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Evidence Synthesis Report: 2

Circular Bioeconomy Outlook Study 2030-2050 in Support of Climate Action, Sustainable Food and Biobased Systems

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

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- Oversee the implementation of the Environmental Noise Directive;
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3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

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EPA RESEARCH PROGRAMME 2021–2030

Circular Bioeconomy Outlook Study 2030–2050 in Support of Climate Action, Sustainable Food and Biobased Systems

(2021-GCE-1021)

A copy of the end-of-project Technical Report is available on request from the EPA (research@epa.ie)

Prepared for the Environmental Protection Agency

by

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

This report provides an outlook for Ireland's circular bioeconomy for the period 2030–2050, highlighting the potential to create economic, environmental and social opportunities for new biobased innovations. We report on bioeconomy best practice internationally to show how Ireland can benefit from others and tailor the learning to develop a bioeconomy fit for Ireland now and in the future. The circular bioeconomy has the potential to address major interrelated societal challenges, such as climate change, sustainable food production, biodiversity loss, and the production of biobased materials, biobased chemicals and biobased energy, to help support a modern sustainable society. This can help Ireland to increase its competitiveness, resilience and job creation, delivering a positive environmental, social and economic impact at local, regional and national levels.

The circular bioeconomy should use renewable sustainable biological resources from land and sea, such as crops, forestry, fisheries, aquaculture and wastes, and converts these resources and their processing by-products into value-added biobased products including, but not limited to, proteins, oils and fats, feed, fertilisers, plastics, building block chemicals and energy. Many of the products identified are currently imported, often unsustainably and at high cost, and could, in a circular bioeconomy, be produced sustainably by indigenous companies, using local resources, creating local jobs and increasing resource security. A circular bioeconomy can optimise resource use, build resilience in biological production systems and contribute to Ireland's economic competitiveness. Given its strong indigenous agri-food sector, vast marine space and forestry potential, Ireland has great potential to exploit the opportunities presented by the circular bioeconomy. The innovation potential identified in this report will serve as a valuable signpost for Irish enterprises to supply global markets with sustainable products and technologies. Despite the potential of the circular bioeconomy, there are risks and barriers that can inhibit its development, including a lack of awareness of biobased products, large-scale investment requirements, fragmentation of stakeholders, a lack of supporting policies, and the need to balance ecosystem protection and biodiversity with production systems.

In this report we provide information on high-potential biobased products, key conversion technologies and key feedstocks and their potential for Ireland. We look at patents relating to biobased innovations as well as to bioeconomy digitalisation, natural capital and ecosystem services. By linking these, we attempt to provide technological pathways towards a sustainable circular bioeconomy and a vision for the large transformations that can bring benefits for rural communities and Ireland as a whole. The transition requires significant public investment, which will stimulate private investment. Part of that investment will be in biorefineries, factories of the bioeconomy, which are rapidly being developed and scaled up across Europe with the help of initiatives such as the Circular Bio-based Europe Joint Undertaking programme to accelerate scale-up and deployment of biobased innovations over the period 2021–2031. By detailing specific high-potential bioeconomy pathways, and enabling policy recommendations, this report provides a focal point for implementing and scaling up Ireland's bioeconomy.

Ireland must increase its commitment to the sector in order to meet its stated objective of becoming a global leader in the bioeconomy. The development of a circular bioeconomy is supported in various government policy documents such as the Climate Action Plan 2021, the Food Vision 2030 Strategy and the Circular Economy Strategy 2021. The report examines the EU, national and non-EU policy landscape for supporting the development of the bioeconomy. The report also highlights the barriers to and support required for commercialisation in the bioeconomy based on stakeholder engagement and input. The report finishes with specific recommendations to support the development and implementation of a sustainable and circular bioeconomy for Ireland.

1 Introduction

The main aim of this report is to provide an outlook for the potential of a circular bioeconomy to support climate action, sustainable food and biobased systems over the 2030–2050 period. In the crisis-to-crisis period we are living through, including the climate and biodiversity emergencies, a sustainable and circular bioeconomy can help build resilience in our local biological resources, environment, economy and society. A circular bioeconomy can help us to address challenges that are key to our everyday lives, from climate change mitigation and adaptation to regional economic and social development, **to ensure the availability of the food, energy and materials on which we depend**.

In addition to supporting Ireland's transition to a climate-neutral economy, a sustainable bioeconomy will be key to maintaining and enhancing the competitiveness of the Irish economy in the 21st century. A recent report by the McKinsey Global Institute (Chui *et al*., 2020) highlighted the global innovation potential of the bioeconomy and reported that its annual direct economic potential is between €2 and €4 trillion per year for the next 10–20 years, with a potential for 60% of the world's physical inputs to be made using biological means. It cites a "visible pipeline of applications, around 400 use cases across agriculture, aquaculture and food, consumer products and services, materials, chemicals, and energy production". This report looks at the potential for Ireland **to benefit from these new opportunities, building on the innovation potential that already exists** for Ireland's bioeconomy. Ireland has a strong focus on the development and growth of Irish enterprises in world markets. Enterprise Ireland (EI) works in partnership with Irish enterprises to help them start, grow and innovate and win export sales in global markets. In this way, EI supports sustainable economic growth, regional development and secure employment. The innovation potential identified in this report will serve as a catalyst and valuable signpost for Irish enterprises to serve global markets with more sustainable products and technologies.

While investigating the innovation potential of the Irish bioeconomy, the report also places **sustainability** and **circularity** at its heart. According to the 2018 EU Bioeconomy Strategy Update, sustainability and circularity are essential to a successful bioeconomy, which will drive the renewal of our industries and the modernisation of our primary production systems and contribute to the protection of the environment while enhancing biodiversity. In this report, our definition of the bioeconomy is the sustainable use of renewable biological resources and industry technologies to produce biobased products and services for societal, environmental and economic gain now and in the future. In this respect, the bioeconomy uses renewable biological resources sourced more sustainably from land and sea, such as crops, forestry, animals, fisheries, aquaculture and wastes, and converts these resources and their processing by-products into value-added biobased products including, but not limited to, proteins, oils and fats, feed, fertilisers, plastics and energy. **Many of these products represent materials that Ireland currently imports, often unsustainably and at high cost, but that in a circular bioeconomy could be produced sustainably and indigenously by local companies, with local resources, creating local jobs and moving away from fossil-based resources towards biobased resources and increasing resource security (BIC, 2022)**.

Ireland is an island rich in natural biological resources, and so the bioeconomy opportunities are very relevant and truly vast. **Despite this potential, several risks and barriers may inhibit the development of the bioeconomy.** These can range from a lack of private and public awareness of biobased products and difficulties in attracting initial investment resulting from high costs and longer payback periods, to challenges in building alliances between the multiple cross-sector stakeholders required to deliver these new biobased value chains, a lack of supporting policies and the need to balance ecosystem protection and biodiversity with production systems (Overbeek and Hoes, 2018; Barrett *et al*., 2021).

1.1 Pathway to a Sustainable and Circular Bioeconomy

This report presents a snapshot of potential innovation scenarios for Ireland's bioeconomy over the 2030–2050 period, along with recommendations to inform policy development for the further development of a sustainable and circular Irish bioeconomy.

To aid in this, Chapter 2 of this report compiles information on **high-potential, sustainable, biobased products** with domestic and export potential; **key conversion technologies** building on research and demonstration activities at EU and global levels; and **key feedstocks** from Ireland's agriculture, forestry, marine and waste sectors. Chapter 3, meanwhile, explores **patents** relating to biobased innovations worldwide, with a particular focus on those feedstocks relevant to Ireland's bioeconomy, along with other key bioeconomy innovation areas such as **bioeconomy digitalisation, natural capital and ecosystem services**. By linking high-potential feedstocks to innovations and products, via research and innovation projects and patents, the project provides technological pathways towards a sustainable, circular bioeconomy. It is critical that Ireland also focuses on innovation actions in primary production as many of the environmental impacts and future benefits will come from innovations on farms and in forests and the marine. There is also a need to support the development of this sector through policy, financial and ecosystem interventions, such as developing agricultural knowledge and innovation systems. Chapter 4 of the report examines the **policy landscape** for supporting the development of the bioeconomy, including EU-level policies such as the European Bioeconomy Strategy 2018, but it also compares bioeconomy policy in Ireland with that of other EU Member States and, finally, highlights some key international bioeconomy policy initiatives from non-EU jurisdictions.

Building on this research, the project team engaged extensively with a stakeholder network during the project. This network represents the diverse range of stakeholders required to implement Ireland's bioeconomy, including primary producers, academia, industry, policymakers and innovation clusters. This engagement has been through interviews and the hosting of a stakeholder workshop to understand the barriers to and support required for commercialisation of the bioeconomy. These activities are highlighted in Chapter 5.

Finally, building on the combination of research and stakeholder engagement, in Chapter 6 the project team makes specific recommendations, including **policy recommendations**, that can help support the development and implementation of a sustainable and circular bioeconomy for Ireland. These include both strategic recommendations and practical recommendations for implementation. Alongside the technological pathways, these recommendations complete the pathway to a sustainable and circular bioeconomy for Ireland.

By detailing specific high-potential bioeconomy pathways and enabling policy recommendations, this report provides a focal point for implementing and scaling up Ireland's bioeconomy. This main report also highlights Ireland's considerable natural biological resources, which can provide the country with a competitive advantage in certain areas of the bioeconomy. We highlight bioeconomy best practice happening elsewhere in terms of both technology development and deployment and policy implementation. In this sense, Ireland can benefit from the learned experiences of others and tailor these learning points to develop a bioeconomy fit for now and beyond: a bioeconomy that is circular and sustainable, protects nature and the environment, and builds on the cascading principle to increase competitiveness, resilience and job creation, delivering a positive environmental, social and economic impact at local, regional and national levels.

2 Scientific Literature Review

The EU Bioeconomy Strategy Progress report provides the following definitions and explanations:

1. The bioeconomy encompasses all sectors and associated services and investments that produce, use, process, distribute or consume biological resources, including ecosystem services. Therefore, it is a natural enabler and result of the European Green Deal transformation.
2. Bioeconomy policies take a cross-sectoral perspective to improve policy coherence and identify and resolve trade-offs, for example on land and marine and biomass demands.
3. Bioeconomy policies contribute to building a bioeconomy addressing all three dimensions of sustainability:
   (a) environment: management of land and biological resources within ecological boundaries;
   (b) economy: sustainable value chains and consumption;
   (c) society: social fairness and just transition.
4. EU and national bioeconomy strategies complement sectoral policies and enable countries and regions to design transition pathways according to their specific challenges and opportunities, benefiting from a non-prescriptive, integrated and systemic framework.

There is a strong focus on developing biorefineries both in Europe and throughout the world, as they provide opportunities for job creation, economic growth and the substitution or replacement of products that currently come from fossil-based resources such as gas and oil (BIC, 2017). It is important to note that bioeconomy strategies are evolving with greater emphasis on innovation opportunities within the farm, forest and marine systems, as they can support, for example, carbon sequestration and greenhouse gas (GHG) emissions abatement, increasing biodiversity and with it the resilience of production systems. The provision of ecosystem services by natural capital is now seen as an economic and an environmental opportunity. Thus, while biorefineries are critically important to any bioeconomy, they are one of several key pillars.

We will start this part of the report with an overview of the types of biorefineries that currently exist, within and outside the EU. Subsequently, we will set out key products, conversion technologies and underlying feedstocks with innovation and growth potential in the context of the Irish bioeconomy, drawing on research and pilot and commercial activity.

2.1 Biorefineries in the EU: An Overview

Biorefineries are industrial units that refine biological resources. According to International Energy Agency (IEA) Bioenergy Task 42, biorefining is “the processing of biomass into a portfolio of marketable bio-based products, which could include co-production of food and feed, chemicals, materials, and bioenergy (power, heat/cold, fuels)” (Cherubini *et al*., 2009; MarketWatch, 2022). The products from biorefineries are many and varied, from high-value chemicals used in cosmetics, pharmaceuticals and food additives to high-volume biobased plastics or chemical building blocks (e.g. lactic acid, succinic acid) (Road to Bio, 2019; European Commission, Directorate-General for Research and Innovation, 2021).

2.1.1 Biorefineries in the EU

The most recent report by the European Commission (Baldoni, 2021a,b), in 2021, indicated that there are 298 biorefineries producing materials and chemicals in the EU. Most of these products are produced from agricultural feedstocks (Figure 2.1a), with a relatively small number (11) of marine biorefineries. Chemicals make up the single biggest category of biorefinery products (Figure 2.1b). The 2021 report does not focus on the 363 biorefineries in the EU that produce liquid biofuels reported in 2018 by the Joint Research Centre (Parisi, 2018).

Within the report by the European Commission, Directorate-General for Research and Innovation (2021), a closer look reveals that plant oil and starch

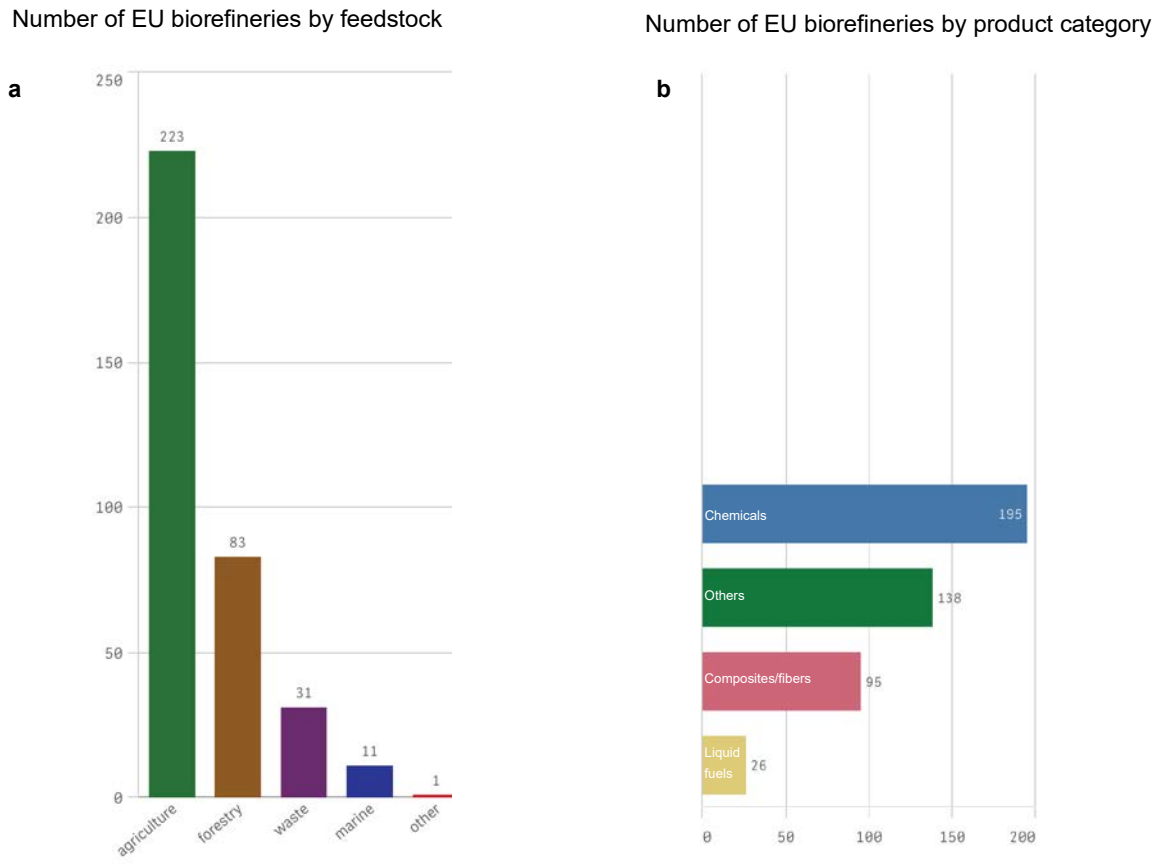


Figure 2.1. EU biorefinery types based on (a) feedstock and (b) products. Sources: European Commission, Directorate-General for Research and Innovation (2021); Baldoni *et al.* (2021b,c). See https://knowledge4policy.ec.europa.eu/visualisation/chemical-material-biorefineries-eu_en. Licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

crops are the two biggest biorefinery feedstocks (Figure 2.2a). A detailed breakdown of biorefinery products demonstrates the diversity of their use as pharmaceuticals, nutraceuticals, animal feed, fertilisers, paints, lubricants, solvents, etc. (Figure 2.2b).

Finally, the end-of-project Technical Report (available on request from the EPA) accompanying this Irish bioeconomy outlook report (the main report) provides a deeper dive into biorefineries outside the EU. From this research, we see that the product portfolio is diverse, with polymers dominating and pharmaceuticals, chemical building blocks, nutraceuticals and food making up the rest of the top five products (Figure 2.3).

Biorefineries are a significant investment in the order of many tens of millions of euros but, given Ireland's agricultural capability, a huge opportunity is available for the country to invest in a sector with multiple addressable global markets. Ireland has a strong food technology and pharmaceutical production industrial base, which can provide the skilled workers needed for biorefinery operations.

2.2 Key Products with Potential for the Irish Bioeconomy

2.2.1 Introduction

Many fossil-based products, on which the global economy relies, can be replaced by biobased alternatives (Kircher, 2019). According to the Central Statistics Office (CSO, 2022), Ireland's total fossil fuel subsidies amounted to €2.2 billion in 2020 and €2.8 billion in 2019. A movement of these subsidies towards the promotion of biobased equivalents and new biobased products with no fossil equivalent needs to be built into budgetary and decision-making processes if we are to successfully transition to

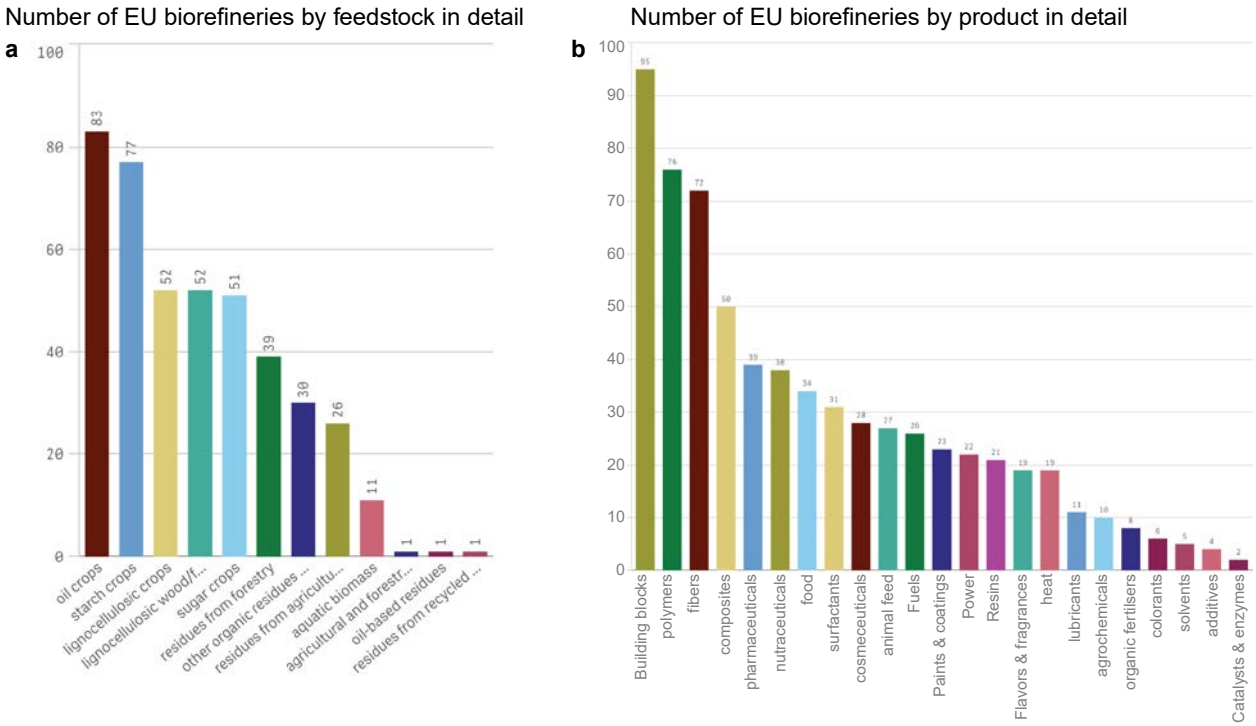


Figure 2.2. A detailed breakdown of (a) feedstocks and (b) products from EU biorefineries. Sources: European Commission, Directorate-General for Research and Innovation (2021); Baldoni *et al*. (2021b,c). See https://knowledge4policy.ec.europa.eu/visualisation/chemical-material-biorefineries-eu_en. Licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

a world that is less dependent on fossil-derived inputs. Biobased materials or products are wholly or partially derived from molecules of biological origin (Porta, 2021). A recent report found the total turnover of the bioeconomy for EU Member States and the UK to be just over €2.4 trillion, with the food and beverage sector accounting for around 50% of that turnover. Biobased industries, such as chemicals, plastics, pharmaceuticals, paper, forest-based industries, textiles, biofuels and bioenergy, account for approximately 30% of the €2.4 trillion, and the primary sectors of agriculture and forestry account for 20% (Porc *et al*., 2021). This main report examines some of the most promising biobased products emerging from the bioeconomy (Table 2.1). From a products perspective, it is important to take into account the biomass value pyramid, presented in Figure 2.4, which ranks value-added products from high to low value: (1) pharma, (2) food and feed, (3) bioplastics and polymers, (4) bulk chemicals and fuels and (5) energy and heat (Lange, 2014).

Details on the methodology used can be found in the Technical Report accompanying this main report. Conversion technologies were selected for inclusion in this report based on their suitability and potential for Ireland and their technology readiness level (TRL5 and above).

2.2.2 Protein

With an increasing population, there is a growth in demand for food, including sources of protein for human consumption, in addition to the realisation that the European reliance on imported protein products, largely South American soybean, is unsustainable (Lindberg *et al*., 2016; European Commission, 2018a; United Nations, 2019). The EU Farm to Fork Strategy explicitly recognises the need to foster EU-grown plant proteins to reduce dependency on critical feed materials, such as soybean grown on deforested land (EIP-Agri, 2015; European Commission, 2020a). This is a challenge and an opportunity for Ireland's grass-based beef and dairy production systems, which produce high-quality animal-based proteins.

2.2.3 Bioactive compounds

Bioactive compounds are a key growth area in the global economy as people seek natural ingredients

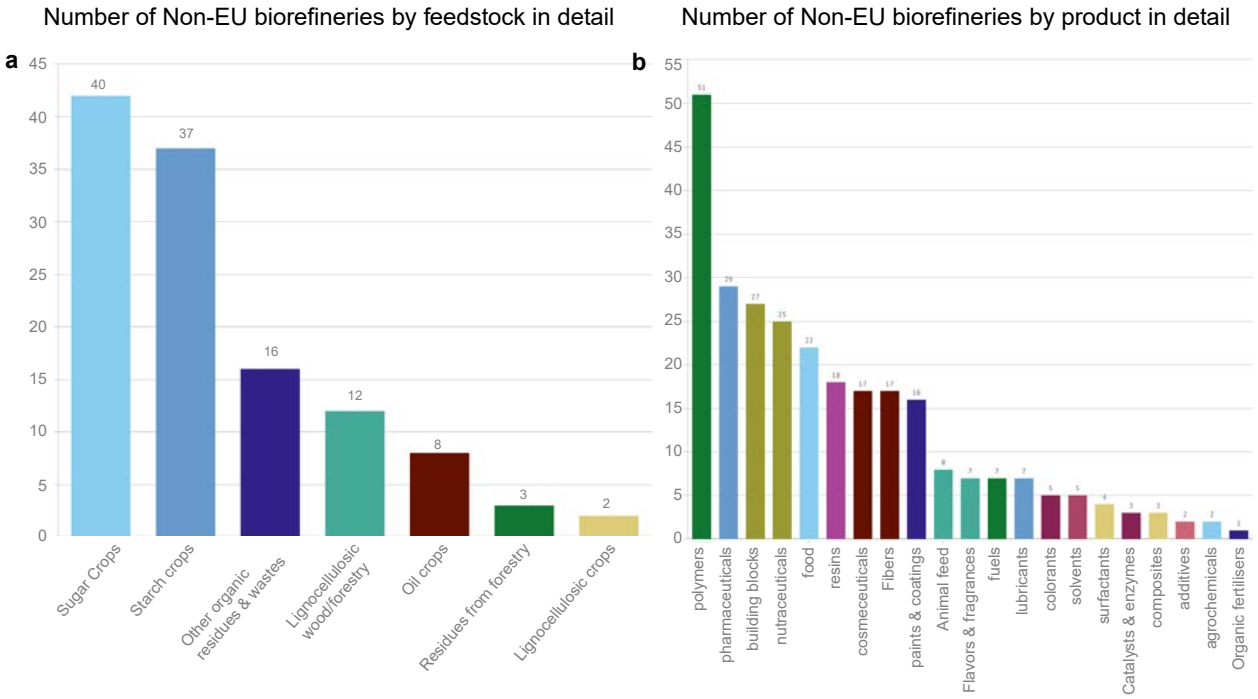


Figure 2.3. A breakdown of (a) feedstocks and (b) products from chemical and material biorefineries outside the EU. Sources: European Commission, Directorate-General for Research and Innovation (2021); Baldoni *et al*. (2021b,c). See https://knowledge4policy.ec.europa.eu/visualisation/chemical-material-biorefineries-outside-eu_en. Licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Table 2.1. Feedstocks, conversion technologies and products covered in the main report

Feedstocks	Conversion technologies	Products
Agricultural products and side streams (including grass)	Fermentation	Protein
Marine by-catch	Anaerobic digestion	Building block chemicals
Seaweed	Insect technologies	Biobased and biodegradable plastics, fibres and textiles
Forestry residues	Biocatalysts/enzyme technologies	Bioactives
Food waste	Chemical/thermochemical technologies	Biobased fertilisers and biobased pesticides
Biogenic carbon dioxide	Carbon capture and reuse	

that prevent disease and contribute to everyday health and wellbeing. We will not supply a list of bioactives here but instead highlight resources, such as substances and biobased chemicals, that either are found in Irish biomass such as seaweeds and mushrooms (Dubost, *et al*., 2007; Ford *et al*., 2020) or can be made through the microbial fermentation of biomass to produce a fermented product containing one or more bioactives. Indeed, mushrooms are the product of a solid substrate fermentation, and they contain a range of bioactives.

Polyphenol is a term used to refer to flavonoids, tannins and phenolic acids and their various derivatives (Williamson, 2017). Polyphenols originate only from plant-based food and are also sometimes referred to as “antioxidants” and “dietary bioactives” (Williamson, 2017). They are widely distributed and are part of every diet consumed through, among other things, fruit and vegetables, plant oils such as olive oil, coffee and cereals (Abbas *et al*., 2017).

2.2.4 Bioplastics (and biobased solvents and resins)

Given the environmental issues associated with plastics, one of the strategic solutions is to reduce

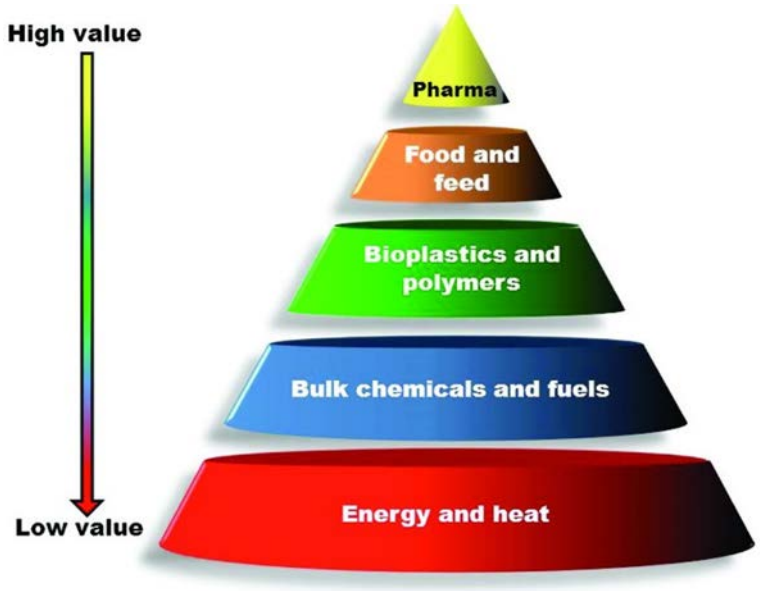


Figure 2.4. Biobased value pyramid. Source: courtesy of Peter Westermann. Reproduced from Lange (2014); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

the use of plastics (or prevent and minimise their use) and increase their recycling (European Commission, 2018b; Ellen MacArthur Foundation, 2017) where they are used but also seek to replace fossil-based plastics with biobased plastics (Porta, 2021). Society should also be looking to include biobased biodegradable plastics in its material portfolio to increase the end-of-life options for plastics.

Some of the bioplastic innovations being explored in the context of the Circular Bio-based Europe Joint Undertaking and/or Horizon 2020 funding programmes include:

- using natural fibres from wood and other plant-based materials;
- using polymers such as starch and cellulose from plant-based materials (BARBARA, 2017);
- making plastics from building blocks (monomers) present in vegetable oils (FIRST2RUN, 2022).

As of 2018, biobased chemicals and plastics accounted for 2% of the total turnover in the bioeconomy in EU Member States and the UK (Porc *et al*., 2021), but there is potential to increase this figure.

2.2.5 Biobased fibres and textiles

Due to factors that include growth in gross domestic product (GDP) and population growth, a shortage of land and water for cotton production and environmental concerns relating to alternative materials, demand for cellulose-based textile fibres is increasing (Kallio, 2021). Wood-based cellulosic fibres can be used in textiles and also have applications in health and hygiene products (Kallio, 2021). A recent study on customer preferences in Italy suggested that customers would be willing to pay a premium for biotextile products (Sandra and Alessandro, 2021).

Some of the biobased fibre and textile innovations being explored in the context of the Circular Bio-based Europe Joint Undertaking and/or Horizon 2020 funding programmes are:

- the diversification of the use of wool, which has been examined in a wool feasibility study (DAFM, 2021a), outlining potential funding streams and the proposed development of an industry-led wool council, which will include industry stakeholders to drive collaboration and innovation (DAFM, 2021b);
- the production of foams for the construction and automotive industries using biomaterials and natural fibres (ReInvent, 2018).

2.2.6 Chemical building blocks

Chemical building blocks are used to make multiple different products such as plastics, solvents, detergents, glues, paints and even pharmaceuticals (Werpy and Petersen, 2004). The market for biobased

chemicals is anticipated to increase at a compound annual growth rate of 16% over the period 2017–2025 (Reportlinker, 2017). Given the environmental impacts of our dependence on fossil-based products, there is a clear value proposition in the production of renewable chemicals and fuels from non-edible biomass, including agricultural residues and forestry waste (Chandel *et al*., 2020), but we must also evaluate the impact of their production using tools such as life cycle assessment (Saraiva, 2016).

Some of the biobased routes to the production of chemical building blocks being explored in the context of the Circular Bio-based Europe Joint Undertaking and/or Horizon 2020 funding programmes include:

- the use of municipal solid waste as a feedstock to develop intermediate chemical products including lactic acid and succinic acid (PERCAL, 2017);
- the use of biobased feedstocks to produce biobased FDCA (2,5-furandicarboxylic acid) (PEFerence, 2017);
- the development of lignocellulosic value chains to produce biobased building blocks or end-products (such as butanol, resin acid, enzymes and FDCA) (BIOFOREVER, 2016).

2.2.7 Fertilisers and pesticides

As the global population grows, so does the demand for food production. Increasing agricultural productivity is a priority, but the resulting increased need for fertilisers, particularly synthetic fertilisers, poses environmental risks (Cucina *et al*., 2021). The use of biobased fertilisers reduces waste, improves nutrient recycling and contributes to the circular economy (Tsegaye *et al*., 2021).

As part of the Circular Bio-based Europe Joint Undertaking and/or Horizon 2020 funding programmes, some of the fertiliser-/pesticide-focused innovations being explored include:

- the use of biowaste, including nutrients from ashes, struvite and compost and non-microbial biostimulant from biomass, to produce sustainable and innovative fertiliser products (B-Ferst, 2019);
- agricultural and food waste valorisation based on flexible multi-feedstock biorefinery processing technologies for new high value-added applications (Agrimax, 2016);
- nutrient recovery from biobased waste for fertiliser production (NEWFERT, 2015);
- the need to develop biopesticides to meet strict EU policy targets (work on this is ongoing at University College Dublin).

2.3 Key Conversion Technologies

Bioconversion is the means of turning raw biomass into useful biobased products and fuels (Nicoletti *et al*., 2019). Bioconversions are technologies applied alone or in combination with chemical and physical technologies in a biorefinery. Biomass bioconversion is a major driver of the green economy, which will replace petroleum-based products and services with renewable resources and biodegradable products (Wietschel *et al*., 2019). Innovative bioconversion technologies are one of the keys to the green transition, as they can enable the valorisation and transformation of virgin and residual biomass (wastes/side streams) into building block chemicals and a portfolio of marketable biobased products. The examples of bioconversion technologies listed below have been selected based on their high potential for Ireland.

2.3.1 Fermentation and anaerobic digestion

Fermentation

Fermentation is a process in which microorganisms such as bacteria, yeast or fungi, as single or mixed communities, convert biobased starting materials (biomass and waste streams) into chemicals that can be used as pharmaceuticals, food additives, food, animal feeds and other useful products (Worsfold *et al*., 2005; Erickson *et al*., 2012; BCC Market Research, 2019). Fermentation has been used by humankind for millennia to produce fermented foods such as cheese and sauerkraut, but improvements and high-tech applications have grown since the middle of the 20th century as a result of a greater understanding of the behaviour and capability of microorganisms. The advent of synthetic biology has further enhanced the capability of microorganisms and expanded the capacity of humankind to produce products of value. Because fermentation processes are already widely used in Irish industry (e.g. cheese, yoghurt and alcohol production) and various academic

research-performing organisations, the knowledge and skills are available locally to enable the scaling up of new fermentation-based innovations. Fermentation is also used to produce liquid biofuels such as ethanol and in anaerobic digestion to produce biogas.

2.3.2 Insect technologies

Insect farming could be part of a wider solution to the growing population challenge, as it can reduce pressure on agricultural land used to produce animal protein. It also has a low water demand and does not require the use of antibiotics. Insect technologies present opportunities for Ireland to diversify agricultural activities and can complement existing farming and can, if designed correctly, contribute to the development of a holistic sustainable production system. For example, wastes from agriculture can be valorised by insects,[1] increasing resource efficiency and producing more nutrients, in particular protein, per hectare of land.

Other bioconversion technologies detailed in the Technical Report include:

- biocatalysts/enzyme technologies;
- chemical/thermochemical technologies;
- carbon capture and reuse.

2.4 Key Feedstocks for the Irish Bioeconomy

2.4.1 Introduction

Feedstock availability is essential for the bioeconomy to thrive, and the exercise of mapping and matching feedstock supply and demand will be a vital step in meeting EU-level targets for renewable energy and biobased products (Attard *et al*., 2020). Equally, to protect investments in the bioeconomy, it is important to ensure that nature is not overburdened, planetary boundaries are respected and ecosystem services are preserved (Kircher, 2019). A sustainable bioeconomy must pursue a balance between bioresource production and consumption, and environmental pressures and ecological limits (Neill *et al*., 2020; Holden *et al*., 2022). The natural capital approach and associated methodology can be useful in securing an environmentally sound bioeconomy (Neill *et al*., 2020). An exhaustive examination of feedstocks with various degrees of potential application for Ireland would not be feasible; however, this section examines a selection of feedstocks that have the potential for initial, or further, development in the context of the Irish bioeconomy, and should always be subject to considerations around the preservation of natural capital and ecosystem services that should be examined on a case-by-case basis before action is taken (Table 2.2). In the accompanying Technical Report, we have highlighted a number of projects that are at different levels of technology or deployment readiness.

2.4.2 Agricultural products and side streams

The agri-food sector is Ireland's largest and oldest indigenous export sector, with approximately 137,500 farms producing €8.2 billion in output (DAFM, 2021b). From a bioresource perspective, agricultural biomass can be divided into three categories: agricultural side streams (sometimes referred to as "residues"), dedicated crops and meat co-products (co-processing steams) (Fryda *et al*., 2007; Shirsath and Henchion, 2021). Examples of products and side streams are provided in the Technical Report.

Source: FreeImages.com/blary54.

2.4.3 Grass

As of 2018, grassland accounted for just under 60% of total land use in Ireland (CSO, 2020, 2021). Based on 2016 data, of the total 4.9 million hectares of

1 For example https://www.farmyng.eu (accessed 4 May 2022), https://hexafly.com (accessed 13 May 2022).

Table 2.2. Annual feedstock availability estimates

Feedstock	Annual production (tonnes)	Source
Grass (residual grass)	1,900,000	McEniry *et al*., 2013
Straw residues	1,100,791	Attard *et al*., 2020
Mushroom residues	171,390	Attard *et al*., 2020
Cattle co-products and offal	280,000	AgroCycle, 2016
Dairy cow manure	18,310,513	AgroCycle, 2016
Pig manure	1,874,200	AgroCycle, 2016
Dry matter (grasslands)	1,700,000	Devaney *et al*., 2017
Rapeseed oil	>30,000	Zahoor and Forristal, n.d.
Marine discard	72,000	Devaney *et al*., 2017
Seaweed[a]	40,000	Houses of the Oireachtas, 2018
Fish processing waste	15,000	BIM, 2021
Forestry and other lignocellulosic materials	345,000,000 (wood); 2,000,000 (residues)[b]	Data CSO.ie; Attard *et al*., 2020
Forestry residues	736,896	Attard *et al*., 2020
Biogenic CO_2	Unknown	
Household food waste	250,000	EPA, 2021

[a]Volume harvested only, as there is no estimate of total seaweed availability.

[b]2 million tonnes of forestry residues and cereal straw.

agricultural area used in Ireland, almost 4.1 million was used for grassland (CSO, 2016). Food Vision 2030 (DAFM, 2022) proposes a goal to embed the agri-food sector in the circular, regenerative bioeconomy, which includes an action to "develop new bio-based value chains based on Ireland's comparative advantage in the production of grass, legumes and other perennial species". A recent literature review identified further business cases in which grass or green fodder has been used as the main feedstock, including paper, fibre boards, straws, fertiliser, plastic, feed protein, bioenergy and seeds (Orozco *et al*., 2021).

Source: FreeImages.com/cruinneog.

2.4.4 Marine by-catch and residues

Approximately 10,000 to 12,000 tonnes of whitefish waste is produced in Ireland annually, with a significant portion of this being wasted flesh, fish trimmings and residual flesh on the bone (BIM, 2021). More broadly, it was estimated that around 72,000 tonnes of marine discard is available in Ireland annually, at a relatively low cost (Devaney *et al*., 2017) and with the potential to be processed into fishmeal and fish oils and protein, among other products (Miles and Chapman, 2006; Devaney *et al*., 2017; European Commission, 2019).

Source: Phil Darby/Shutterstock.com.

2.4.5 Seaweed

Approximately 40,000 tonnes of seaweed are currently harvested in Ireland each year, over 95% of which is naturally grown (Houses of the Oireachtas, 2018). The total availability of seaweed biomass in Ireland has not yet been quantified (Devaney *et al*., 2017), although a 2018 report estimated the value of the algae and seaweed harvesting ecosystem service at €3,914,000 based on data available at that time (Norton *et al*., 2018). A range of products such as food supplements, fertilisers, cosmetics and pharmaceuticals can now be produced from seaweed (Tedesco and Stokes, 2017), bolstering Ireland's opportunity to exploit seaweed. It is recognised that the predominant uses of seaweed have traditionally been in high-volume, low-value products such as animal feed, while a much smaller proportion of seaweed (approximately 1%) is used in high-value applications such as food, cosmetics and therapies, with that 1% generating 30% of the seaweed industry's value (Houses of the Oireachtas, 2018). Recently, seaweed has been identified as a potential methane-reducing dietary ingredient in animal feed and so it offers higher-value potential in that sector. In developing the Irish seaweed industry, the risks associated with overexploitation must be considered and managed (Mac Monagail *et al*., 2017), particularly given the role of seaweeds as foundational species and primary producers in marine ecosystems (Sharp *et al*., 2006; Mac Monagail *et al*., 2017).

Source: A.G. Baxter/Shutterstock.com.

2.4.6 Forestry residues: lignin, cellulose and hemicellulose

Trees and plants convert solar energy into lignocelluloses (Ayeni *et al*., 2019). Lignocellulosic biomass is made up of three polymers, celluloses, hemicelluloses and lignin, along with other valuable, extractable materials such as amino acids, proteins, fats and resins (Ayeni *et al*., 2019). In 2017, it was estimated that forest area makes up around 11% of land area in Ireland, with approximately 89.3% of that forest area completely or partially occupied by trees (DAFM, 2020). Given the important role of forests as carbon sinks (EIP-AGRI, 2019; Government of Ireland, 2021) and the natural capital associated with forestry, afforestation is a priority (DAFM, 2021b). The type of forests planted and their function are important considerations in the development of a bioeconomy strategy. To the extent that licensed forestry felling is permitted, any residues thereby produced can be valorised in the context of the bioeconomy, but equally the ecosystem services provided by forests need to be accounted for. The valorisation of lignin presents an opportunity under the forestry pillar of the bioeconomy. Lignocelluloses can replace fossil fuel resources in the fabrication of many fuels and chemicals (Ayeni *et al*., 2019) and can be used in the production of phenolic resins, biofuels, cement additives, energy, ethanol, solvents, nanocellulose and paper and cardboard, among other things (Romaní *et al*., 2020). More detail is provided in the end-of-project Technical Report.

2.4.7 Biogenic carbon dioxide

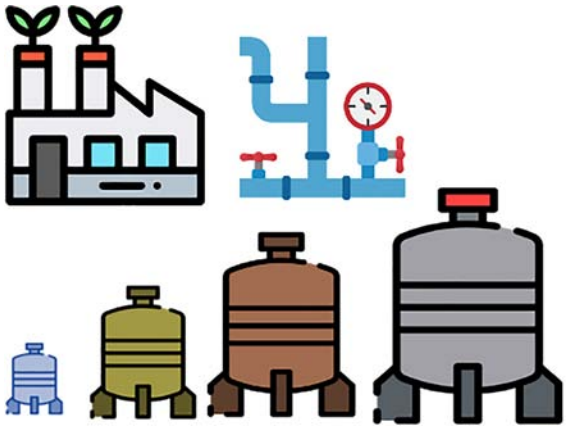
We address carbon capture and reuse in section 2.4.6 of the Technical Report accompanying this main report review. This subsection will consider biogenic carbon dioxide as a feedstock. Biogenic CO_2 can be defined as the carbon emissions that originate from biological sources such as plants, trees or soil (Harris *et al*., 2018). Biogenic CO_2 is a subset of the broader category of renewable carbon (which also includes recyclates, for instance) (vom Berg *et al*., 2022). Curbing the introduction of fossil carbon from deep under the ground into the atmospheric system must be a priority in achieving our GHG reduction targets (Renewable Carbon Initiative, 2022). However, if the carbon sources such as CO_2 produced above the ground are captured and used, the levels of CO_2 in the atmosphere will cease to increase (vom Berg *et al*., 2022). As a society, we should be using carbon and other elements in a cyclic way, mimicking nature (Dibenedetto *et al*., 2014). Biotechnological processes such as yeast fermentation are a rich source of biogenic CO_2, as 50% of the carbon feedstock consumed by the yeast ends up as CO_2 due to the

nature of yeast metabolism. The use of CO_2 as a resource is preferred to storage, as the former option offers the potential to maximise its use and reduces pressure on land used to produce food and materials (Muthuraj and Mekonnen, 2018).

Source: KaliAntye/Shutterstock.com.

2.4.8 Household food waste

Food waste is a major environmental issue both in Ireland and across the world (World Bank, 2018). Globally, more than 25% of food produced is wasted (EPA, 2021). Food waste is the third biggest contributor to GHG emissions globally (CAIT, 2015; FAO, 2015). In Ireland, it is estimated that approximately 250,000 tonnes of food waste, or around 150 kg per household, is generated per year (EPA, 2021). The EU Landfill Directive limits the volume of waste that can be disposed of in landfills, and, as a result, a significant proportion of waste is available for use as feedstock (Devaney *et al*., 2017). When it comes to food waste, prevention initiatives such as Ireland's National Food Waste Prevention Roadmap and SHARECITY (McGeever and Davies, 2021) can offer dual benefits for retailers looking to donate surplus food and the communities that benefit from this. Value-added products, including but not limited to biohydrogen, bioelectricity, lactic acid, succinic acid and biopolymers, can be produced from unavoidable food and kitchen waste (Sindhu *et al*., 2020). To ensure sufficient scale and volume, co-digestion with other feedstocks, such as agricultural side streams, may be necessary (Devaney *et al*., 2017). There is also a growing interest in the use of insects as natural converters of organic waste (including food waste) into valuable products (Magee *et al*., 2021; Ynsect, n.d.).



2.5 Infrastructure for Core Bioeconomy Technologies

The development of bioeconomy-based technologies requires significant investment in pilot and demonstration facilities. While the technologies within the bioeconomy are many and varied, there are fundamental infrastructures such as fermenters, chemical reactors, membrane filtration devices and centrifuges that are common to various main biorefinery processes. Thailand, a country with a similar GDP to Ireland, has recently announced a €90 million investment in pilot-scale facilities, while Belgium has invested €25 million to expand the Bio-based Europe Pilot Plant facilities within its existing pilot-scale facility, which had previously received a €50 million investment. These pilot-scale facilities are essential not only to enable the scaling up of technologies but also to enable collaborations between technologists, industry and universities and to enable investments in new technologies and start-ups that support industrial development and innovation. One such development is the new anaerobic digestion plant at the Grange Teagasc College in Dunsany, County Meath. Due to be commissioned in 2022, it is intended as a working example of how biogas can be produced from grass silage and cattle slurry. The BioMarine Ingredients pilot facility in Monaghan is a private sector example.

3 Patent Literature Search Review

The bioeconomy is underpinned by research and innovation, two key drivers of economic growth. Patents drive innovation by creating a reward and drive commercialisation. This legal exclusivity also enables contractual arrangements (e.g. licences and R&D cooperation agreements) for the exploitation of patented inventions (EPO and EUIPO, 2019). In Europe, industries that make intensive use of intellectual property rights account for 45% of the EU's GDP and 39% of employment (EPO and EUIPO, 2019). Research also shows that organisations that pursue intellectual property rights employ more people and are more likely to grow than others (EUIPO, 2016). The OECD analysis of environmental patents in 2015 indicated that innovation is essential to establish new patterns of production and consumption and that it opens new market opportunities (OECD, 2015). The report also highlighted that China has seen the biggest increase in environmental technology patent applications (>1000%) and in all areas (~600%). This compares with a 76% increase in environmental technology patents and a decrease of >18% in all patents in the USA (OECD, 2015). However, China is starting from a much lower historical patent application baseline than the USA. Interestingly, while China has seen a large increase in patent applications, it has a very low implementation and development score (Figure 3.1) (OECD, 2015).

The protection of intellectual property rights is crucial in supporting the development and commercialisation of biobased innovations (European Commission, 2018a,c). Innovations make a transformative impact, ultimately changing how society produces and consumes resources, and opportunities for patentable inventions are vast in the bioeconomy, encompassing a wide array of subsectors. These include data and digitalisation, biomass conversion to value-added products, feedstocks, chemical building blocks, protein, bioactives, biobased plastics/materials and biodegradable plastics, technologies, grass, sugar beet, forestry, food waste, seaweed, plant oils and carbon dioxide. The patent literature search review in the Technical Report accompanying this "fast track to policy" report gives a concise overview of the patents and technologies affecting the development of the Irish bioeconomy at present.

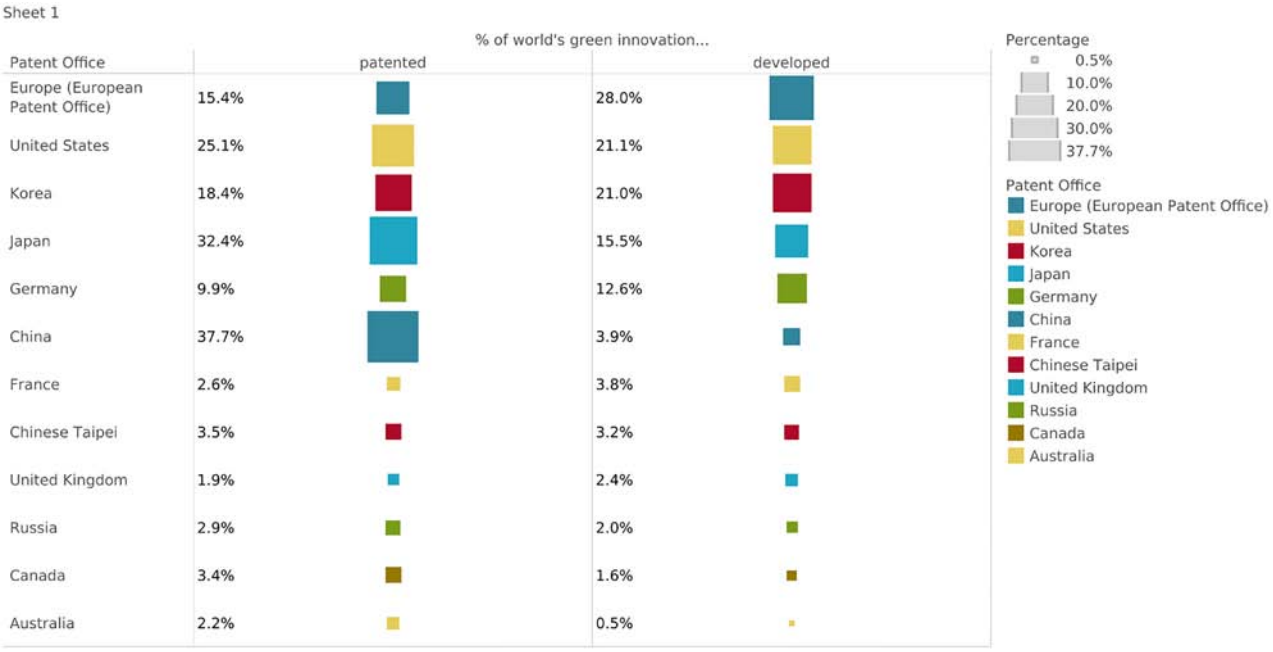


Figure 3.1. Environmental technology patent protection and diffusion. Reproduced from OECD (2015; *Green Patents*, https://www.oecd.org/environment/indicators-modelling-outlooks/green-patents.htm).

4 Policy

4.1 Policy Review

4.1.1 Introduction

For a circular bioeconomy to be established and thrive in Ireland, a supportive policy framework is essential. Seizing the opportunities and mitigating the risks both depend on how policy and regulation guide the transition to a (circular) bioeconomy (Imbert *et al*., 2017). This chapter will begin with an overview of EU policy and then provide a comparison of Irish, German and Italian approaches to bioeconomy policy.

4.2 EU Policy Overview

The first EU Bioeconomy Strategy was published in 2012 (updated in 2018). The updated strategy defines the bioeconomy as covering "all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles" (European Commission, 2018a, p. 4), recognising that the European bioeconomy must have sustainability and circularity at its heart in order to succeed (European Commission, 2018a, p. 4). The updated Bioeconomy Strategy sets out five main objectives, namely:

1. to ensure food and nutrition security;
2. to manage natural resources sustainably;
3. to reduce dependence on non-renewable and unsustainable resources whether sourced domestically or from abroad;
4. to mitigate and adapt to climate change;
5. to strengthen European competitiveness and create jobs.

These objectives are supported by three broad action areas: to strengthen and scale up biobased markets and unlock investments and markets; to deploy local bioeconomies rapidly across Europe; and to understand the ecological boundaries of the bioeconomy (European Commission, 2018a, p. 10).

The updated Bioeconomy Strategy and the adoption of the Bioeconomy Strategy progress report[2] in June 2022 should be considered in the context of the set of policies that make up and support the European Green Deal, with its focus on elements including, but not limited to, the preservation and restoration of ecosystems and biodiversity, healthy and environmentally friendly food systems, a zero pollution ambition and the supply of clean energy (European Commission, 2019, p. 3). Of particular significance is the Farm to Fork Strategy (European Commission, 2020a) and the new Circular Economy Action Plan (European Commission, 2020b). The latter recognises the importance of biological resources to the EU economy and establishes the key aim of ensuring the sustainability of renewable biobased materials at EU level (European Commission, 2020b, p.12). Also noteworthy is the EU's Biodiversity Strategy to 2030, which seeks to protect and conserve nature and ecosystems (European Commission, Directorate-General for Research and Innovation, 2022). In December 2021, a report was published to provide guidance on managing healthy and resilient ecosystems in the context of bioeconomy activities (Nel *et al*., 2021). In terms of funding programmes, the Technical Report covers the BBI-JU (Bio-based Industries Joint Undertaking) and its achievements to date.

4.3 National Strategies in the EU: An Examination of Policy in Ireland, Germany and Italy

4.3.1 Introduction

In this section, German, Italian and Irish bioeconomy policy documents will be examined using the framework set out in Imbert *et al*. (2017). The German bioeconomy policy was chosen as it is long

2 https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/adoption-bioeconomy-strategy-progress-report-2022-06-09_en

established (Bioökonomie.de, 2012; BMEL, 2020), and the Italian policy was chosen because of its all-government approach to bioeconomy strategy and policy development.

4.3.2 The Irish National Policy Statement

The Irish National Policy Statement (NPS) on the bioeconomy was published in 2018 (Government of Ireland, 2018) and has the stated purpose of capitalising on the potential of the Irish bioeconomy, with policy objectives built on three pillars of investments in:

1. research, innovation and skills;
2. enhancement of markets and competitiveness;
3. reinforced policy coordination and stakeholder engagement (Government of Ireland, 2018).

The NPS also includes four strategic policy objectives: (1) a sustainable economy and society, (2) decarbonisation of the economy, (3) jobs and competitiveness and (4) regional prosperity (Government of Ireland, 2018). To promote the success of the Irish bioeconomy, the statement sets out key actions, including:

- ensuring coherence between relevant sectoral strategies;
- establishing an industry/public body network to inform future development of the bioeconomy;
- promoting collaboration between research/academia and industry;
- assessing the legislative definition of waste and redesignation;
- ensuring greater sectoral coherence within the bioeconomy;
- progressing leading value chain propositions by establishing the required conditions for their commercial viability;
- examining building awareness of the bioeconomy and its products.

The NPS was created in consultation with stakeholders involved in the bioeconomy in Ireland (Government of Ireland, 2018). A stakeholder forum and policy implementation group (Bioeconomy Implementation Group) was established, chaired jointly by the Department of Agriculture, Food and the Marine and the Department of the Environment, Climate and Communications. The latter reports to the government on the implementation of the policy statement (Government of Ireland, 2018).

4.3.3 The German National Bioeconomy Strategy

A German bioeconomy research strategy was published in 2010, followed by the German National Bioeconomy Strategy (NBS) in 2020 (BMEL, 2020). This was founded on two broad guidelines of the importance of biological knowledge and advanced technology as the pillars of a future-oriented, sustainable and climate-neutral economy and the need for a sustainable and circular economy based on the use of biogenic resources. Given the use of biological materials by industry, the NBS sets out strategic goals and actions (BMEL, 2020; see Figure 4.1 and also the Technical Report accompanying this main report for more details). The NBS includes measures from

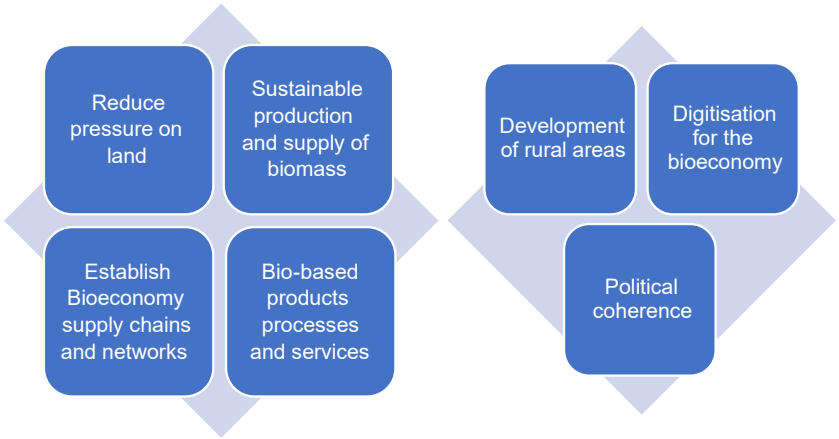


Figure 4.1. Key actions from the German National Bioeconomy Strategy.

the establishment of a comprehensive bioeconomy monitoring system, measurement and analysis of biomass flows and implementation of comparative sustainability assessments of the use of converging technologies such as digitalisation (BMEL, 2020).

The strategy also provides action items that focus on capacity building and cooperation, such as the promotion of clusters and model regions and the establishment of an advisory group with broad expertise (BMEL, 2020), with an emphasis on conversation and dialogue around the bioeconomy. It was developed using a participatory approach that is to be maintained as the NBS is implemented (BMEL, 2020). An independent and thematically diverse advisory body was also established under the NBS (BMEL, 2020).

4.3.4 The Italian BIT II Bioeconomy Strategy

The primary objective of this strategy is to increase the turnover and jobs generated by the Italian bioeconomy by 15% by 2030 while also increasing the level of circularity in the economy (Italian Committee for Biosafety, Biotechnology and Sciences of Life, 2019). The principal measures and actions are shown in Figure 4.2.

BIT II includes key performance indicators (KPIs) as well as specific sustainability indicators to assist the implementation and monitoring of its objectives (Italian Committee for Biosafety, Biotechnology and Sciences of Life, 2019). It also has a detailed implementation plan for 2020–2025 focusing on policy and standards, pilot actions, regeneration of ecosystem services, and stakeholder engagement (Italian Committee for Biosafety, Biotechnology and Sciences of Life, 2021).

4.3.5 Comparative summary

The Irish, German and Italian bioeconomy strategies have common objectives and actions, as outlined in the comparative summary in Table 4.1.

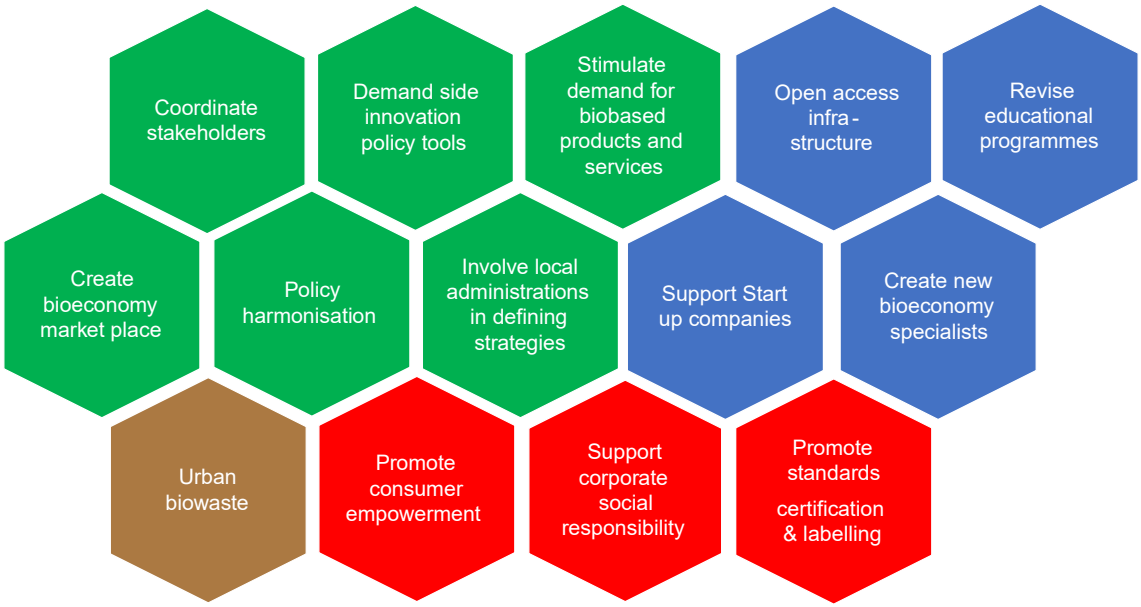


Figure 4.2. Principal actions from the Italian BIT II Bioeconomy Strategy.

Table 4.1. Summary of the Irish, German and Italian bioeconomy strategies

	Irish NPS	German NBS	Italian BIT II
Policy objectives/ measures	The NPS outlines the overall vision and guiding principles. Four strategic policy objectives with focus on social and economic sustainability, decarbonisation, jobs and competitiveness and regional prosperity. Key actions support these objectives (Government of Ireland, 2018).	The NBS sets out key guidelines, and extensive goals and actions focused largely on the themes of biological knowledge, sustainability and circularity innovation and collaboration.	The overall BIT II policy objective centres on increasing bioeconomy turnover and employment while increasing circularity. BIT II then sets out a detailed research and innovation agenda and extensive support measures for the bioeconomy, including measures such as demand-side policy tools, education and training for bioeconomy specialists and promoting the use of sustainability standards.
Institutional capacity	Certain key actions, such as the establishment of a policy implementation group and industry/ public forum, the promotion of sectoral coherence and greater collaboration and awareness are linked to developing institutional capacity (DAFM and DECC co-chair the bioeconomy implementation group and a bioeconomy forum has been founded).	Certain action items focus on capacity building and cooperation, such as the promotion of clusters and model regions and the establishment of an advisory group.	BIT II specifically mentions bioeconomy-focused training for local administrations, as well as the need for collaboration, best-practice sharing and involvement of local administrations in strategy building.
Policy process	The NPS was developed through consultation with a range of departments and agencies through a whole of government approach and involved participating stakeholders through a public consultation and workshop.	The NBS was developed through a participatory approach. The NBS also has a section dedicated to conversation and dialogue.	BIT I was developed through broad stakeholder consultation. The updated BIT II was developed with the input of a range of ministries, regions and clusters and was open to comment by the public and stakeholders.
Other elements of note	As it is a policy statement rather than strategy, the NPS takes a long-term visionary approach seeking to structure the bioeconomy policy development and undertake co-creation and co-development processes. In this respect, it is less detailed than the NBS or the BIT II. The NPS sets out a policy framework including a vision and principles to guide it, namely the precautionary, sustainability, cascading and food-first principles and strategic policy objectives.	One of the NBS goals is to develop bioeconomy solutions for the UN Sustainable Development Goals. The report contains an infographic dividing goals into a type of Venn diagram using social, economic and environmental sustainability categories. There is a strong emphasis throughout the NBS on biological knowledge and ecological boundaries.	BIT II includes extensive KPIs and sustainability indicators to measure BIT II implementation and bioeconomy performance. BIT II dedicates a chapter to numerous examples of the bioeconomy in everyday life, from biodegradable bags and packaging to biodegradable herbicides, and a further chapter to the social dimension of the bioeconomy. BIT II is supported by a detailed implementation strategy, KPIs and sustainability indicators.

5 Barriers to and Support for Implementation and Commercialisation

For the purposes of gathering input for this report, various actors across the Irish and EU bioeconomy were interviewed using the PESTLE (political, economic, social, technological, legal and environmental) approach. This allowed the team to engage with different strands of and interests in the Irish and EU bioeconomies. We also looked at the types of support that businesses see the need for in an Irish context. A stakeholder engagement event was organised at University College Dublin on 3 May 2022, which was attended by a cross-section of bioeconomy stakeholders.

5.1 Methodology

A cross-discipline approach based on PESTLE was used to gather inputs on the barriers to and support for implementation and commercialisation of the Irish bioeconomy. In this context, and to meet the government's own ambition to be a "global leader for the bioeconomy", some key themes emerged, which we have set out in the Technical Report. PESTLE is a framework or tool used to monitor, investigate and analyse external issues that most influence the development of the project or industry, in this case the bioeconomy, that needs to promoted (Espinoza *et al*., 2019). Bioeconomy stakeholders representing each of these PESTLE pillars were consulted for their up-to-date inputs in the context of emerging government policies and action plans. The groups included 15 bioeconomy companies, six academics, representatives of four agencies operating in the bioeconomy and three farmers. The Technical Report explores the barriers encountered across these pillars and explains the rationale for the suggestions for support. The section below sets out some of these supports, with the rest presented in the Technical Report. If the bioeconomy is to fulfil its potential, there is now a need to increase the level of support, including catching up with investment levels already in place in other EU countries. This is a major theme that has emerged from our research and stakeholder engagement activities and will be key to allowing the Irish bioeconomy to meet the challenges of its future climate-friendly ambitions.

5.2 Supports

Since the publication of the NPS in 2018, Ireland has taken several positive steps towards laying the foundation for a thriving bioeconomy. Several strategic coordination and consultative groups have been established, such as the Bioeconomy Implementation Group and the Bioeconomy Forum. Funding has been allocated to the first bioeconomy research centre, namely BiOrbic. The Irish Bioeconomy Foundation is attempting to build pilot-scale facilities, but the limited scale of investment and the terms and conditions linked to public investment make the realisation of the vision extremely challenging. When compared with other EU countries, government investment in the Irish bioeconomy, while currently at €57 million, is still very low. Meanwhile, jobs created in the bioeconomy in countries that have invested grew by an average of 7.2% value added in 2017 compared with 2016 (Ronzon *et al*., 2020).

Below we list some of the supports and initiatives that various actors could take to enable and speed up the uptake of bioeconomy opportunities in Ireland.

5.2.1 Practical supports

Capital investment is needed to support demonstration projects and progression from **TRL5 to TRL9.** EI and non-EI companies with specific bioeconomy growth potential should be eligible for funding support. These companies should have a particular status if they do not otherwise qualify through their stage of growth. Major investment in infrastructure is needed to allow these companies to access pilot- and demonstration-scale facilities that are not affordable for any one company.

- A **fast-track model** to sustainable growth is needed; the "Green Deal" initiative[3], undertaken in

3 See https://www.greendeals.nl/english (accessed 20 January 2023).

the Netherlands since 2011, could be implemented here. The Green Deal is undertaken to overcome the challenges faced by companies, civil society organisations and local and regional governments that are creating initiatives that stimulate sustainable economic growth across thematic areas such as energy, food, water, resources, biodiversity, mobility, biobased economy, climate and construction. This helps to **address non-regulatory barriers** inhibiting sustainable innovation, as a voluntary agreement is signed with the aim of overcoming a given barrier and making the innovation operational within 3 years. **Dedicated resources** are allocated to focusing on this activity. Since 2011, 227 Green Deals have been brokered, involving 1300 partners.

- Mirroring the **Green Start EI grant**, a similar type of support is needed by both bioeconomy-promoting businesses and primary producers for specific aspects of their development such as business modelling and life cycle analysis work.
- **Common Agricultural Policy (CAP) ecoscheme** – a particular measure to include natural capital quality assessments and how these link with contributing to the bioeconomy; this would be a measure to help enable better management of biodiversity, soil health, water, etc. on farms, which in turn could underpin and support a strong bioeconomy.
- Further resources and proper **enforcement of existing environmental protection** measures are needed to support our natural capital enhancement.
- Stakeholders requested that **more resources** be allocated to some government agencies, as there is currently an issue with the slow **pace of licensing** in several sectors (e.g. forestry, seaweed harvesting, waste collection).
- Encourage wider use of ecolabels and certification schemes for biobased products. Ecolabels include the EU Ecolabel, the Nordic Ecolabel or "Swan", and the Blue Angel ecolabel. Certification schemes can be used to indicate sustainable biomass use (e.g. Forest Stewardship Council), biobased (carbon) and content of products (e.g. TÜV Rheinland/DIN CERTCO, TÜV Austria and European Bio-based Content).
- A market pull initiative could be to have **a lower VAT rate on biobased products**; this has been done in some other countries and has helped bolster the uptake of this alternative to fossil fuel-based materials.
- **Compostable packaging and bin bags** are to become standard through legislation; reporting on packaging used also necessitates a new category for reporting to Repak, facilitating better monitoring of the growth of this market.
- Provide **clarity to seaweed farmers and companies** on the steps required to develop offshore seaweed farms, either standalone or co-located.
- Create a sustainable growing and harvesting policy for seaweed in offshore areas.

5.2.2 Natural capital

- While the CSO is developing ecosystem service accounts, the **natural capital register**[4] needs further investment by government.
- For businesses, look at introducing a natural capital "protocol". There is a need to assess impact and dependencies each time using the protocol; this can be derived from assets and ecosystem services. There is a need for a **mindset change** around their dependencies. It is essential that, when assessing how to address biodiversity loss, industrial and agricultural ecosystems are considered. **A systemic change** is needed so that the start of the circular chain, and how it will be impacted by the economic activity under consideration, is assessed before everything else.
- Finally, as the fossil fuel sector accounts for one-fifth of national emissions, removal of fossil fuel subsidies and investments in renewable energy and biobased technologies could be further reviewed for Ireland's transition to a low-carbon economy (O'Sullivan, 2021; Social Justice Ireland, 2022).

4 See https://www.cso.ie/en/releasesandpublications/in/ea/informationnoteonecosystemaccounting/structureofecosystemaccounting/ (accessed 24 January 2023).

6 Conclusion and Policy Recommendations

As already outlined in Chapter 4, the NPS on the bioeconomy sets out several key actions that seek to frame a thriving Irish bioeconomy.

Our analysis of the scientific literature and policy, and through stakeholder engagement highlighted challenges (see Technical Report for more details). The government, its agencies and planning authorities could take the actions proposed to address the challenges and key matters as set out below. The outcome would be the faster realisation of the bioeconomy's potential in Ireland.

6.1 Strategic Recommendations

- A **national bioeconomy strategy** should be prepared at the next opportunity, with alignment to and a framework for the upcoming Bioeconomy Action Plan 2023–2025, which will provide clear recommendations and assist the policy recommendations of this report here. This will be an important framing document for setting out a pathway to a sustainable circular bioeconomy – and should incorporate the political commitment in the programme for government, the Climate Action Plan 2021, Food Vision 2030, and so on. Along with national objectives and implementation steps, it should include appropriate measurement tools, including KPIs across different sectors relevant to the bioeconomy, and define which targets (e.g. biobased product targets, reduced GHG emissions, circularity) Ireland seeks to reach and in what timeframe. It should also show how the bioeconomy will contribute to the Climate Action Plan and the upcoming Nature Restoration Law.
- There needs to be **stronger recognition at all governance levels** of the potential of Ireland's bioeconomy. While the government has stated its ambition to be a global leader in the bioeconomy, the level of commitment in terms of both **resources** and **capital investment** needs to be bolstered to match that of other countries already active in the area. The National Bioeconomy Campus at Lisheen, Páirc Na Mara and other projects have faced uphill battles due to funding and planning challenges, and the scale of investment in Ireland does not match international investments; for example, the Belgian government has invested over €75 million in a facility equivalent to one in Lisheen receiving €5 million. While several very innovative developments are happening across the country at individual company level (e.g. Tirlan, a dairy side stream biorefinery, Brandon Biosciences and Nutramara, a seaweed biorefinery, and Biomarine Ingredients, a fish biorefinery), much more widespread development and further incentives are required in this critical area at a national level.
- A **public–private partnership (PPP) model** is needed. This is critical, as public investment will help to de-risk private investment. Although the Irish Government funds BiOrbic through Science Foundation Ireland, and also the pilot-scale facilities at Lisheen, a PPP to co-fund the development of biorefineries is required. This should also feed back into growing the pilot-scale facilities at Lisheen to match the diverse and growing needs of industry seeking to invest in biobased technologies and biorefining. As part of the PPP, a national programme on ecosystem strategies is required across farm, forest, marine and waste management to support the delivery of ecosystem services in the bioeconomy.
- **A detailed set of targets and KPIs** for all sectors of the bioeconomy could be established so that actors in these sectors have clarity on the roadmap to 2030 and 2050 (Table 6.1). These targets can constitute a framework within which actors can operate, including government departments and agencies.
- **Market push or pull policies** that can support the bioeconomy should be considered here, as these have proven useful in other EU countries (e.g. Italy) and in the USA (BioPreferred programme; USDA, 2022, USDA, 2021). KPIs can be monitored at sector (e.g. national bioeconomy) and programme level.
- **Education and training**. It is essential to create a career path for bioeconomy professionals in Ireland. That could be done by reskilling current workers and building confidence in the job and

Table 6.1. Proposed KPIs for Ireland's bioeconomy

Target description	Ireland's proposed target to 2030	EU target (for reference)
Reduction in import of unsustainable protein	50%	50%
Reduction in import of potash and phosphorus for fertiliser use	25%	25%
Farm bioenergy – deployment of renewable technologies in energy-intensive farming systems	20%	TBC
Increase in use of biobased chemicals and materials	30%	30%
Number of new cross-sector interconnections	10	36
Number of new circular biobased value chains	4	10
Number of biomass producers leading/integrated into value chains producing climate-neutral products	2	5
Number of new value chains for unavoidable waste	2	5
Number of "nitrogen-neutral" agricultural products	3	No target
Number of carbon-neutral biobased products	3	No target
Increase in number of biobased and biodegradable materials used in packaging	10%	No target
Number of new regional biorefinery clusters	5 clusters	10 new regional biorefinery clusters raised
Number of converted facilities or new biorefineries	3 biorefineries	10 conversions of existing and unused facilities into biorefineries

The above list of KPIs is proposed as a basis for the accurate collection of data about the Irish bioeconomy with a view to reporting on these in future. Basic datasets need to be gathered or improved on, where they exist, to enable reporting on these in future.

career opportunities across different sectors within companies active in the area.

6.2 Practical Implementation Recommendations

- There need to be **harmonised pathways** for innovators, entrepreneurs and businesses who want to invest and participate in the bioeconomy, regardless of sector, that provide them with confidence to stay the course and develop their business in Ireland.
- **Best practices** from other EU countries, including an approach like the Green Deal in the Netherlands, could be implemented in Ireland to speed up the transition to new biobased value chains and business models. In the Netherlands, this is a government-led initiative, spread across different departments that have dedicated resources assigned to ensure that this happens[5] (Ellen MacArthur Foundation, n.d.). The Irish Government could take a similar approach.
- Any new biobased commercial activity needs to be based on a holistic view, from the extraction of resources from natural and managed ecosystems through primary producer, feedstock availability and processing technologies to product development and market development. In each step, the positive and negative impacts on capitals (natural, human and manufactured) need to be considered, as does as the capacity for those capitals to be replenished. This **holistic view**, using tools such as **life cycle analysis** and **natural capital accounting**, should be established and understood so that decision-makers along the route to market can be as well informed as possible. This will be helped by considering the concept of biocircularity as an integrated systems approach to sustainable production, extending and maximising use and avoiding the failure of "end of life". It is also crucial that any bioeconomy solutions implemented and

5 See *Addressing Barriers to Support Business Innovation*: *The Netherlands*: https://ellenmacarthurfoundation.org/circular-examples/the-netherlands-addressing-barriers-to-support-business-innovation#:~:text=This%20 was%20a%20Green%20Deal,Platform%20 to%20 execute%20the%20agreement (accessed 31 May 2022).

their business models have the potential to be replicated and scaled up as appropriate.

- Ireland needs a number of **deep demonstration projects**[6] that are part of a coherent strategy to enable practitioners, entrepreneurs, investors, researchers and societal actors to see the bioeconomy in action and enable its development. These demonstrators (farms, forests, biorefineries, ecosystem restoration, pilot-scale facilities) will enable the development of expertise, skills, technologies and knowledge, foster collaboration and create new business opportunities.
- **Business models for primary producers** in particular need more targeted study in an Irish context and to reflect today's prices, input costs and market needs. This will support the growth of actors "converting" to supporting an Irish bioeconomy input system. Some suggestions for practical implementation here include establishing long-term contracts to provide biomass to a biorefinery and a share in the downstream profits from the high-value products going to market. This could take the form of **a cooperative model** and would need to recognise the local needs of the community and stakeholders concerned.
- The direct and indirect economic potential for Ireland and its rural and urban communities needs to be considered and well understood. A **focused study on regional development outcomes** could be prepared that would set out what a thriving bioeconomy in each region could represent for economic, environmental and social goals. This could involve a macroeconomic quantitative insights analysis to establish what should be planned where.
- **Rural economic development zones** for specific sectors and suited to local conditions (from county to county) need to be explored. Building on the existing mapping of biomass, the further development of realistic and sustainable sectors needs the support of policy through an allocation of priorities; taskforces could be established to tackle barriers in each sector. These taskforces could work on the co-design of solutions and options, which could be promoted through local and public consultation steps, workshops and engagement. Regional centres of excellence could be established as examples of what to participate in and how, and how to update practices in line with sustainable bioeconomy goals. The development of an "IFSC (International Financial Services Centre) of the bioeconomy" in special development zones that promote inward investment in the bioeconomy can encourage innovation.
- It would be helpful to have **"ambassador"**-type roles for primary producers, who can showcase best practice and lead the way, so that their peers can learn from them and talk to them; these local and community-based representatives would meet other producers at their level, avoiding lack of understanding at central levels. A form of **social network analysis** could be another way to reach actors in different sectors; for agriculture, this could also work as a representative group working on how the bioeconomy can be supported through future CAP ecoschemes by involving such groups. Reaching people in their own community is essential; using small-scale local producers and educators could cascade information and knowledge outwards.
- Any **market push or pull policy** that can support the bioeconomy should be considered, as these have proven useful in other EU countries (e.g. Italy).
- As commercial opportunities evolve alongside rapid innovation, it is necessary to ensure that **research and innovation programmes and projects** are fully supported throughout the journey from low to high technology readiness levels so that commercial viability in Ireland can be achieved as quickly as possible. This includes government investment in key national pilot-scale and demonstration-scale facilities.
- Target the education and training sector, including primary, post primary and third level, to educate children and young people and provide information on key bioeconomy messages. This could include age-appropriate junior achievement programmes, young scientist competitions and transition year programmes.
- Improve public knowledge and perception. This could be done by using all types of communication tools such as traditional (newspapers, national and local) and digital methods, including social media, to reach the public. Research has indicated that,

6 For example https://biorbic.com/farm-zero-c/ (accessed 11 January 2023).

although there is an increasing consumer appetite and preference for purchasing biobased products instead of fossil based, there is a considerable knowledge gap on how to purchase them.

- Product certification and labelling to deliver clear unambiguous information to consumers. The labelling should align with certification schemes and standards in Europe. The labelling should better inform consumers and businesses so that they can make sustainable choices. This again builds understanding and increases overall awareness.
- Consider a "branding" of the Irish bioeconomy to link and align these communication and education efforts. Due consideration needs to be given to the quality and credentials of this branding to avoid any perceptions of "greenwashing" when it is rolled out. Certification and labelling are critical factors in ensuring transparency and traceability.
- Increase the transparency and availability of data on flows of biological resources and wastes in the economy to more accurately assess the opportunities for developing a sustainable bioeconomy.
- Integrate the ongoing bioeconomy research activities from Europe and Ireland more firmly into Ireland's system, increasing connectivity between researchers across institutions and with primary producer advisory services, which could enable farmers to benefit from the latest research and knowledge on the bioeconomy

6.3 Closing Remarks

This report provides a snapshot of a sector that has huge innovation potential for Ireland. The world is entering the final stages of the fossil economy. It is an era in which Ireland does not have the fossil-based resources to compete on a global scale with the major oil-producing countries. However, the bioeconomy is an opportunity for Ireland to play to its strengths, namely its natural resources. The bioeconomy offers the opportunity to reduce GHG emissions, contribute to biodiversity, contribute to the circular economy, produce goods that will satisfy our own national needs and export into areas of major global growth where biobased products will replace fossil-based products. We can build on our expertise in the agri-food sector, which has strong global brands. Like all opportunities, enabling Ireland to achieve its full bioeconomy potential will require significant investment.

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Abbreviations

CSO	Central Statistics Office
EI	Enterprise Ireland
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
KPI	Key performance indicator
NBS	National Bioeconomy Strategy
NPS	National Policy Statement
PESTLE	Political, economic, social, technological, legal and environmental
PPP	Public–private partnership

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

- Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
- Sceitheadh fuíolluisce uirbigh;
- Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- Foinsí radaíochta ianúcháin;
- Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
- Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

- Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

- Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

- Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
- Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

- Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

- Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

- Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

epa Research

Evidence Synthesis Report: 2

Circular Bioeconomy Outlook Study 2030-2050 in Support of Climate Action, Sustainable Food and Biobased Systems

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