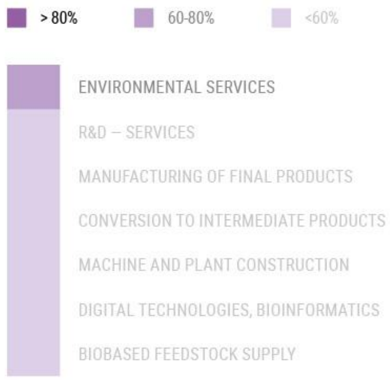


EXPECTED IMPACT



IMPACT ON INDUSTRIAL SECTORS



CONTRIBUTION TO SDGs

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36 **Smart drop-ins**

INNOVATION DESCRIPTION

Smart drop-in chemicals are bio-based chemicals that are not only chemically identical to their fossil-based counterparts, but the biomass feedstock used for these smart drop-ins already provides relevant functional groups. As a consequence, only few processing steps from the feedstock to the final product are required, resulting in resource and energy efficient bio-based production processes.

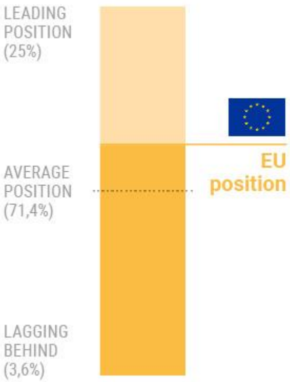
ILLUSTRATIVE EXAMPLE

Examples for biobased smart drop-ins are epichlorohydrin, vanillin, acrylic acid, adipic acid, isoprene, succinic acid, or 1,3 propane diol. Epichlorohydrin is a highly reactive building block used in the manufacture of plastics and epoxy resins. It is industrially produced from propylene in a three-step process. However, in a smart drop-in model, epichlorohydrin could be produced from bio-based glycerol, a readily available chemical from biodiesel production. This can be accomplished in only two reaction steps, because the hydroxy-group is already provided by the glycerol molecule.

PRIORITY ISSUES

Priority issues are cooperations between feedstock providers, smart drop-in producers and smart drop-in users, flanked by regulations and standards which create market opportunities for smart drop-ins.

INTERNATIONAL COMPARISON



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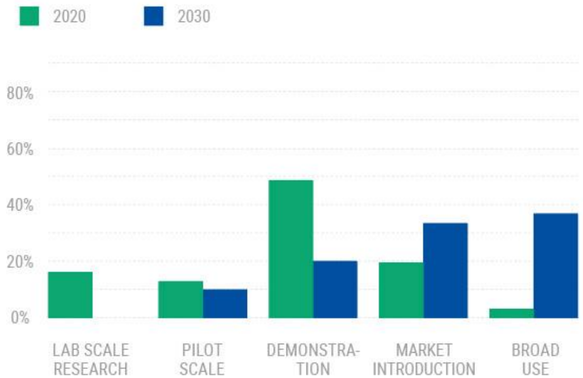

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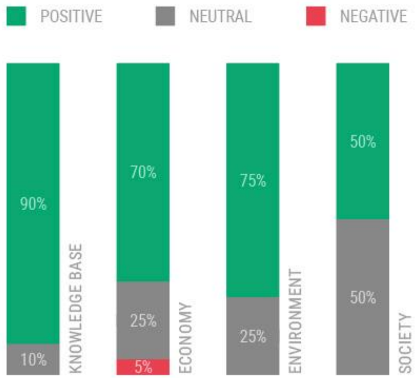

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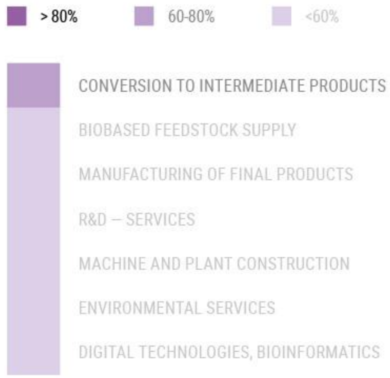


CONTRIBUTION TO SDGs

REFERENCES

Carus, Michael; Dammer, Lara; Puente, Angel; Raschka, Achim; Arendt, Oliver (2017): Bio-based drop-in, smart drop-in and dedicated chemicals. nova-Institut GmbH. Huerth. Available online at https://www.roadtobio.eu.

37 Dedicated bio-based chemicals

INNOVATION DESCRIPTION

Dedicated bio-based chemicals are chemicals that do not have a direct fossil-based equivalent and are produced via a dedicated synthetic route. Several dedicated bio-based chemicals can become platform chemicals that open up the potential of many new products as well as a source for bio-based drop-in chemicals. Many dedicated bio-based chemicals have the advantage that, besides being bio-based, they have a different performance than fossil-based chemicals and may therefore have unique or improved properties.

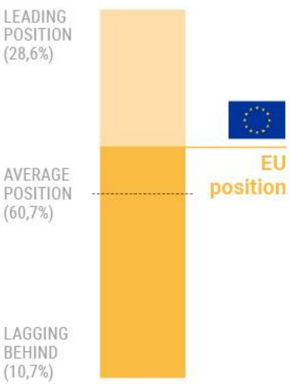
ILLUSTRATIVE EXAMPLE

Examples for dedicated bio-based chemicals are e.g. itaconic acid, polylactic acid (PLA), several bio-based lubricants and surfactants, e.g. sophoro- and rhamnolipids, and nano- and microcellulose. Succinic acid and itaconic acid are typical examples of promising new bio-based building blocks and platform chemicals obtained by fermentation. These products have been shown to have lower environmental impact than functionally equivalent fossil-based chemicals.

PRIORITY ISSUES

Priority issues are creating market opportunities, e.g. by regulations and standards which support the unique selling proposition of dedicated bio-based chemicals and by addressing consumers to increase their willingness to buy dedicated bio-based chemicals.

INTERNATIONAL COMPARISON



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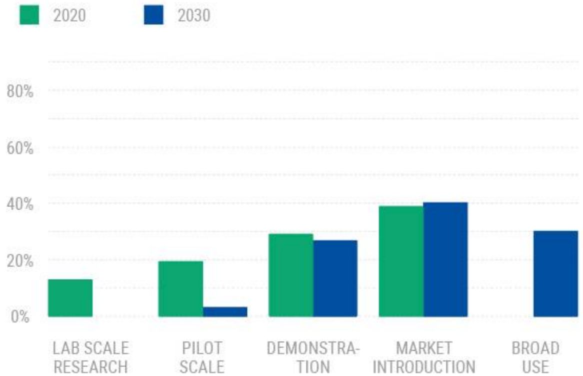

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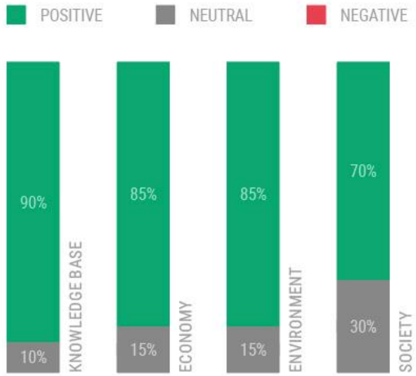

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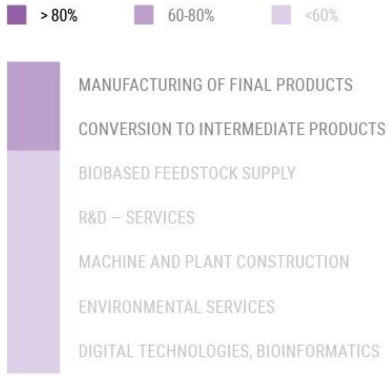


CONTRIBUTION TO SDGs

REFERENCES

Carus, Michael; Dammer, Lara; Puente, Angel; Raschka, Achim; Arendt, Oliver (2017): Bio-based drop-in, smart drop-in and dedicated chemicals. nova-Institut GmbH. Huerth. Available online at https://www.roadtobio.eu.

38 Bio-based materials

INNOVATION DESCRIPTION

Bio-based innovative materials are developed which satisfy consumers' and brand owners' demand for more sustainable products, or their markets are created by environmental legislation. Their competitive advantage over inexpensive fossil-based products with highly optimised production processes is their favourable environmental footprint, being e.g. bio-based or biodegradable or recyclable. Examples are bio-based materials for packaging, electronics, insulation and automotive applications.

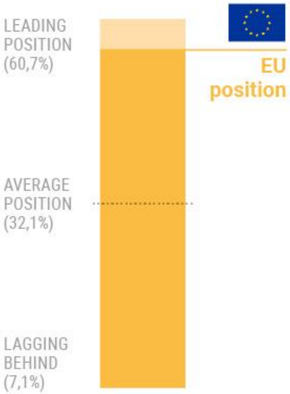
ILLUSTRATIVE EXAMPLE

There are many examples in the fields of bio-based packaging, household items, electronics, insulation, automotive, agri- and horticulture materials, as well as coatings, inks, glues and binders.

PRIORITY ISSUES

Priority issues are creating market opportunities for bio-based materials, e.g. by innovation financing as well as regulations and standards which support the unique selling proposition of bio-based materials and their adoption by industrial customers.

INTERNATIONAL COMPARISON



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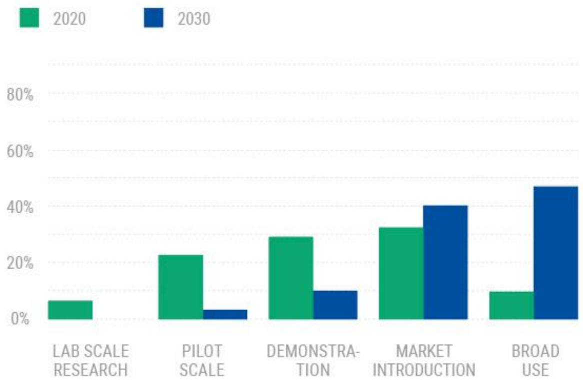

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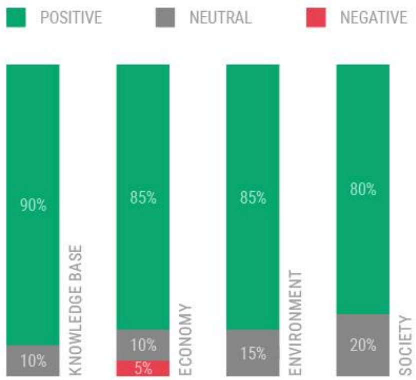

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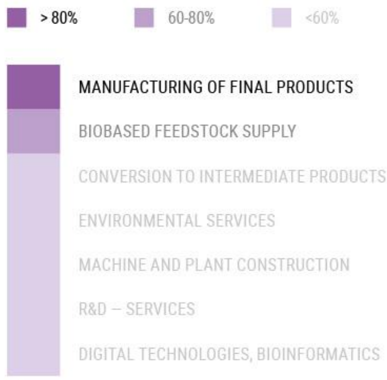

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39 Bio-functional materials

INNOVATION DESCRIPTION

Bio-functional materials are materials with new functionalities or smart materials which change their properties depending on the environmental conditions. These materials can be obtained by integrating active biomolecules into the (bio- or fossil-based) material, e.g. enzymes, cells, antibodies, biosensors. Different technologies are used to conjugate or integrate the bioactive agents with the material, e.g. grafting, inkjet printing. Functionalities are e.g. surface properties, molecular recognition, temperature responsiveness.

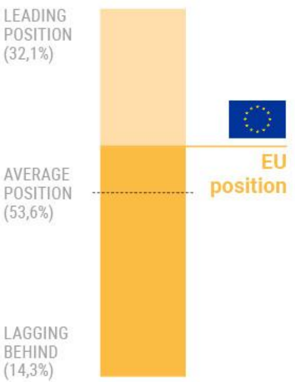
ILLUSTRATIVE EXAMPLE

During production, the bioplastic polylactic acid (PLA) is mixed with a PLA-degrading enzyme. The enzyme remains inactive during PLA product use. It is only activated under the conditions of a composting facility and speeds up the PLA decomposition. Other biofunctional materials have been developed for medical applications which support healing and tissue regeneration and prevent growth of pathogenic microorganisms.

PRIORITY ISSUES

For more mature bio-functional materials, priority issues are creating market opportunities, e.g. by regulations and standards which support the unique selling proposition of bio-functional materials.

INTERNATIONAL COMPARISON



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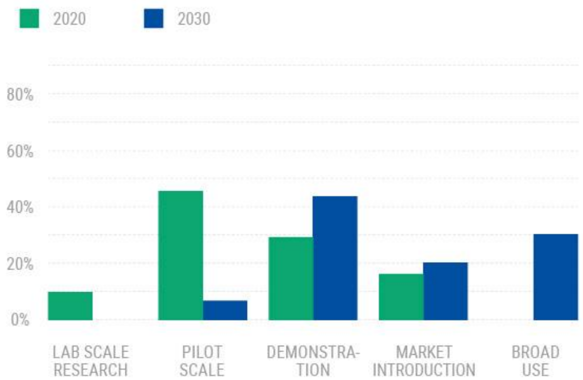

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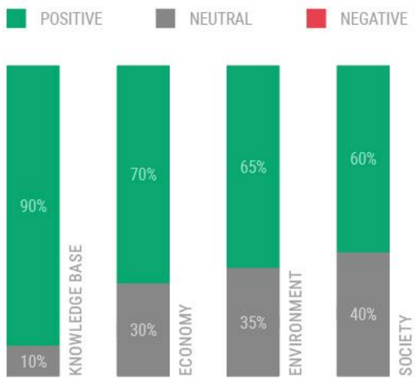

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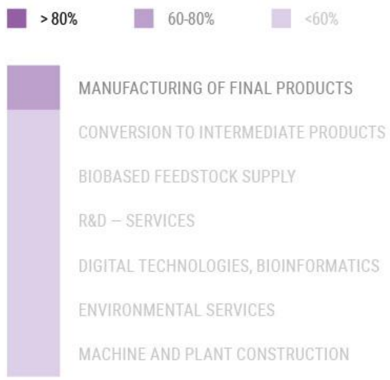

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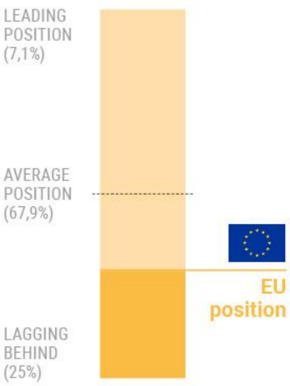
40 Novel algae products

INNOVATION DESCRIPTION
Micro- and macroalgae or other currently underexploited marine organisms are exploited for the production of molecules for pharma, nutraceuticals, food additives and cosmetic applications. These products have new functionalities (e.g. favourable nutritional composition, high protein content, fast skin repair) that may have positive health effects or higher convenience or desired functions for the end consumer.

ILLUSTRATIVE EXAMPLE
Extracts from microalgae have been commercialised as food, food colorant, ingredient of cosmetics, component of various health products, and as feed additive and fertilizer. The potential of bioactive compounds in algal biomass, e.g. proteins, polyunsaturated fatty acids, carotenoids, vitamins and minerals, has not yet been exploited.

PRIORITY ISSUES
R&D for the identification, characterisation and development to marketable products as well as academia-industry cooperation is required to harness the potentials of still underexploited marine resources. The relevant regulations for the targeted markets must be taken into consideration already early in the R&D process.

INTERNATIONAL COMPARISON


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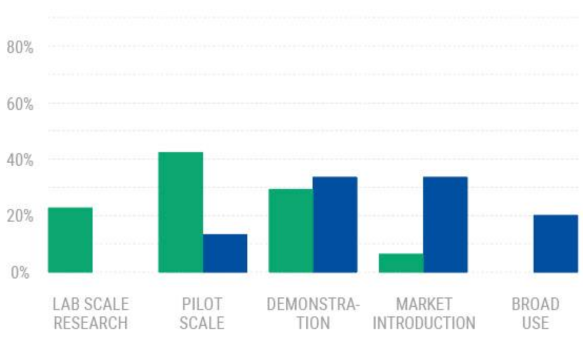

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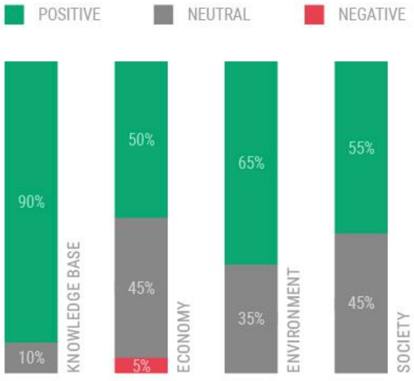

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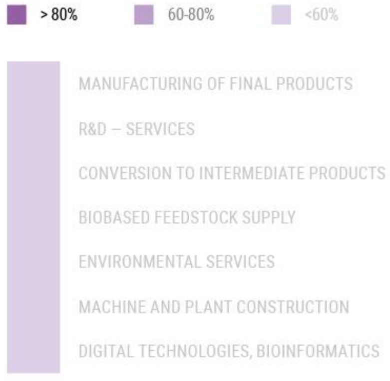

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41 Crop improvement targeting genome and epigenome

INNOVATION DESCRIPTION

Genome-editing tools are used in crop breeding for intentional, direct, precise and efficient alterations of DNA and genomes and for the exploitation of epigenetic modifications for crop improvement. This broadens the range of traits that can be engineered in order to increase food and feed productivity and food security for a growing world population under climate change conditions.

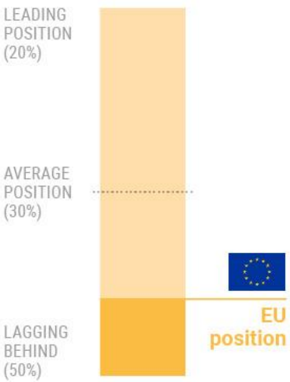
ILLUSTRATIVE EXAMPLE

Favourable traits which occur in wild species but cannot be easily crossed into commercial crops could be introduced by genome editing. These include plant architecture, nutritional content, or tolerance towards stress, e.g. by drought, temperature, pathogens. Differences in epigenetic patterns often account for differences between wild-type and domesticated plant species: Gene expression differs even if the primary genetic sequence remains the same.

PRIORITY ISSUES

Negative public perception of genetically modified crops as well as ongoing controversies whether genome-engineered crops should be regarded and regulated as genetically modified crops is perceived as a major hurdle in the EU for this innovation.

INTERNATIONAL COMPARISON



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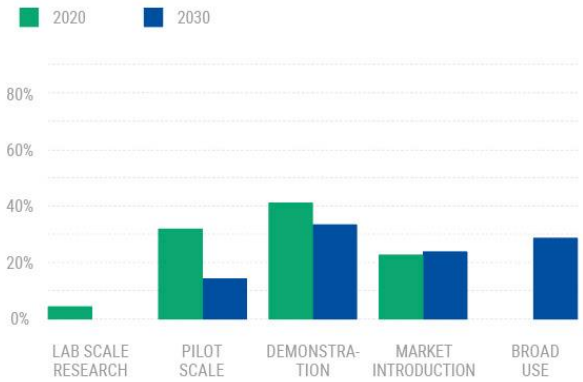

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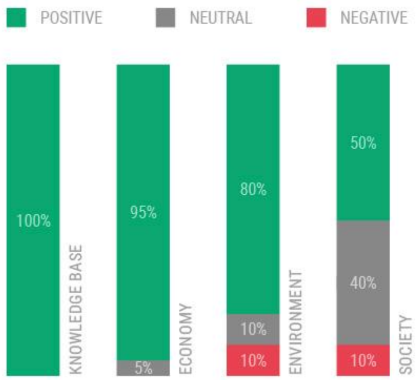

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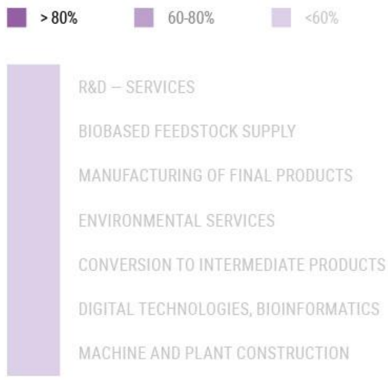

CONTRIBUTION TO SDGs

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42 **de novo domestication**

INNOVATION DESCRIPTION

Crop plants may have lost valuable traits during the breeding process which are still present in wild species of the crop. In order to combine the favourable traits in one plant, de novo domestication, a novel strategy for accelerated crop breeding, can be applied. It uses multi-omics, genome editing and synthetic biology approaches in order to re-domesticate wild or semi-wild plant species: Agronomically or nutritionally favourable traits are introduced while avoiding loss of other useful traits. Relevant traits are e.g. plant architecture, nutritional content, flowering times, yield, stress tolerance, pathogen resistance. This strategy could for example be applied to breed crop varieties adapted to changing climate conditions.

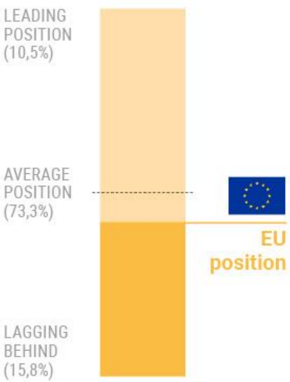
ILLUSTRATIVE EXAMPLE

De novo domestication of wild tomato was performed using genome editing. Six genes that are important for yield and productivity in commercially grown tomato lines were edited in a wild tomato line for its de novo domestication. Compared with the wild tomato line, the new lines exhibit altered morphology, and increased size, number and nutritional value of the tomato fruits.

PRIORITY ISSUES

De novo domestication requires support of collaborative R&D, but is also hampered by ongoing controversies how the application of genome editing in crop plants should be regulated in the EU.

INTERNATIONAL COMPARISON



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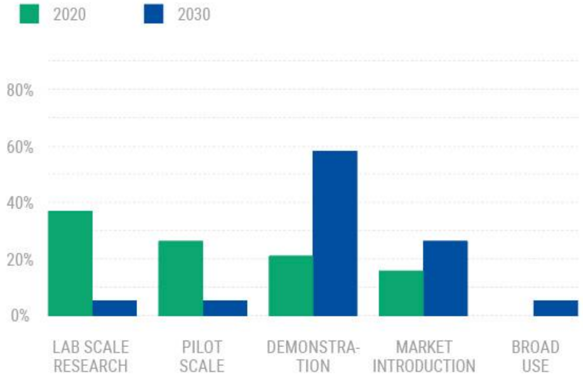

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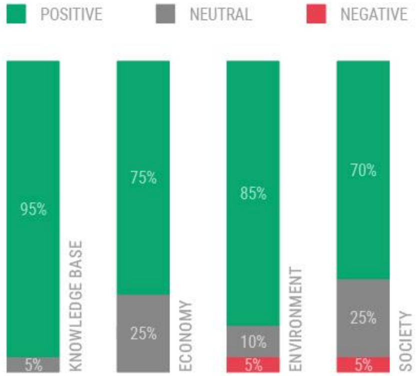

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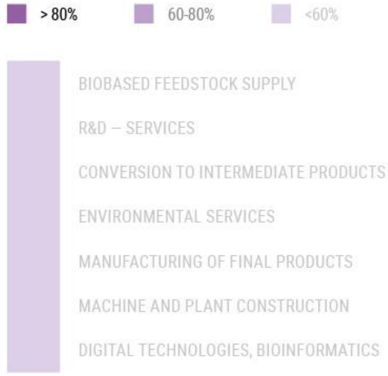

CONTRIBUTION TO SDGs

REFERENCES

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43 Asexual reproduction of seeds

INNOVATION DESCRIPTION

Many high performance crops are hybrids. Their superior performance, the so called hybrid vigour, is usually not stable in following generations. The hybrid vigour can only be maintained if the hybrids are produced each season from their parent plants by fertilization. An innovative approach has been developed to engineer the ability to produce seeds asexually, i.e. without prior fertilization (so called apomixis), into rice. The innovation of asexual reproduction of seeds could significantly speed up breeding programmes and enable hybrid seed production in a more rapid and cheaper way.

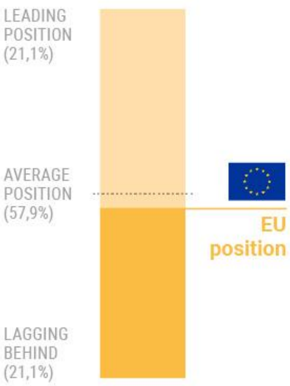
ILLUSTRATIVE EXAMPLE

Rice is a major food crop, but lacks the ability to be propagated without prior fertilization with pollen. In 2018/2019, researchers succeeded in introducing an apomixis-like trait into rice. By changing four genes, they altered two components of the plant's reproductive system. Research is underway to optimise this approach and transfer it also to other cereals than rice. If successful, the innovation could make access to high performance hybrid seeds easier and cheaper, also for smallholders. The innovation also bears the potential that farmers could produce hybrid seeds themselves, instead of having to buy them every season from seed companies.

PRIORITY ISSUES

Although proof of principle of engineering the apomixis-like trait has been shown for rice, R&D is required to increase the efficiency and to introduce this trait also into other major food crops.

INTERNATIONAL COMPARISON



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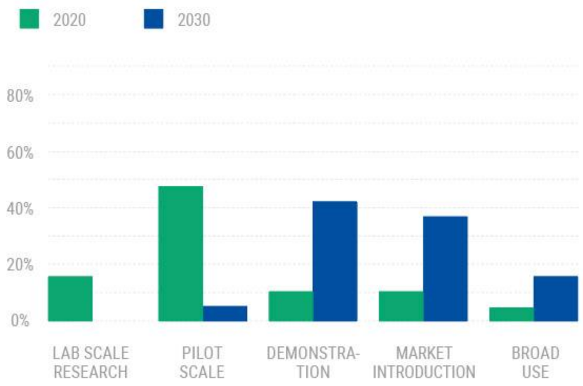

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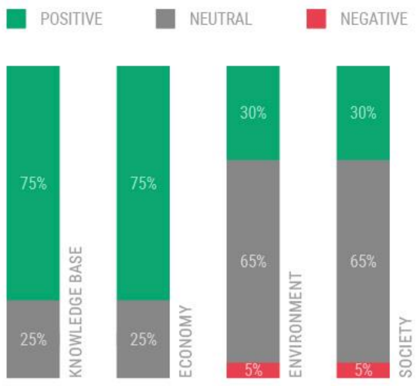

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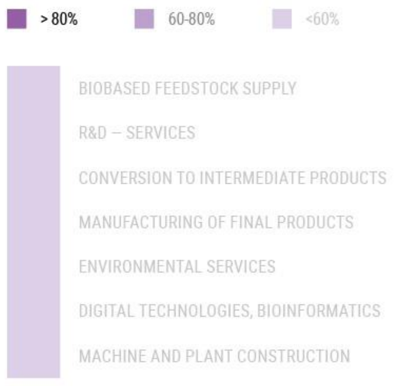

CONTRIBUTION TO SDGs

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44 Increasing and maintaining soil fertility

INNOVATION DESCRIPTION

Soil fertility has become an important objective in the efforts to increase yields in agriculture. Novel approaches for maintaining and improving soil fertility target the biological diversity (soil microbiomes, plant diversity), crop cultivation techniques (i.e. focus on root growth) and biological strategies for pest control. They aim at maintaining robustness and stability of soils as adaptable ecosystems with respect to carbon, nitrogen, phosphorus and water cycles, and thus are more sustainable alternatives to fertilizers and pesticides.

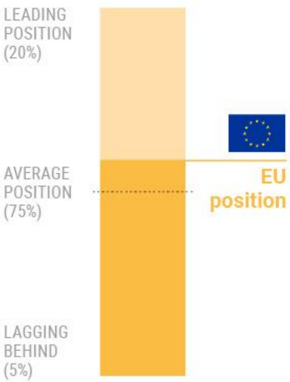
ILLUSTRATIVE EXAMPLE

In the Farm to Fork Strategy, the EU has set the targets to reduce the use of chemical pesticides by 50% and the use of fertilizer by at least 20% by 2030. Microbial inoculants have been commercialised which increase the availability of soil nutrients and minerals to the crop plant. These microbial fertilizers will soon be complemented by products and application techniques that in addition promote the effective, long-term colonization of the soil by the introduced microbiota, and by tools to manipulate the microbiome in situ to attract and maintain activities of beneficial microorganisms.

PRIORITY ISSUES

Interdisciplinary R&D into the soil ecosystem is required to broaden the knowledge base for the development of sustainable alternatives to fertilizers and pesticides. Knowledge transfer from academia and industry to agriculture is key to broadly implement more sustainable soil management practices. The Global Initiative of Crop Microbiome and Sustainable Agriculture should be expanded or be complemented by similar initiatives.

INTERNATIONAL COMPARISON



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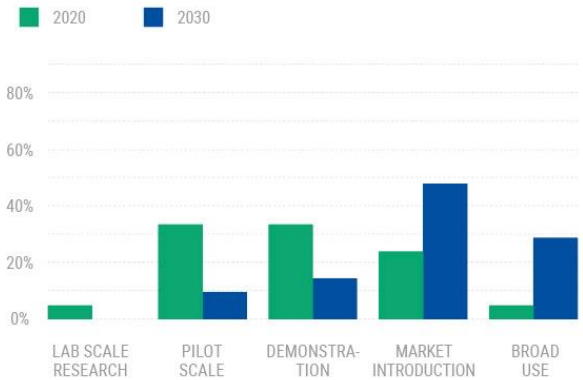

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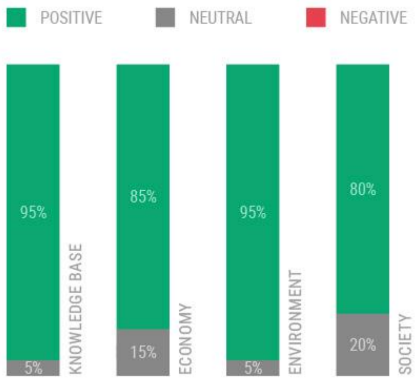

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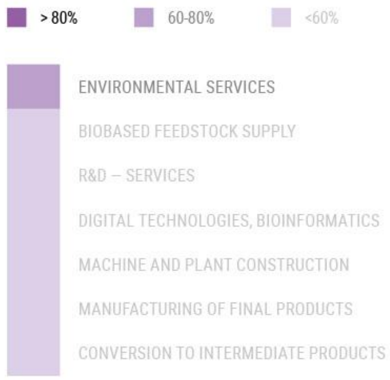

CONTRIBUTION TO SDGs

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45 Novel farming concepts

INNOVATION DESCRIPTION

Novel farming concepts are closed, highly automated and controlled indoor systems with closed water and nutrient cycles for farming in urban and non-arable regions. In vertical farms, plants are grown in vertical, multi-storey greenhouses under LED light. In aquaponics, aquaculture is synergistically combined with plant cultivation without soil (hydroponics): Fish excretions, metabolized by bacteria, serve as fertilizer for the plants.

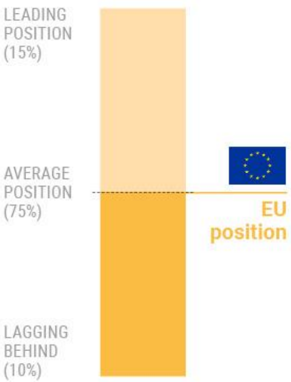
ILLUSTRATIVE EXAMPLE

Vertical hydroponic farming systems can provide reliable supply of fresh fruit even if conventional agri- and horticulture is not possible, e.g. in arid regions. Plans have been announced to build the world's largest vertical farm near Dubai airport. The farm will supply airline caterers at Dubai airport with fresh leafy vegetables like lettuce. Indoor farming concepts could also contribute to urban farming, could be operated in mobile units (e.g. shipping containers) or underground, e.g. in abandoned mine shafts ("deep farming").

PRIORITY ISSUES

The implementation of novel farming concepts requires cross-sectoral cooperations, between academia, farming system providers and e.g. municipalities as location for novel farming systems. Financing investments into such farming facilities may be a hurdle, as well as regulations in regional and urban planning.

INTERNATIONAL COMPARISON



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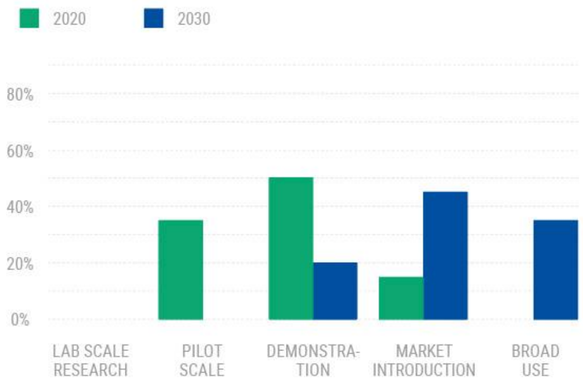

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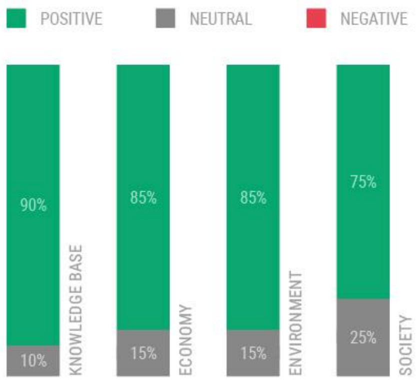
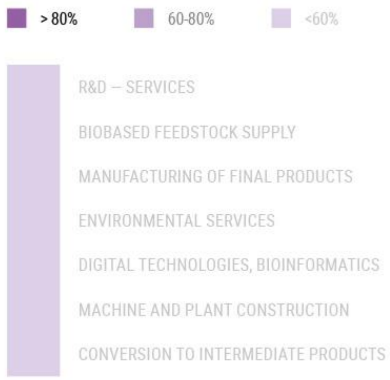


IMPACT ON INDUSTRIAL SECTORS



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46 Novel protein sources

INNOVATION DESCRIPTION

New food and feed protein sources are exploited in order to sustainably meet the growing worldwide demand for nutritionally valuable proteins without expanding livestock farming. Sources are

a) side streams from the processing of crop plants, vegetables, fruits or marine organisms which are biotechnically valorised to protein-rich food ingredients,

b) insect proteins from automated large scale insect production,

c) applying tissue engineering technologies for cultivating livestock muscle cells to produce meat in bioreactors instead of livestock farming.

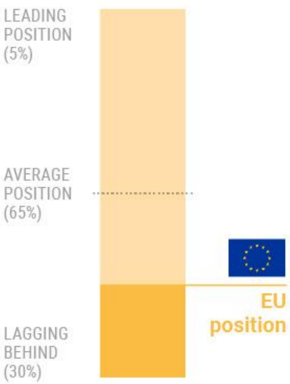
ILLUSTRATIVE EXAMPLE

By cultivating bovine muscle cells, beef for human consumption can be produced in bioreactors. In 2013, the first prototype of a lab-grown burger patty was presented. Research is ongoing to significantly reduce the costs for producing cultured meat, to improve its structure and taste, and to scale up production.

PRIORITY ISSUES

R&D is required to reduce costs and scale-up to industrially relevant production. This can only be achieved in cross-sector industrial cooperations, linking biotechnological, automation, IT and food/feed expertise. For specific processes (e.g. waste as substrate), products and uses (e.g. insects as feed/food), existing regulations may be seen as a hurdle.

INTERNATIONAL COMPARISON



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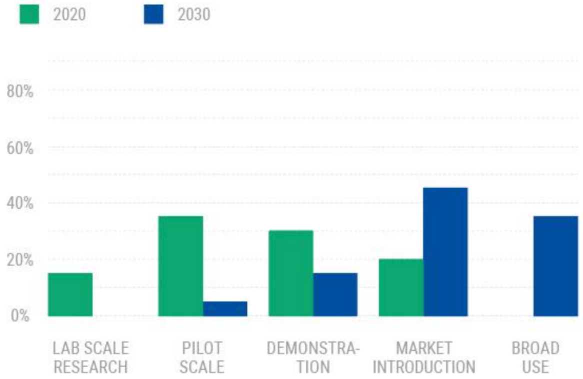

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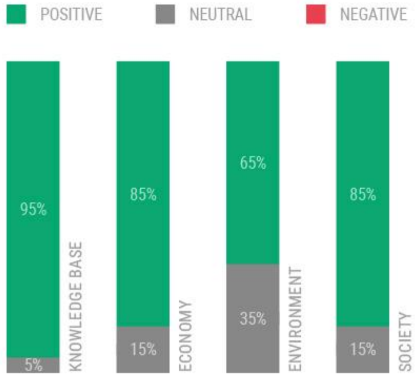

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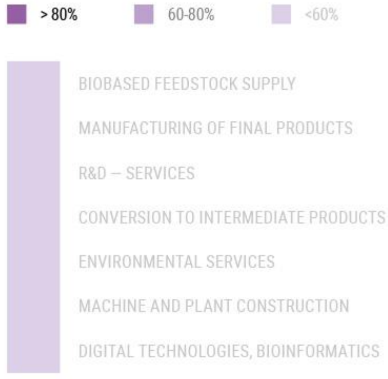

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47 **Health-promoting ingredients**

INNOVATION DESCRIPTION

Health-promoting food and feed ingredients are derived from naturally occurring bioactive substances which are beneficial for human or animal health if consumed regularly. Many ingredients affect the microbial communities which inhabit the gut (microbiota, microbiomes). Exploitation for novel health-promoting products requires studying host-microbiome interactions and their control by nutritional factors; screening of underexploited sources (e.g. marine organisms, microbial communities, side streams of food processing); development of industrial production processes; ingredient administration in bioactive and tasty form; safety and health effect assessments.

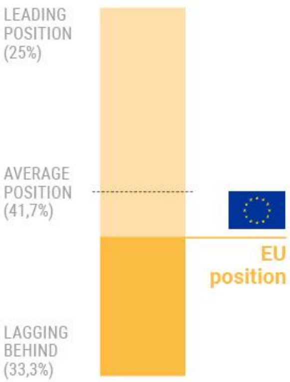
ILLUSTRATIVE EXAMPLE

It has been established recently that microorganism communities inhabiting the human gastrointestinal tract play an important role in well-being and diseases, ranging from infectious diseases, metabolic diseases (e.g. diabetes), autoimmune diseases (e.g. allergies) to mental or psychological diseases. This has triggered the development of food and feed containing beneficial microorganisms (probiotics) or of additives which stimulate growth of these microorganisms (prebiotics). Human breast milk contains oligosaccharides which stimulate the development of healthy microbiota in babies and may contribute to disease prevention in later life. Infant formula are on the market which contain microbially produced oligosaccharides in order to support the development of a healthy gut microbiome in babies who cannot be breast-fed.

PRIORITY ISSUES

R&D into the mechanisms of the health-promoting effects is required. Providing scientific evidence for the health-promoting effects in humans or animals require substantial financial resources and academia-industry collaborations. The relevant regulations for the targeted markets must be taken into consideration already early in the R&D process.

INTERNATIONAL COMPARISON



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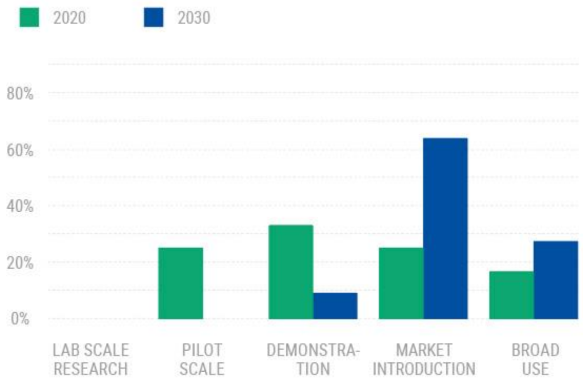

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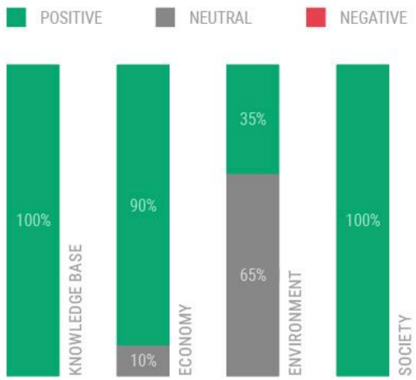

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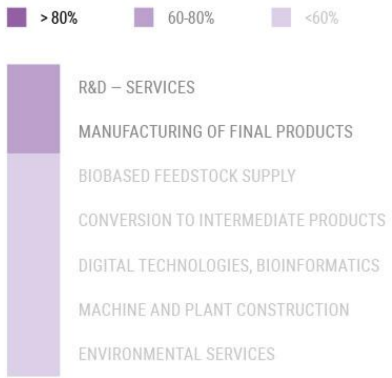

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48 Novel antimicrobial agents

INNOVATION DESCRIPTION

There is an urgent need for new classes of antibiotics in the fight against the continuous rise of antibiotic resistant pathogens both in human and veterinary medicine. Promising candidates for novel antimicrobial agents are antimicrobial peptides like bacteriocins. They are produced by bacteria or fungi and inhibit the growth of other bacteria. Due to their potency, they are candidates for new narrow-spectrum antibiotics. Further biotechnological strategies for fighting pathogenic microorganisms are antibodies directed against pathogens and phage therapy, the therapeutic use of bacteriophages (viruses that attack bacteria).

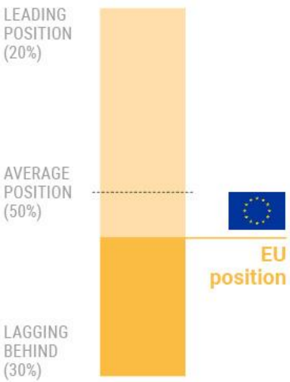
ILLUSTRATIVE EXAMPLE

Lantibiotics are short peptides with high potency against multiresistant human pathogenic strains. Therefore, they are interesting candidates to complement classic antibiotics in times of increasing multidrug resistance of pathogenic bacteria.

PRIORITY ISSUES

The priority issue in developing effective antibiotics against multi-resistant pathogens is to provide appropriately targeted financial support and economic incentives for the collaborative, costly R&D process until regulatory approval of the new drug.

INTERNATIONAL COMPARISON



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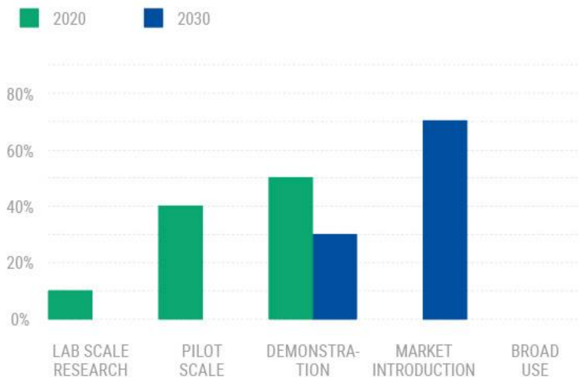

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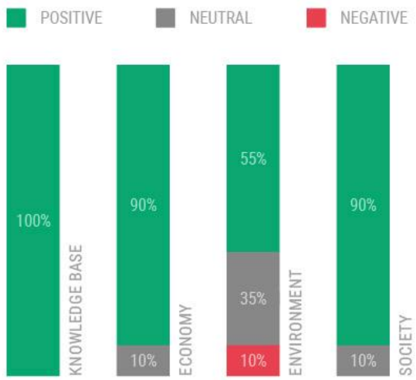

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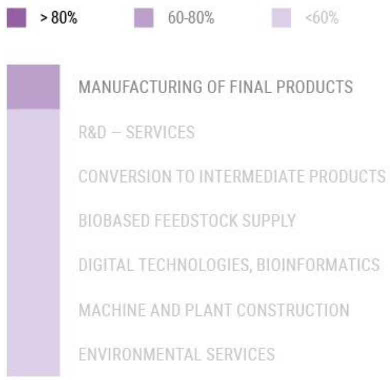

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49 Probiotic sanitation strategies

INNOVATION DESCRIPTION

Probiotic sanitation is a strategy within hygiene concepts which exploits the natural competition between bacterial species. Probiotic sanitation aims at establishing stable, healthy microbial communities which prevent the colonization by pathogenic microorganisms. Thus, the risks of surface-associated infections and the spread of pathogenic microbes are reduced. As this strategy does not aim at eliminating all microbes from surfaces, it also prevents the emergence of bacteria which are resistant against disinfectants and antimicrobial agents.

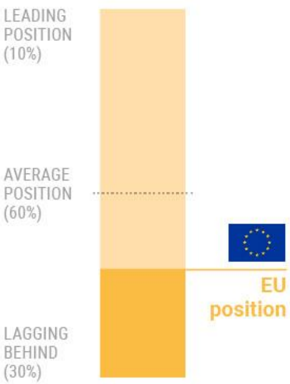
ILLUSTRATIVE EXAMPLE

Probiotic cleaning agents contain a mixture of spores of different beneficial bacterial strains. If these cleaning agents are applied to surfaces, the likelihood is reduced that pathogenic microbes, e.g. multiresistant strains, can also colonize this surface. This approach could be used for treating large surfaces, e.g. floors in animal life stock farming or in hospitals.

PRIORITY ISSUES

R&D is required to reduce the time needed for establishing stable microbial communities on surfaces, with the aim of broadening the application range beyond prophylactic use to immediate decontamination. Evidence for effectiveness in reducing the emergence of multiresistant pathogens still has to be provided. Standards for antimicrobial agents and strategies may need adaptation.

INTERNATIONAL COMPARISON



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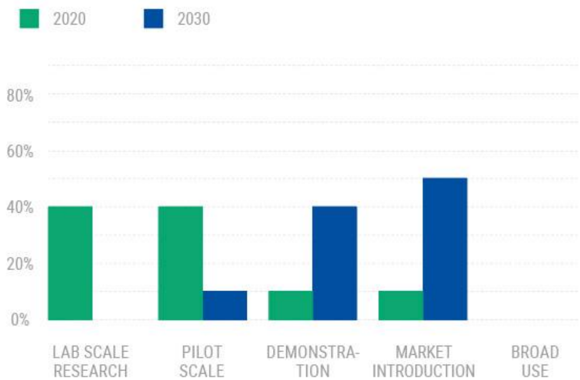

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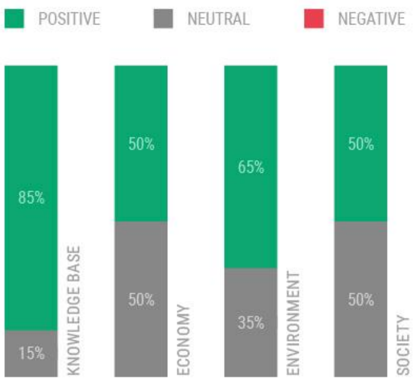

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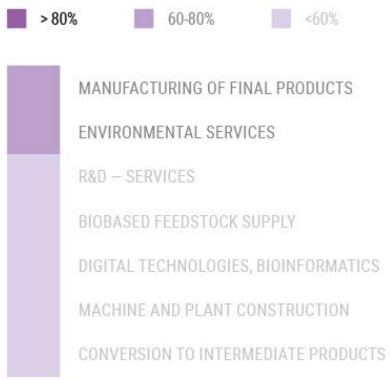

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50 Veterinary DNA vaccines

INNOVATION DESCRIPTION

DNA vaccines are an innovative vaccine concept: Instead of administering an antigen, its genetic sequence is injected, triggers the production of antigenic proteins in the vaccinated animal and stimulates a specific protective immune response. Advantages over conventional vaccines are: rapid development through bioinformatics-supported design based on the genome sequence of the pathogen; stimulation of both humoral and cellular immune responses; no infectious agent in the vaccine; relative ease of large-scale manufacture.

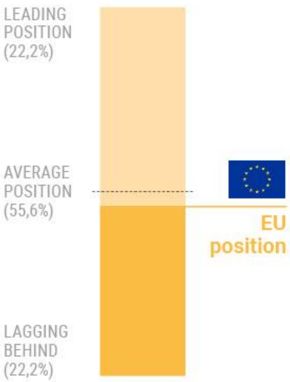
ILLUSTRATIVE EXAMPLE

In the EU, the first veterinary DNA vaccine has been authorised in 2016 for use in farmed salmon, to protect against Salmon Pancreas Disease. In the USA, a DNA vaccine was conditionally approved in 2019 for use in chicken, to protect against avian flu (H5N1).

PRIORITY ISSUES

R&D in academia-industry cooperation is required to increase the immunogenicity of DNA vaccines, to reduce their costs and to overcome restrictions in combining DNA and conventional vaccines. Financing of the R&D process until regulatory approval is also important.

INTERNATIONAL COMPARISON



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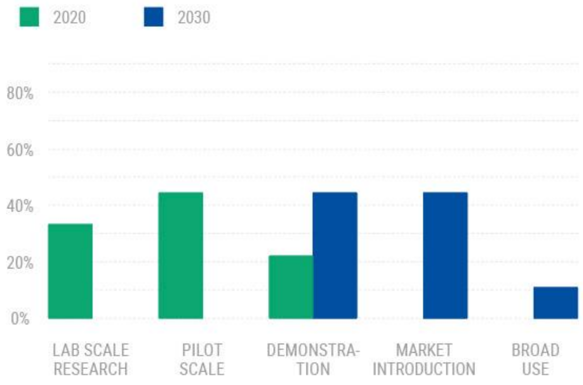

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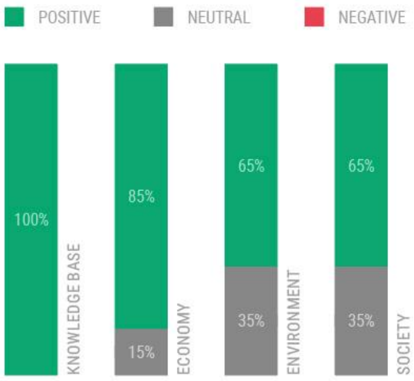

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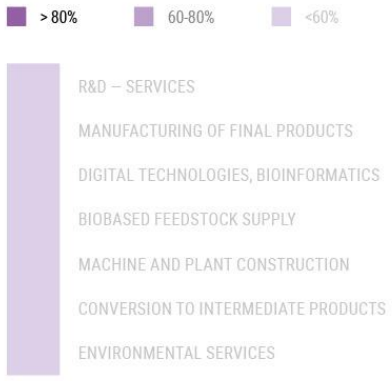

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Life and biological sciences and technologies are enablers for bio-based innovations that bear the potential to use natural resources sustainably, by reducing dependence on fossil fuels, by protecting the environment and climate, ensuring food security, and maintaining international competitiveness. This study presents the 50 most significant bio-based innovations for the next 5-20 years. The portfolio of top 50 bio-based innovations covers on the one hand cross-cutting technologies and approaches, enabling many different applications, on the other hand innovation areas or solutions to challenges, which may be enabled by different technologies or approaches. Together with a policy and innovation ecosystem analysis and four bio-based innovation scenarios for Europe in 2030, the study provides strategic knowledge for policy makers, innovation stakeholders and society. It reveals that in order to fully exploit the potential of bio-based innovations stakeholders have to implement strategic approaches and various actions. Potential measures are ranging from further support of Research & Development, to knowledge transfer and collaboration, demand-oriented measures as well as to strive for higher coherence between different regions in the European Union.

Studies and reports

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