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The European bioeconomy strategy revision: An opportunity to go against the tide and secure a sustainable future

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ABSTRACT

In today's tense geopolitical landscape, marked by strained relations among major powers and deep-rooted dependence on fossil-based economies, the emerging modern bioeconomy can provide resource independence and resilience, in tandem with economic, social, and environmental benefits, and thus has the potential to underpin a sustainable future. The bioeconomy is a vital cross-cutting meta-sector, but it is not inherently circular or sustainable; without intentional design, it risks becoming a linear, unsustainable replacement of the fossil-based economy. Realising its full promise requires purposeful engineering to address climate change, biodiversity loss, strengthen resource independence, support food security and resilience, create jobs, promote social inclusion, boost competitiveness and autonomy, and improve human, animal, and environmental health. The potential is enormous, but so are the challenges society faces in realising the vision for a biobased, nature-positive future.

1. Introduction

The bioeconomy is over 10,000 years old, dating back to the advent of settled human agricultural, fishery, and forestry activities. For millennia, humans have used biobased resources for multiple purposes such as materials (e.g., housing and clothing), fuels (e.g., cooking and heating), chemicals (e.g., dyes and bioactive substances extracted from plants), food and health supplements (e.g., biomedicines and biomolecules for medical uses). The emergence of the fossil industry in the mid-1800s led to biobased resources being replaced with new synthetic equivalents or the emergence of fossil-based products without a biobased equivalent (e.g., plastics) over a relatively short period (~100 years).

The fossil era is having a disproportionate impact on Earth relative to its timespan due to greenhouse gas emissions and pollution from the extraction, manufacture, use, and end-of-life of fossil-based products.

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Therefore, the bioeconomy is an opportunity not only for substituting fossil feedstocks but also for providing society with biobased solutions and products that promote human, animal, and environmental health while at the same time ensuring social cohesion and growth, especially in rural and coastal areas.

Reaffirming the centrality of the bioeconomy within the European Union's (EU) competitiveness agenda is more urgent than ever. Amid growing geopolitical instability, energy insecurity, and global competition for strategic resources, there is a risk of deprioritising the bioeconomy in favour of short-term priorities. Yet, as the 2025 EU Competitiveness Compass and the Draghi Report on European Competitiveness stress, securing Europe's prosperity requires strengthening technological sovereignty, reducing strategic dependencies, and investing in sustainable raw materials, all areas where the bioeconomy is uniquely positioned to deliver (European Commission, 2025a; European Political Strategy Centre, 2025). While both the Draghi and Letta reports (European Political Strategy Centre, 2025; Letta, 2024) emphasise the circular economy, the bioeconomy is notably absent from their framing, highlighting the need to elevate it within mainstream policy discourse. Anchoring the bioeconomy more firmly in the Green Deal Industrial Plan, Single Market reform, and cohesion funding will ensure it remains a strategic driver of innovation, resilience, and strategic autonomy for Europe (Directorate-General for Research and Innovation, 2022; Greenacre, 2024).

In parallel with these debates on competitiveness and strategic autonomy, the European Commission has now adopted A Strategic Framework for a Competitive and Sustainable EU Bioeconomy (European Commission, 2025b). Building on the 2012 Bioeconomy Strategy and its 2018 and 2022 reviews, the new framework explicitly positions the bioeconomy as a key driver of green growth, resilience, and technological sovereignty. It sets out a 2040 vision in which integrated biorefineries and advanced biomanufacturing provide fossil-free materials and products across Europe. It structures EU action around four pillars – scaling up innovation and investments, creating lead markets for bio-based materials and technologies, ensuring sustainable biomass supply, and harnessing global opportunities – which closely resonate with the strategic priorities discussed in this perspective. The European Commission (EC) is demonstrating a political commitment to this critical area for EU sustainable development, as the title of the new strategy indicates. This strategy now needs an ambitious action plan that will provide focus and momentum for the European bioeconomy, which should in turn create the platform for an overdue Bioeconomy Act that will help EU member states to deliver regional impact through mandated sustainable bio-based innovation.

In line with its purpose as a policy perspective, this manuscript is based on a targeted review of EU strategies, official assessments, and international reports published between 2018 and 2025, complemented by selected peer-reviewed literature on the circular bioeconomy, innovation systems, and biomanufacturing. Sources were chosen for their policy relevance, recency, and analytical contribution. It integrates quantitative data already available in authoritative datasets, including sectoral value added and employment figures from the EU Bioeconomy Strategy reviews, competitiveness indicators from the Draghi and Letta reports (European Political Strategy Centre, 2025; Letta, 2024), biomass availability estimates (Carus et al., 2025), biotechnology market shares (Eurostat, 2025; Statista, 2021), and investment metrics such as the Circular Bio-based Europe Joint Undertaking's (CBE JU) €2.5 billion leveraged investment in scale-up projects. These data are used throughout the manuscript to contextualise policy developments and to support the assessment of Europe's bioeconomy competitiveness, scale-up bottlenecks, biomass constraints, and circularity challenges. This approach reflects the objective of the article: to synthesise major strategic developments, identify systemic gaps, and propose actionable priorities for implementing a competitive and sustainable EU bioeconomy.

2. A globally competitive EU bioeconomy sector

The bioeconomy is a critical meta-sector that can help deliver on the European Green Deal and the new Competitive Compass objectives recently set (European Commission, 2025a), as it has the potential to foster sustainable growth, support climate neutrality, and secure global industrial leadership. While the European Union has established a strong scientific foundation and policy commitment to sustainability, it has yet to fully capitalise on its potential on the global stage. At this scale, countries have adopted different regulations and plans to advance the bioeconomy sector. United States' policies focus on biotechnology and large-scale biomanufacturing, supported by strategic initiatives such as the National Bioeconomy Blueprint, the 2016 Strategic Plan for a Sustainable Bioeconomy (Negi et al., 2021), and more recent whole-of-government actions under the 2022 Executive Order on Advancing Biotechnology and Biomanufacturing (White House, 2022). China has integrated circular economy principles into its green development strategy within the five-year plans, supporting biotechnology, biomass, and urban waste valorisation/utilisation (Negi et al., 2021). Brazil, by contrast, introduces a biodiversity-bioeconomy nexus into its policy framework, most recently through the 2024 National Bioeconomy Strategy and its RenovaBio programme, whose aim is to support the decarbonisation of the transport sector. These initiatives all contribute to scaling-up processes and industrial deployment; however, several challenges remain, such as the need to develop and adopt policies that are consistent, stable, and specific for each country's economy (Zhang et al., 2025). Overall, Europe occupies a highly competitive position within the global framework, due to its integrated regulations, strong research and innovation capacity, and commitment to green and bio-based sectors.

Alongside a strong European policy framework, several research studies promote a strategic direction towards a circular bioeconomy. Recent papers provide governance strategies analysis, innovation pathways, and measurement approaches for circularity, demonstrating a deep engagement in promoting bioeconomy across Europe (Skondras et al., 2024). Practical monitoring and modelling approaches that can inform policy and regional pilots are introduced by Bianchi's research team (Bianchi et al., 2024), while structured indicator sets and categories, including product-level circularity metrics and biomass utilisation efficiency, are proposed by several studies (Gerster, 2025; Mesa et al., 2024). Specific typologies of regional governance strategies and public-sector practices are also reported by Skondras study (Skondras et al., 2024), aiming to enable circular bioeconomy deployment in Europe. Finally, life-cycle assessment (LCA) based frameworks have been proposed to integrate circularity within product and value-chain assessment (Kumar et al., 2025). This comprehensive academic literature, combined with EU policies, provides methodological and governance tools that support circularity in the bioeconomy. Nevertheless, EU policy alignment is necessary to maintain and reinforce its advantages in a rapidly evolving bioeconomy landscape.

The EU's advantage lies in its comprehensive research and innovation (R&D) frameworks, notably Horizon Europe and the CBE JU, which fund biobased technologies from low to higher Technological Readiness Level (TRL). While more investment is needed in the Framework programme for bioeconomy early-stage research, competitiveness cannot rely solely on upstream R&D. Strengthening EU competitiveness will require a more coherent and systemic approach that aligns scientific excellence with industrial deployment, regulatory harmonisation, and effective regional replication. As stated above in the "scaling the bioeconomy" section, the EU must increase investment capacity for scale-up, demonstration, and commercialisation.

Market integration is also constrained by fragmented certification schemes, underdeveloped labelling mechanisms, and underutilised green public procurement. The Competitiveness Compass for the EU (European Commission, 2025a) and the European Commission's 2025 Public Consultation on the Future EU Bioeconomy Strategy (European

Commission, 2025c) acknowledge the need for harmonised EU-level standards to foster investor confidence and enable cross-border market development. Creating a coherent policy environment that combines standardisation, certification, and demand-side instruments such as bio-based procurement quotas would stimulate consumer trust and industrial uptake.

One promising vehicle for this expansion is the wider replication of regional circular bioeconomy systems across the EU. They integrate local biomass resources, infrastructure, and innovation actors into territorially embedded ecosystems that enhance resilience and sustainability. The report on the EU competitiveness underscores that successful replication of these models depends on targeted EU support for cross-regional knowledge exchange, alignment of structural funds with innovation strategies, and the institutional coordination of actors at regional and national levels (European Commission, 2025a; Directorate-General for Research and Innovation, 2017). Building on the EU's Smart Specialisation Strategies (RIS3) and interregional platforms, regional circular bioeconomy systems can generate inclusive growth, support rural revitalisation, and close innovation gaps (Hegyi et al., 2021). Another high-gain opportunity for the EU Bioeconomy is to initiate a new international collaboration program. Sharing (non-proprietary) knowledge can open new trade relations and emerging markets.

Building on these methodological and governance advancements, the faster use of new knowledge is also an important aspect which needs attention for strengthening EU competitiveness in the circular and bio-based sector. International collaboration is critically important to Europe as it can accelerate biobased developments and enhance EU trade relations. The Strategic Framework for a Competitive and Sustainable EU Bioeconomy (European Commission, 2025b) explicitly echoes these concerns, underlining that Europe's bioeconomy already generates trillions of euros in value added and millions of jobs, yet still faces underinvestment, strong international competition and persistent regulatory and market barriers that risk diverting innovation to non-EU markets.

Sustained competitiveness also relies on long-term investment in R&D, skills development, and knowledge ecosystems. As noted in the Bioeconomy Strategy Progress Report (Directorate-General for Research and Innovation, 2022), embedding research in regional ecosystems is essential to ensuring that innovation (technologies and products) reaches the market as quickly as possible. It requires better integration between academia, SMEs, and industry, supported by education and skills initiatives targeting the bioeconomy workforce. Strategic alignment between research policy and industrial strategy is crucial for achieving technological sovereignty (European Commission, 2024).

3. Creating efficient demand for more value from fewer resources

3.1. Cohesive policy to create a level playing field for the bioeconomy

The transition away from a fossil economy to a fully functioning circular bioeconomy is urgently needed, but complex and challenging. Cohesive policy is critical to enabling the bioeconomy to achieve its potential for Europe. In the call for evidence "Towards a Circular, Regenerative and Competitive Bioeconomy", the EC recognises that significant progress in the bioeconomy has been made due to the European Bioeconomy strategies of 2012 and 2018 but that "trade-offs and fragmentation of the policy framework are hampering the potential of the EU to achieve a leading position in a rapidly expanding market" (European Commission, 2025a). This is also supported by recent studies focused on governance analysis and national case studies, which highlight the need to coordinate tools and down-scaling mechanisms of EU policies to ensure coherence and effectiveness (Faulkner et al., 2024; Pender et al., 2024). The same communication recognises that the bioeconomy is in line with "the Competitiveness Compass, the Clean Industrial Deal and the EU Climate Law" and "plays a key role in supporting the EU in reaching its climate and energy goals by 2030 and climate neutrality by 2050 while combating biodiversity loss and pollution" (European Union, 2025a). Cohesion across these and other EU policies (e.g., Biotech and Biomanufacturing, Life Sciences) is essential to create demand for biobased products and services and to achieve a circular, regenerative, and competitive bioeconomy. The bioeconomy must be an integral part of key policies aimed at promoting sustainable resource use, addressing climate change and biodiversity loss, increasing food security (Albinelli et al., 2024), and societal resilience, promoting health and social inclusiveness, which closely match to the United Nations' Sustainable Development Goals (UN SDG).

To avoid incomplete and inefficient outcomes, integrated indicators, including LCA combined with circularity metrics for bio-based systems, should be integrated into policy decisions. Recent studies provide a solid foundation for evidence-based policymaking by proposing insightful frameworks for evaluating circularity and biomass use efficiency (Bianchi et al., 2024; Mesa et al., 2024).

Finally, academic literature shows that the bioeconomy is not inherently sustainable. Trade-offs related to land use, biodiversity, and the food sector must be considered within policy frameworks that account for bio-geophysical limits and systemic evaluations (Holden et al., 2023; Warchold and Pradhan, 2025).

Building on this diagnosis, A Strategic Framework for a Competitive and Sustainable EU Bioeconomy (European Commission, 2025b) responds directly to the call for "a circular, regenerative and competitive bioeconomy" by integrating competitiveness, climate neutrality, and nature-positive outcomes into a single strategic agenda. It recognises that fragmented policy frameworks and inconsistent incentives remain major obstacles, and calls for better alignment between bioeconomy, climate, energy, biodiversity, industrial, and single-market policies, precisely the type of policy cohesion we argue is necessary for the bioeconomy to move from niche to norm. A circular bioeconomy act could significantly enhance policy cohesion and serve as the umbrella for interconnected areas of strategic importance for Europe's sustainability.

Significant investment, dedication, and perseverance are needed, along with a willingness to address difficult truths about the continued subsidisation of fossil-based products (European Energy Agency, 2025), despite huge profits in the fossil sector. Such fossil subsidies significantly hamper the transition to a circular regenerative bioeconomy and decarbonisation. A 2023 International Monetary Fund (IMF) working paper on fossil subsidies has stated that "globally, fossil fuel subsidies were $7 trillion in 2022 or 7.1 % of GDP. Explicit subsidies (undercharging for supply costs) have more than doubled since 2020 but are still only 18 % of the total subsidy, while nearly 60 % is due to undercharging for global warming and local air pollution" (Black et al., 2023).

3.2. High-value products manufacturing for europe to lead in the bioeconomy

Europe should develop a diverse set of biorefineries where higher-value products are emphasised. The European bioeconomy can play to its existing strengths in the agriculture, chemical, and biotechnology sectors by producing high-value products (e.g., food and feed ingredients, bioactive substances, proteins, fine chemicals) through the cascading use of biomass, which will also generate the higher volume products (biomaterials, bulk chemicals) and subsequently biofuels and bioenergy from residual biomass. Several studies demonstrate the suitability of these approaches for producing high-value bio-based products, showing both technical and environmental advantages (Perez-Almada et al., 2023; Segers et al., 2024). The cascaded use of biomass can enhance resource efficiency and economic value, while mitigating environmental effects (Agnihotri et al., 2025). By leveraging these efficiencies, the knowledge and market access of these industries can increase Europe's chances of retaining jobs, creating new jobs, and providing high-value products for domestic and international markets,

thus driving growth in the Bioeconomy and sustainable development of society at large, not least rural development and improved livelihoods.

Biotechnology (White, Green, Red, Blue, etc.) (Kafarski, 2012) and chemical technologies are key pillars of biomanufacturing. The chemical industry in Europe had sales of €785 billion in 2023, with €523 billion of exports (Eurostat, 2025). Therefore, the deployment of chemical technologies in the bioeconomy has enormous potential given the European chemical industry's capabilities and reach. Europe accounts for 12 % of the €720 billion global biotechnology market but needs to catch up with the USA, which accounts for 60 % (European Commission, 2024). Growth in biotechnology is forecast at close to 20 % per annum and is a huge opportunity for the European economy (Statista, 2021). Biotechnology uses living organisms (e.g., microbes, bacteria) and biological mechanisms in the manufacture of products. It therefore differs from other manufacturing technologies. It is developing in tandem with advances in life sciences, and the sector can create highly innovative solutions to societal challenges. It has significant untapped potential to replace fossil-based synthetic products and generate products of higher value and functionality. Therefore, the EU Biotech and Biomanufacturing Initiative Action Plan and Life Sciences Strategy must acknowledge the enabling role and benefits biotechnology can bring to the Bioeconomy and Europe's competitiveness through the production of valuable biobased products from biobased resources.

3.3. *Strategic cohesive financing to grow demand and de-risk investment*

An update to the existing EU bioeconomy strategy is timely. It is a huge opportunity for Europe to build resilience for the future and gain a competitive advantage over regions such as the USA, which are changing direction. The revised bioeconomy strategy must continue to support research, innovation, and scale-up to de-risk investments, build critical mass, and increase the chances of translating potential into market reality. The bioeconomy can contribute to our competitiveness through the creation of jobs, innovative high-value products and industrial biomanufacturing processes, autonomy reinforcement, reduced greenhouse gas emissions, increased biodiversity, and improved air and water quality. A concerted effort is key to achieving these goals in a timely fashion. Investment in the bioeconomy must be viewed in the context of the scale of public and private investments made in the fossil economy over more than a century (World Economic Forum, 2022). Public-private partnerships over an extended period of time are critical to sustainable bioeconomy development in Europe.

The subsequent adoption of a Strategic Framework for a Competitive and Sustainable EU Bioeconomy (European Commission, 2025b) confirms this assessment. It explicitly identifies significant financing gaps across the bioeconomy value chain – particularly for scaling biomanufacturing, advanced bio-based materials, and circular infrastructure – and stresses the need to bridge two "valleys of death" between demonstration and commercial deployment through blended finance, coordinated investment instruments, and improved access to scale-up facilities (Fig. 1).

Evidence from recent analyses indicates that coordinated public-private investment is crucial for bridging these "valleys of death", enhancing both market adoption and sustainability outcomes (Gatto and *Re*, 2021; Sierra et al., 2021). These orientations are entirely consistent with our call for long-term, strategic public-private partnerships and a step-change in investment levels if Europe is to translate its scientific strengths into globally competitive bio-based industries.

The CBE JU, a public-private partnership, began in 2014 and has demonstrated that coordinated strategic investment can bring considerable impact. The CBE JU has transformed the European landscape for bioeconomy innovation and scale-up with 22 flagship biorefineries and 77 demonstrators (Circular Bio-based Europe Joint Undertaking, 2025a). These innovation actions have driven €2.5 billion of investment in Europe (Circular Bio-based Europe Joint Undertaking, 2025b). The CBE JU has leveraged €3.5 of private funding for every €1 of public funding invested. It is a high level of SME participation that brings together stakeholders, such as farmers, engineers, researchers, manufacturers, and brand owners, to build flagship biorefineries, produce new biobased products, and bring them to the market (Circular Bio-based Europe Joint Undertaking, 2025b). All 27 member states participate in CBE JU-funded projects with 10 "associated" countries and 8 "third" countries. Indeed, CBE JU's achievements continue to be exemplary in delivering impact and transforming the European landscape through public-private partnerships. It is critically important that this investment continues to grow and stays the course for decades to come. To grow and sustain a bioeconomy that contributes to Europe's competitiveness and resilience, there is a need to have a long-term public-private partnership that stimulates innovation and investment, and that can evolve to ensure Europe fully realises its ambition for a

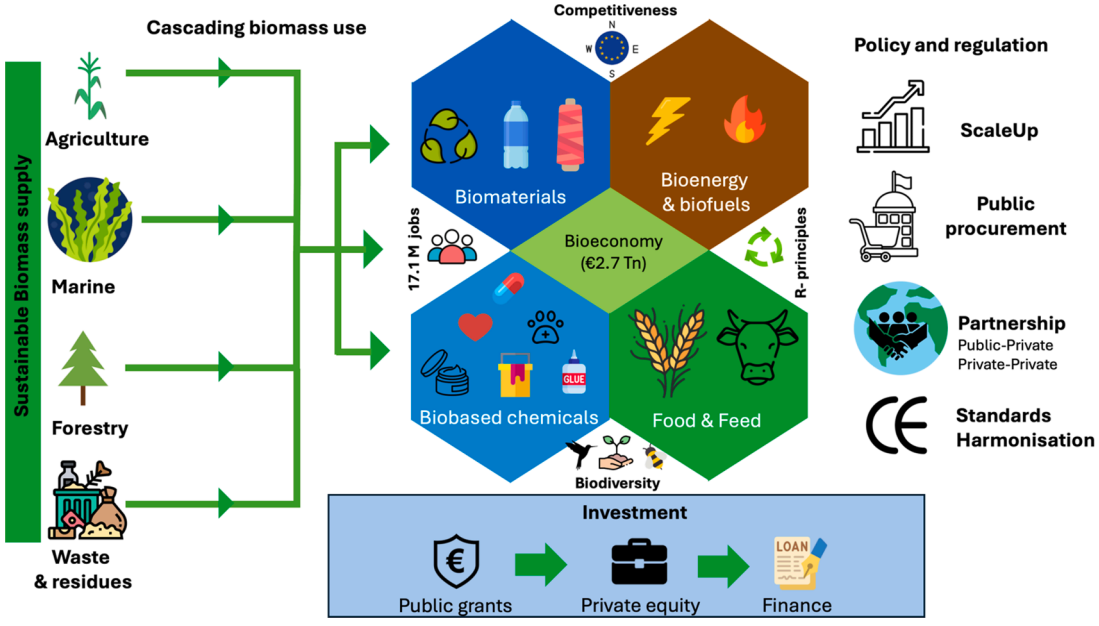

Fig. 1. Resources, value, market opportunities, drivers, and levers of the European circular bioeconomy (authors' workout).

circular biobased society.

4. From lab to fab: priorities for scale-up to accelerate the development of the bioeconomy

As the CBE JU Strategic Research and Innovation Agenda (Circular Bio-based Europe Joint Undertaking, 2022) affirms: the EU must address a critical weakness, such as limited capacity for scale-up and commercialisation. The deficits in pilot and demonstration infrastructure, particularly in rural and structurally weaker regions, leave many innovations stranded between TRL5 and 7. These infrastructural gaps are compounded by regional disparities in innovation readiness and limited access to risk finance (Greenacre, 2024).

The new EU Bioeconomy Strategic Framework (European Commission, 2025b) similarly highlights that limited access to pilot and demonstration infrastructure, fragmented authorisation procedures, and insufficient late-stage finance are preventing promising innovations from reaching the market, particularly in biomanufacturing and advanced fermentation. It emphasises the need to de-risk scale-up through blended finance instruments, improved coordination between EU and national funding, and targeted support for first-of-a-kind biorefineries and biomanufacturing facilities. Our recommendations on open-access regional scale-up facilities, long-term public-private co-investment, and a dedicated industrial strategy for the bioeconomy can thus be seen as concrete, implementation-oriented proposals that operationalise this EU-level vision (Fig. 2).

Investment in scale-up requires integrating very-early TRL1–3 with mid TRL4–6 and higher TRL7–8 activities to drive collaboration between technology developers, scale-up experts, industry, and market players. Also, technology developers need open advanced research infrastructures available to academics, SMEs, and industries. This is especially needed in biotechnology where mastering machine learning and automation technologies is crucial for utilising the rapidly evolving biological knowledge and know-how. Europe must thus invest in lower TRL infrastructure to advance technologies and create a pipeline for higher TRL actions to access data that can accelerate the development of biobased solutions. An example of such infrastructure is the EU-IBISBA, a pan-European research infrastructure dedicated to industrial biotechnology (at TRL2–6) to accelerate the development of biotechnology and synthetic biology. These need to be seamlessly linked to open technology infrastructures that operate at higher TRLs.

Technology developers and the investment community need regional demonstrators (pilot- and demo-scale facilities). The size of these facilities can vary, and they can even be mobile, but regional/local facilities are essential for creating bioeconomy innovation communities that cluster industries, policymakers, researchers, innovators, entrepreneurs, and investors. Regional development plans need to have pilot and demonstration-scale facilities to promote economic and regional development. Scale-up facilities should be seen as a public investment in fostering innovation. There is little to no value in industry and investors funding the purchase of stainless steel, but immense value to the industry in paying for access to facilities for scale-up. Scale-up facilities provide data, prototypes, and invaluable biomanufacturing experience (biotechnology, chemical technology, biomass pre-processing, and down-stream processing) that help de-risk investment and shorten the route to market. However, state aid rules are a significant barrier to the establishment of these regional pilot-scale facilities and hamper regional innovation.

The CBE JU is an excellent example of significant funding for research at higher TRL (pilot/demo) that stimulates industry-academic collaboration, the establishment of biorefineries, and regional innovation. Europe needs more biorefineries that need public support to de-risk the seminal phase of the new bioeconomy. Regional biorefineries create jobs and revenues, provide a pipeline of new technologies and products, and act as beacons for replication. Regional scale-up facilities, in turn, offer biobased industries opportunities for education, training, and re-skilling of a workforce not just in technological subjects but also in regulation, market trends, funding, and finance, and are therefore hubs for knowledge creation and sharing.

Despite these promising models, bridging the two "valleys of death" remains a major barrier to commercialisation. The first valley, between research and scale-up, reflects high technology risk and a lack of infrastructure. The second, between demonstration and market uptake, is shaped by weak industrial policy, uncertain market demand, and regulatory obstacles and fragmentation (Sarpong et al., 2023; Tippmann et al., 2022). According to the Competitiveness Compass for the EU 2025 report, effective responses include expanding public-private co-investment platforms, providing open-access scale-up infrastructure, and institutionalising a dedicated EU industrial bioeconomy strategy with tools such as green procurement targets and consistent product standards (European Commission, 2025a; 2025c).

5. Securing sustainably-sourced biomass in a circular bioeconomy

5.1. Biomass availability

The sustainability of biomass plays a central role in the development of Europe's bioeconomy, where the transition towards renewable biological resources aims to reduce reliance on fossil fuels, achieve climate neutrality, be nature positive, and contribute to human and animal health. A crucial factor for a competitive bioeconomy is the availability of biomass, which must meet the growing demands of multiple sectors, including food production, bioenergy, bioplastics, bioactive substances, food ingredients, feed ingredients, and bio-based chemicals, without compromising food security or the quality of ecosystems. Therefore, biomass availability relative to the products made in biorefineries remains a major challenge.

The Strategic Framework for a Competitive and Sustainable EU Bioeconomy (European Commission, 2025b) acknowledges the same

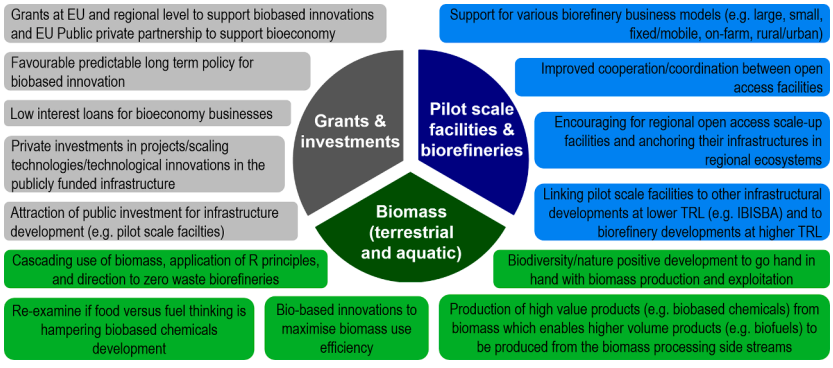

Fig. 2. Recommendations for accelerating the development of the bioeconomy in Europe (authors' workout).

tension, stressing that planetary boundaries constrain the bioeconomy and that responsible and efficient biomass use is "key for long-term competitiveness, supply stability and ecosystem health". It calls for directing biomass towards higher-value applications, using residual streams for energy in hard-to-abate sectors, and improving transparency of biomass flows in policy and investment decisions: an approach that aligns closely with our emphasis on cascading use, nutrient circularity, and nature-positive biomass sourcing.

A recent study shows that meeting 20 % of the total global carbon demand of the chemicals and derived materials sector by 2050 from biomass is achievable without compromising food and feed supplies and biofuel demand (Carus et al., 2025). European policy needs to recognise that applying the data from the evident competition that biofuels create with food production to lower-volume materials and chemicals will restrict the development of a key aspect of the high-value bioeconomy in Europe. The potential for a higher share of biobased chemicals depends on demand for biofuel production. Sustainable fuel policies influence this, as well as the decrease in feed production for animals, which can be driven by the shift toward more plant-based protein consumption, and the future efficiency of the agricultural system (Carus et al., 2025). The use of marine resources is particularly relevant for Europe, not only to reduce the burden on terrestrial resources, but also to provide products unique to marine biomass. Protecting the marine environment, as well as the use of marine resources to provide ecosystem services, can create business opportunities and build resilience for Europe's coastal (and ocean) communities.

5.2. Cascading use and regeneration of biomass

Focusing on resource efficiency is particularly important for advancing the circular bioeconomy. Biomass, being inherently organic and renewable, naturally supports the principles of a regenerative and circular bioeconomy. To provide sufficient biomass, improve sustainability, and reduce land use for the biomass production, Europe has prioritised the cascading use of biomass. The objective of cascading is to enhance resource efficiency, maximise value creation from the biomass, and have a positive impact on the environment. While the major focus is on carbon, it should be recognised that nitrogen and phosphorus use efficiency and the circularity of nutrients are equally critical to a functioning bioeconomy, promoting environmental and human health.

5.3. Increasing efficient use of biomass

Creating technologies with high valorisation potential in zero-waste biorefineries is critical to improving biomass use efficiency in a circular bioeconomy. Europe needs to do more with the biomass it has. Biotechnology, biomanufacturing, and chemical technologies can play a critical role in increasing biomass use efficiency and converting virgin and waste biomass into a diverse array of higher-value products. These technologies open up possibilities that promote human and environmental health, e.g., medical ingredients, nutraceuticals, cosmeceuticals, biobased crop protection, plant stimulants, improved nutrient efficiency, soil additives, ruminant methane inhibitors, biopolymers, bioplastics, and other biomaterials, and biobased chemical building blocks. These can be bio-manufactured using biotechnology and/or chemical technologies, using plant and animal biomass, both from land and aquatic sources (agro and forestry side streams, grass, macro- and microalgae, fungi and other microbial biomass, slaughterhouse waste, food processing side streams, fisheries side streams, etc.). The use of marine resources is particularly relevant for Europe, not only to reduce the burden on terrestrial resources, but also to create ecosystem services, resilience, and opportunities for Europe's coastal (and ocean) communities to produce products unique to the marine (Directorate-General for Maritime Affairs and Fisheries, 2023). The growth of technologies such as anaerobic digestion and fermentation will generate biogenic CO_2 from plant and animal biomass. Biobased CO_2 is a valuable alternative resource that provides opportunities for Europe to increase carbon efficiency.

5.4. Biomass for biobased products, biofuels, and bioenergy

The European bioeconomy strategy has recognised, and must continue to do so, that there is insufficient biomass to satisfy Europe's energy needs through biofuels/bioenergy alone and that a diversified portfolio of renewable energy generation is needed. When biomass is cascaded, the final residual biomass can be used to make biofuels and bioenergy. Therefore, the EU needs to keep to its strategy of developing a range of low-carbon energy and fuels derived from a range of sources (wind, solar, tidal, hydro) to generate electricity, which can be used for heating, transport, etc., and to make hydrogen (fuel). Chemicals and materials are carbon-rich and thus require biobased carbon for their manufacture, but energy can be carbon-free (e.g., hydrogen, solar-, wind-, and hydro-generated electricity). Carbon-rich biofuels will likely be a transient solution as the global economy moves towards decarbonisation. During that transition, liquid and gaseous biofuels as well as bioenergy should be generated from wastes/residues while adhering to the cascading use principle.

5.5. Biomass and biodiversity

Another essential dimension of biomass supply is biodiversity, both in terrestrial and aquatic environments. As large-scale monocultures can lead to biodiversity loss, soil degradation, and water resource depletion, diversifying biomass supply is key for food, feed, and non-food/feed products. In addition, the EU Biodiversity Strategy (European Commission, 2020) for 2030 aims to protect nature, reverse the degradation of ecosystems, and advocate for biomass sourcing that preserves or enhances ecosystem services. Biodiversity contributes to soil health. Soil is the cornerstone of the bioeconomy, and thus, biodiversity is critical to the resilience of the bioeconomy.

5.6. Circular bioeconomy

The bioeconomy is not inherently circular, as the bioeconomy can be constructed to directly replace the linear fossil economy (take, make, dispose), which is not sustainable. However, the bioeconomy has the potential to serve as the biological component of the circular economy. Indeed, as society transitions away from fossil-based resources, the vast majority of the circular economy will be biobased. Assessing the circularity dimension of the bioeconomy is crucial. Therefore, several indicators and metrics have been introduced to effectively measure circularity and evaluate the progress of bioeconomy strategies. However, different classifications of indicators are provided due to the lack of universal definitions (Figueirinhas et al., 2026) and the continuous evolution in the field of circular economy research (Rigamonti and Mancini, 2021). In particular, circularity can be evaluated at different levels, i.e., micro-, meso-, and macro-levels. At the micro-level, indicators mainly refer to products, companies, and consumers, capturing product- and process-related systems such as material flows (Lavallais and Dunn, 2023), as well as product reuse and recycling (Das et al., 2000; Vanegas et al., 2018). At the meso-level, eco-industrial parks and industrial symbiosis are primarily addressed, while the macro-level refers to cities, regions, and nations (Rigamonti and Mancini, 2021). Recent studies support and enrich the EU bioeconomy monitoring framework by proposing life cycle-based indicators for circular business models and bio-based systems (Basile et al., 2024; Bianchi et al., 2024; Colasante et al., 2022). Including these indicators into EU policies would allow the measurement of circularity across: (i) environmental impacts (e.g., biomass cascading efficiency, nutrient-recycling efficiency, greenhouse gas emissions, energy use), (ii) economic impacts (e.g., renewable carbon content, sustainable innovation and responsible financial management), (iii) social impacts (e.g., workers health and

safety, public awareness and community resilience). These indicators can be tested using regional demonstrators and aligned with current EU indicator work to ensure comparability and policy relevance, thereby enhancing a circularity framework that is universally recognized. Furthermore, as global consumption patterns evolve, circular economy strategies will increasingly merge with broader sustainable net-zero initiatives. EU strategy needs to continue to prioritise the use of agricultural residues, forestry and fisheries by-products, organic waste, biogenic CO_2, algae and other aquatic biomass (including side streams) (Philippidis et al., 2018). Waste resource/residue valorisation should thus be a facet of Europe's value creation capabilities. The new EU Bioeconomy Strategy (European Commission, 2025b) already frames the bioeconomy as a key lever for defossilisation and a nature-positive, circular economy, with a 2040 vision built around integrated biorefineries, advanced biomanufacturing, and efficient use of primary and secondary biomass. To fully deliver on this ambition, it should also explicitly promote the R-principles of the circular economy (e.g., Refuse, Rethink, Reduce, Reuse, Repair, Remanufacture, Recycle) and embed them into policy design and monitoring so that Europe can adhere to UN SDG No.12 on sustainable consumption and production.

6. Conclusion

The bioeconomy presents a strategic opportunity to boost European competitiveness and autonomy, strengthen resource independence, create jobs, and address climate change and biodiversity loss. It also supports food security, resilience, improves human, animal, and environmental health, and promotes social inclusion.

The modern bioeconomy is a nascent sector that needs cohesive policy to create a level playing field. Integrated action plans across EU policy areas will enable the bioeconomy to fully establish itself, moving from niche to norm and to contribute to a just transition away from a fossil economy and towards a circular biobased society (bioeconomy). Long-term policy and public funding support for the circular bioeconomy, including strategic cohesive investments such as public-private partnerships, are needed to de-risk private and public investments. To move the bioeconomy from research to economic development, the bioeconomy must be central to the European competitiveness agenda, which will ensure Europe's global competitiveness, future resilience, and autonomy.

The European bioeconomy can play to its existing strengths in the agriculture, chemical, and biotechnology sectors by producing high-value products with a vast array of market applications, for example, food and feed ingredients, bioactive substances, proteins, and fine chemicals, through the cascading use of biomass. This cascading use will also generate higher-volume products (biomaterials, bulk/platform chemicals) and subsequently biofuels and bioenergy from residual biomass.

Accelerating the development of the bioeconomy requires significant investment in open-access scale-up facilities for biotechnology and other key enabling biomanufacturing technologies, as well as funding for SMEs and start-ups to help them survive the "valley of death". The use of modern data-driven technologies can further enhance the efficiency and speed at which the bioeconomy develops.

The supply of sustainable biomass is a major challenge, and so, the cascading principle of biomass use, as well as the use of residues, is critical to an efficient valorisation of biomass in a circular bioeconomy. EU policy must continue to recognise that there is not enough sustainable biomass to address Europe's fuel and energy needs, and so a plethora of low-carbon energy sources are needed (e.g., wind, solar, hydro, and hydrogen). While utilising biomass, the European circular bioeconomy must make room for high-quality natural habitats, as biodiversity will provide resilience against extreme weather events, can reduce external inputs into agriculture and thus support sustainable biomass production.

The adoption of a Strategic Framework for a Competitive and Sustainable EU Bioeconomy (European Commission, 2025b) demonstrates a vision for the acceleration away from the linear fossil economy and the continued evolution of the circular bioeconomy. Its four-pillar structure – scaling innovation and investments, developing lead markets, ensuring sustainable biomass supply, and harnessing global opportunities – broadly reflects the priorities identified in this perspective. To harness global opportunities, Europe must develop and sustain partnerships within and outside the EU, with knowledge sharing between partners key to long-term success.

Implementation will need to be particularly ambitious: establishing a dedicated industrial strategy for the bioeconomy, sustaining long-term public-private partnerships, and anchoring biorefineries and scale-up infrastructures in regional ecosystems so that the strategy's objectives of competitiveness, resilience, and nature-positivity can be realised in practice. The bioeconomy strategy needs a plan that will prioritise key actions and a bioeconomy act as the cohesive force for member states to drive the transition to a fully bio-based society that can secure a prosperous, sustainable future for its citizens.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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