CIRCULÉIRE

CIRCULÉIRE'S CIRCULAR SECTORAL GUIDES

Unpacking the circular innovation opportunities for Ireland's Agriculture and Bio-based Industries

IRISH MANUFACTURING RESEARCH

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Climate-KIC is supported by the EIT, a body of the European Union

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Suggested citation:

Irish Manufacturing Research (2021) Unpacking Circular Innovation Opportunities for the Agriculture and Biobased industries in Ireland, CIRCULÉIRE Circular Sectoral Good Practice Guide, Ireland.

About CIRCULÉIRE

CIRCULÉIRE, the National Platform for Circular Manufacturing seeks to accelerate Ireland's transition towards a net-zero carbon circular economy.

A key objective of the programme is to demystify, de-risk and deliver circular business model innovation for Irish industry.

Want to learn more about CIRCULÉIRE?

Visit our website at **http://www.circuleire.ie/** or contact **circuleire@imr.ie**

Purpose of the Circular Agriculture & Biobased Sectoral Good Practice Guide

This Circular Economy Sectoral Good Practice Guide is intended for those involved in the Irish Agriculture and Biobased industries, including economic operators in the value chain, as well as policy makers. It aims to provide industry stakeholders with an overview of industry-led circular innovations that are shaping the agriculture and biobased industries in other contexts, and to highlight the sectoral opportunities to circularise the sector here in Ireland.

The **Circular Agriculture & Bio-Based Industries Guide** is part of a series of reports targeted at Irish industry players in sectors deemed strategically important to supporting Ireland's transition to a circular economy.

Structure of the Guide

This Guide is structured as follows:

- **Section 1** offers a Landscape Review of the agriculture and biobased sectors in Ireland, including the national and European policy and other drivers that are shaping the Circular Agriculture & Biobased Industries in Ireland.

- **Section 2** builds on desk research and summarises good industry practices of circular agriculture and biobased sector from across Ireland and Europe.

- **Section 3** draws on the lessons learnt from both the industry case studies, as well as insights from public-sector support measures in Europe that are supporting the advancing of circular agriculture and biobased sector. Building on comparative analysis, it offers insights and recommendations about what's needed to advance a circular economy for the agriculture and biobased sectors here in Ireland.

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Section 1. EU & Irish Agriculture & Biobased Sectors

1.1 Irish Agriculture and Biobased Industry Landscape

The agriculture sector in Ireland in 2016 generated 7% of gross value added (€13.9 billion), 9.8% of Ireland's merchandise exports and provided 8.5% of national employment. When employment in inputs, processing and marketing is included, the agriculture sector accounts for almost 10% of employment (Teagasc, 2017). The agriculture sector is an important part of the bioeconomy, which encompasses living organisms (i.e. crops, forests, fish, farm animals and micro-organisms) or their parts and by-products that have potential use or value.

The Irish bioeconomy (as of 2018) was estimated to employ over 200,000 people and extends across sectors including farming and the agri-business, marine, forestry, water and waste management (Government of Ireland, 2018). Irish bioeconomy has a well-established agri-food sector that uses two-thirds of its land and employs over 170,000 people (7.75% of its working population) (Teagasc, 2017).

Agriculture is arguably one of Ireland's most important business sector. According to the Department of Agriculture, Food, and the Marine (DAFM), the total land area in Ireland equates to 6.9mn hectares of which 4.5mn, or approximately 65% is used for agricultural purposes (Walsh et al, 2017). Ireland has healthy and productive soils, as well as suitable climate for producing good grass, hence its thriving beef and dairy production sectors.

Approximately 11 % of Ireland's landmass is covered by forests. Irish forest produces 3.2mn m^3 of material each year (Teagasc, 2017). This is forecasted to increase to 8mn by 2035. Irish forestry sector already employs more than 12,000 people and there is potential for creation of more rural jobs. Forests provide a range of ecosystem services, including the direct benefits of forest products, the indirect benefits of carbon sequestration, as well as the retention and filtering of water. In countries with large areas of forest, these benefits have been argued to far exceed those from timber or conversion to agriculture. Almost all Irish forest is commercially ran and a significant proportion of it comprise of exotic conifers. Conifer trees that proliferate in the Irish climate are mostly fibrous in nature and are mainly used for pulp and board (Bullock, 2008).

In addition, Ireland has one of the most significant seabed territories in Europe which is about ten times its landmass and is an enormous reservoir of genetic material with a vast natural product potential. Oceans provide the primary

sources of protein for over 3.5bn people globally. Seafood delivers more dietary protein than cattle, sheep or poultry, as well as a wide variety of vitamins and minerals. The Irish Marine industry is worth €39bn in exports. The fish catching sector provides over 6,000 direct jobs while an additional 10,000 jobs onshore are dependent on catches from Irish vessels. Ireland also has a growing seaweed industry due to the health benefits of seaweed and the potential for their use in the discovery of naturally occurring bioactive compounds. Marine organisms are potential sources of bio-based products such as enzymes, biomaterials, chemicals, cosmetics and bioactive compounds (DAFM, 2017).

In 2018, Ireland's ocean economy (shipping and maritime transport, tourism and leisure in marine and coastal areas, seafood-fisheries, aquaculture and processing combined, marine advanced technology and marine commerce) had a turnover of €6.2 bn. The direct economic value was worth €2.2 bn or approximately 1.1% of the GDP (SEMRU, 2019). Aside the traditional sectors of the bioeconomy, Ireland also has a booming and rapidly growing biopharmaceutical sector, with 24 out of the 25 largest pharmaceutical companies in the world having a presence in Ireland. Pharma and chemical exports account for 40-50 per cent of total Irish goods exports, worth over €70 billion a year (Irish Times, 2020).

1.2 EU Agriculture and Bio-based Industry Landscape

The bioeconomy (including agriculture and biobased industries) currently is one of the EU's largest and most important sectors with an annual turnover of around €2 trillion and employing around 18 million people (EC, 2018). In recent years, Europe has integrated sustainability and circularity in bioeconomy policy strategies as a way to respond to societal challenges such as limited global resource availability and climate change, land and ecosystem degradation, as well as growing demand for food, feed, biobased materials and energy.

The European Commission (EC) call for a climate-neutral Europe by 2050 highlighted that the systemic adoption of a circular bioeconomy approach at governmental, agri-food and industrial level provides the opportunity to address the multifaceted challenges posed by climate change and land use. It also highlights that the bioeconomy will contribute to addressing the Paris Agreement commitments and to the national achievement of the UN Sustainable Development Goals (European Commission, 2019). This will be achieved by linking competitive and innovative biorefining industrial activity, activating territorial assets and actors for restoring ecosystems (including the oceans), and the responsible production and consumption of biodegradable and biobased products as replacements for energy intensive and fossil-based ones.

Table Box 1A - European and Irish policy, programmes and initiatives (as of 2021)

At the European level, this includes:

- The FP7 BIOTIC Industrial Biotechnology Roadmap,
- EU 2015 Circular Economy Package and the EU Circular Action Plan 2.0
- Bio-Based Industries-Joint Undertaking Fund (BBI-JU),
- European Bioeconomy Stakeholders Manifesto
- The EU Green Deal
- The Farm to Fork Strategy,
- FOOD 2030,
- The Common Agricultural Policy (CAP) 2021-2027,
- The revised 2018 Waste Framework Directive,
- The EU's integrated Maritime Strategy (Blue Growth),
- The EU Biodiversity strategy,
- The 2018 revised Renewable Energy Directive,
- EU Forest Strategy and
- The Ten Point Action Plan to Create a Circular Bioeconomy devoted to a Sustainable Well-Being.
- European Circular Bioeconomy Fund (ECBF)

EU Working groups / committees:

- The Bio-Based Products Expert Group (BBP EG),
- Bio-Based Industries Consortium-Strategic Innovation and Research Agenda (BIC-SIRA) 2030,
- The Standing Committee on Agricultural Research (SCAR) Foresight Report on the Bioeconomy,

National policy and initiatives:

Within the Irish context, key policies include:

- the 2018 National Policy Statement for the Bioeconomy,
- the 2019 Bioeconomy Implementation Group Progress Report,
- the Waste Action Plan for Circular Economy 2020
- The Climate Action Plan 2021
- Project 2040 Ireland
- Food Vision 2030 – A World Leader in Sustainable Food Systems
- Future Jobs Ireland supports the development of employment opportunities in the green/circular/bio economy
- Draft Agri-Food Strategy to 2030 (Forthcoming)

According the ECBF, Europe's circular bioeconomy is projected to grow. It notes that the European bioeconomy was worth EUR 2.4tr in 2017 and has grown by 25% since 2008. Of this, roughly 50% of the turnover is accounted for by the food and beverage sector, and 30% by the bio-based industries (ECBF, 2022). They cite changing consumer demand for more sustainable products, and supportive political and regulatory incentives to foster innovation and decarbonized markets (e.g. Green Deal) as principal growth drivers of Europe's bioeconomy.

In parallel, the circular economy is gaining momentum – with global asset under management (AUM) focused on circularity and managed by public equity funds increased from USD 0.3bn to over USD 2bn in the first eight months of 2020 (*Ibid*.). The biotechnology revolution and advancements in new conversion

technologies have led several financial entities to estimate EUR 1.8tr in net benefits for Europe from the circular economy by 2030 (FinanCE, 2016). Meanwhile, overall merger and acquisition activity in the sector has accelerated (ECBF, 2022).

1.3 The Circular Bioeconomy (CBE)

The bioeconomy, circular economy and circular bioeconomy concepts have gained increased attention within the EU Policy space over the last decade. Merging bioeconomy and circular economy concepts has led to the application of the term 'circular bioeconomy' (CBE).

For the purposes of this Guide, Circular Bioeconomy is defined as the intersection of the bioeconomy and circular economy i.e. ensuring or promoting circularity or circular economy principles within the bioeconomy, and in particular agriculture and other bio-based industries.

Several bioeconomy strategy documents at the EU level described bioeconomy as "the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy". This definition cuts across several sectors including agriculture, forestry, fisheries, food, paper & pulp production, as well as parts of chemical, biotechnological and energy industries (Bugge, Hansen & Klitkou, 2016.

Since the focus of this sectoral guide is agriculture and biobased sectors, there is need to define both contextually for this sectoral guide. Agriculture sector within this sectoral guide are activities involved in the production of renewable biological resources (i.e. plant and animal biomass) for human use, while biobased sector are activities involved in the conversion of renewable biological resources to value-added products such as food, feed, energy and other tangibles.

Circular Economy for agriculture and biobased sectors therefore implies ensuring and or promoting circularity or circular economy principles within the boundaries of production of plant and animal biomass for human use (agriculture sector) on the one hand, and within the context of conversion of plant and animal biomass into value added products on the other hand (biobased sector). Noteworthy, biobased sector in this sectoral guide also include conversion of renewable biological resources from forestry, marine and freshwater sectors to value-added products and not only those from the agriculture sector.

Circular economy approaches within the agriculture and biobased sectors are of two types. The bio-cascading approach (which involves successive use of bioresources via better production, consumption and waste management designs and practices-using rethink, refuse, reduction, reuse, recycling and bio-substitution strategies), and the integrated biorefinery approach (which involves production of multiple biobased outputs from the same bio-resource, within the same space).

1.3 Ireland's Agriculture and Biobased Sectors

Since 2015, following the introduction of the EU Circular Economy Package in December 2015 and during the Dutch Presidency of the EU Council (January-June 2016), there has been a notable increase in activities in the Circular Bioeconomy Landscape of Irish agriculture and biobased sectors. Two landmark policy documents were published within this time frame (the 2018 National Bioeconomy Policy Statement and the 2019 Bioeconomy Implementation Group Progress Report).

Before the publishing of the first one (2018 National Bioeconomy Policy Statement), the Department of Agriculture, Food and the Marine (DAFM) of Ireland funded several collaborative academic-led bioeconomy research projects with focus on the agriculture and biobased sectors. Notable among such projects was the BioÉire research project led by TEAGASC. BioÉire focused on identifying and prioritising interlinking cross-sectoral value chains in the agriculture and biobased sectors of bioeconomy. The results from BioÉire projects and the papers from BiOrbic, UCD and the Marine Institute gained traction with the national department of the Taoiseach and the Interdepartmental Group on the Bioeconomy culminating in a collaborative design thinking workshop in February 2017. These research and workshop activity helped to shape two landmark policy documents: the 2018 National Bioeconomy Policy Statement, which was then followed by the first progress report by the Bioeconomy Implementation Group In 2019.

The Irish agriculture and bio-based bioeconomy sectors has evolved around already existing massive bio-based industries (spanning across agriculture, forestry, freshwater, marine and waste management sectors), as well as an emerging digital bioeconomy sector. A number of sizable, well-coordinated research and innovation funds have been made available to support the development of agriculture and bio-based bioeconomy sectors through the EU, as well as via different Government Ministries and agencies including Department of Agriculture, Food, and the Marine, Department of Communication, Climate Action & Environment, Department of Business, Enterprise and Innovation, Enterprise Ireland, Environmental Protection Agency, Science Foundation Ireland, Irish Research Council etc.

Some of such funds are available for start-up, technology demonstration and innovation research. Examples are described in Table Box 1B. Research and testing facilities for technological validation and demonstration are also available in Ireland. They provide the needed support in preparation for commercialization. Some are located in and ran by third level institutions (i.e. Irish universities and technological institutes), some are ran by government agencies (Teagasc), some are supported by government departments (e.g. Department of Agriculture, Food and the Marine), while some others are supported by

government research and innovation funding agencies (Enterprise Ireland, Science Foundation Ireland etc.).

Those supported by government departments, as well as research and funding agencies are also done in partnership with third level institutions. Examples of agriculture and biobased bioeconomy research and testing facilities in Ireland include Enterprise Ireland's technological gateways (e.g. Shannon Applied Biotechnology Centre), Enterprise Ireland supported innovation hubs and national innovation partners (Irish Manufacturing Research and the National Bioeconomy Campus of the Irish Bioeconomy Foundation), Science Foundation Ireland supported innovation centres (Biorbic), the Department of Agriculture, Food and the Marine supported demonstration pilots (Biorefinery Glas - funded the under the Rural Development Programme 2014 -2020). Particularly important to note is the provision of around €17.8mn through Science Foundation Ireland for the BiOrbic Research Centre, which will explore how to convert biomass resources and the residues produced during food production into higher-value products. Science Foundation Ireland also supported the MaREI (Marine and Renewable Energy Research Development and Innovation Centre) for similar functions. The innovation projects (TRL>5) that evolve from BiOrbic and MaREI will be further scaled up and disseminated via Irish Bioeconomy Foundation (IBF), which is supported and funded by Enterprise Ireland. Most recently, DAFM supported the development of next-generation wood-based products through a collaborative project between the SFI funded centres, AMBER and BiOrbic. Also in favour of the development of agriculture and bio-based bioeconomy sectors is the growing number of researchers from Europe and other parts of the world working in the innovation sector.

Also, Project 2040 Ireland (Ireland's long-term development strategy), acknowledges that important role that agriculture, bio-based sectors of bioeconomy will need to play in achieving Ireland's long-term economic, environmental and social sustainability goals. It highlights a number of actions related to supporting these sectors to grow, whilst supporting climate change mitigation and adaptation actions: It notes that ongoing public capital investments in the agriculture sector will seek to enable the sustainable development of the sector in accordance with the ambition in Food Wise 2025. It includes plans to undertake town-scale pilots of food and agricultural waste to gas in agricultural catchments for local gas networks supply and biogas production (Project 2040; 2019: 75).

Meanwhile, Biopharmaceuticals & Food are identified as priority sectors to develop in the Irish market as a basis for supporting national job creation goals (Project 2040; 2019: 76). Further investment will be provided to facilitate the expansion of the National Institute for Bioprocessing Research and Training (NIBRT)–- a globally recognised centre of excellence for training and research in bioprocessing (Project 2040; 2019: 76). Meanwhile, further commitments are made to strategically invest in R&I for bio-based materials, and to support the work of InterTradeIreland to help businesses across the island grow all-island trade, increase productivity and innovation, and support clustering and

development of bio-economy and advanced manufacturing, which are identified as high-potential sectors for the island of Ireland (Project 2040; 2019: 168).

Table Box 1B
Irish Agriculture and Biobased Bioeconomy Sector Initiatives and Organisations (as at 2021)

In Tipperary county, two promising bioeconomy projects are being developed. The €32mn **AgriChemWhey** project is a first-of-a-kind, industrial-scale bio-refinery which will take by-products from the dairy processing industry and convert them into cost-competitive, sustainable lactic acid which in turn will be used to make value-added bio-based products for growing global markets for biodegradable plastics and bio-based fertilizer. AgriChemWhey project is led by Glanbia Ingredients, co-partnered by 10 other partners across the EU and co-funded by Bio-Based Industries-Joint Undertaking Fund (BBI-JU)- €22mn, and other private investments-€10 mn.

In 2017, **Irish Bioeconomy Foundation (IBF)** secured a €4.5mn Regional Development Enterprise fund from Enterprise Ireland for a pilot-scale bioprocessing demonstration plant in Lisheen. The facility will enable scaling bioeconomy technologies in alliance with industry and research producing organisations. The key objective of IBF is to establish a fora of industry, academia and policy leaders around Ireland's emerging bioeconomy. IBF also promotes the conversion of Ireland's natural land and marine resources to value added products for the development of a sustainable circular bioeconomy that is globally competitive and creates local development.

Monaghan Mushrooms was awarded a €5mn REDF grant for the Development of the **Bioconnect Innovation Centre** in Monaghan, which will work with agri-food producers within the region to grow and develop new biobased products. The Centre will create a space for a consortium of the agri-food sector to use biotechnology services, networking and brainstorming to solve problems facing the companies in a non-competitive environment.

Noteworthy is the Institute of Technology, Tralee's (Now Munster Technological University MTU) participation in Europe's first Digital Innovation Hub for a circular bioeconomy, together with IBF. The **ICT-BIOCHAIN** initiative received funding to the value of close to €1mn under Bio-Based Industries Joint Undertaking, a public-private partnership focused on the development of Europe's bioeconomy. The ICT-BIOCHAIN initiative kicked-off in Brussels on the 28th of June 2018 and ran until May 2020. The project focused on the development of efficient biomass supply chains for sustainable chemical production in bioeconomy regions across Europe. The Bio-based Industries Consortium established a target of 30% of European chemicals coming from biobased sources by 2030, and an increase in available biomass supply chains of 20% by 2030 to help achieve this objective. Since 2016, the European Commission has designated six regions across Europe as Model Demonstrator Regions for Sustainable Chemical production i.e. chemicals produced from locally available biomass, waste or CO2. Three of these regions are represented in the ICT-BIOCHAIN initiative. Ireland's South-East and West, including the Lisheen Bioeconomy Campus are test bed regions to evaluate bioresource potential and feedstock-specific ICT solutions.

In June 2020, ITT (now MTU) secured funding from BBI-JU for the **BIOSWITCH** project. The project aims to encourage and support brand owners to switch to a bio-based approach. It will do this by creating a framework through a series of events and outreach activities. The project will lead to the development of a toolbox/aid that will encourage brand owners to switch to bio-based products. In addition, the project will unlock untapped biomass resources by raising awareness of its potential profitability with owners. So far there are 400 Stakeholders and organizations involved in the project. Thus, this project is anticipated to make the EU a leader in the bio-based economy, strengthening its economic growth and industrial competitiveness.

Table Box 1B - continued

Irish Agriculture and Biobased Bioeconomy Sector Initiatives and Organisations (as at 2021)

BioICEP (Bio Innovation of a Circular Economy for Plastics) is a €12mn pan European-Chinese consortium funded by the EU Horizon 2020, and Athlone IT with LIT and TCD as Irish partners (BioICEP, n.d.). The project's overall objective is to demonstrate a route to a circular economy for plastics by developing advanced waste plastic biotransformation into high market demand bioproducts and bioplastics. The project brings together experts from industry and academia, contributing a set of technologies to achieve the following specific objectives:

1. Develop high-efficiency biodegradation plastic by incorporating microorganism communities that are capable of expressing novel enzymes that enable the degradation of mixtures of plastics.
2. The sustainable degradation of at least 20% of mixed plastics.
3. Bioprocess high-value products, including equivalent bioplastics valorising mixed plastic waste.
4. Sustainable prototype system plan, paving the way to bring the developed solution to the market, fulfilling current needs, futures expectations, and delivering a seamless bio-innovative route for a circular economy for plastics.

Biorefinery Glas facility located in West Cork aims to increase the usable protein from grass by 40% (Cadogan, 2019). It is led by the Institute of Technology, Tralee and has five partners including the Barryroe Co-operative, the Carbery Group, GRASSA B.V. and University College Dublin. Funded by the Agricultural European Innovation Partnership of the EU (EIP-AGRI) and the Department of Agriculture, Food and the Marine under the Rural Development Programme. Biorefinery Glas is a first demonstration of small-scale biorefinery in Ireland, supporting development of new business models and farmer diversification into the circular bioeconomy. Biorefinery Glas is a first step towards changing the role of farmers in the bioeconomy, from suppliers of biomass to producers of finished and semi-finished products. Grass goes into the biorefinery, and one of the products produced is an ideal feed for dairy or beef cattle, because it contains grass proteins that are easily digestible by cattle. As a result, the cattle eating this will generate less greenhouse gas emissions compared to eating untreated grass. The remainder of the grass proteins can be siphoned off to make a concentrate feed for pigs or chickens, which again has only the proteins they can digest efficiently. This feed can replace imported feeds, another small step towards carbon neutrality, by reducing emissions. Another co-product from the biorefinery is fructo- oligosaccharide (prebiotic sugar), which is potentially valuable for the human and animal nutrition markets. This project is particularly suitable for Ireland, as it is the only country in Europe that is more than 50% grassland.

Between 2013 and 2016, researchers at National University of Ireland Galway (NUIG) demonstrated the viability of using Irish Sitka spruce for the manufacture of Cross Laminated Timber (CLT) as part of the project '**Innovation In Irish Timber Usage'** funded by the Department of Agriculture, Food and the Marine (DAFM). This project led to two joint research projects investigating the links between forestry management practices and the properties of Irish timber (Sitka spruce, Norway spruce and Douglas fir). Later, NUIG developed collaborations with the main European producers of CLT panels with Balcas sawmill located in Fermanagh, which was established for the supply of Irish timber. The potential to use native timber in a high-performance building product will have significant environmental benefits if brought to full production and utilised widely in the construction sector (Harte, 2016).

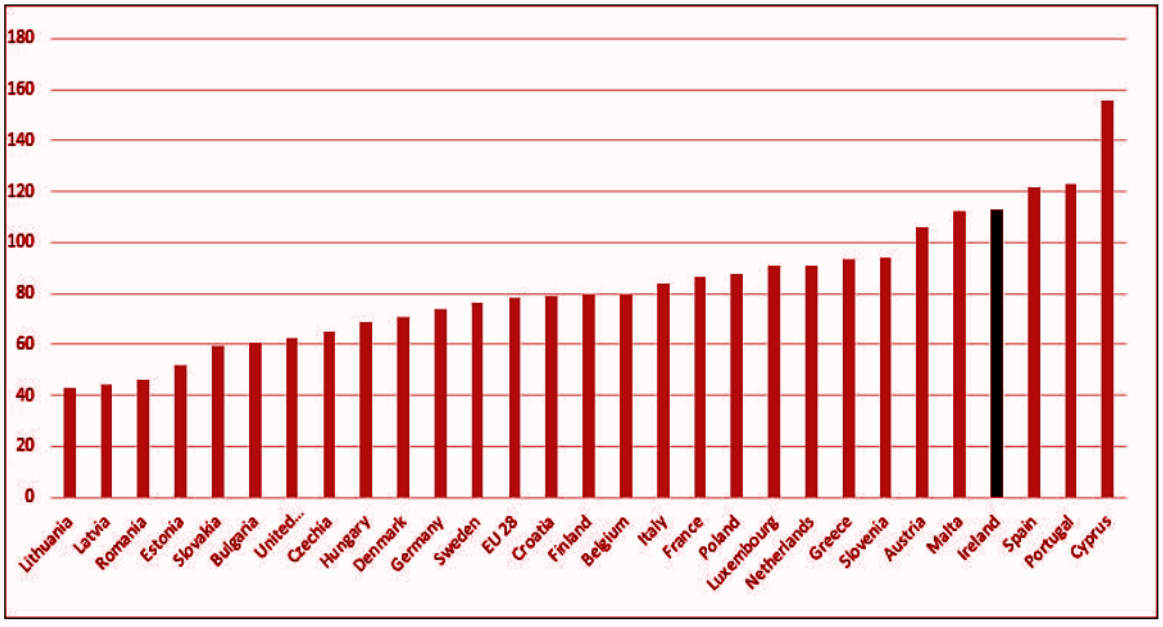
In 2020, the Irish Manufacturing Research facilitated an Industrial Symbiosis innovation demonstration pilot between St Mel's Brewery and Panelto Food of Longford County. This collaboration (i.e. **Symbiobeer project**) was funded through EPA's 2019 Green Enterprise Fund. The project utilized waste bread as a substitute for virgin malted grain to create a new beer and subsequently used the fermented brewer spent grain from the beer production process as yeast for a new bread, hence creating a closed loop (i.e. bread to beer to bread).

In 2018, Enterprise Ireland launched a new Competitive Start Fund (CSF) totalling up to €500,000 to support start-ups in the marine technology and agritech sectors. The goal of the CSF include to increase the number and quality of High Potential Start-Up Companies (HPSUs) that have the potential to employ more than 10 persons and achieve €1 million in export sales within three years.

1.4 GHG Contribution of the Bioeconomy

While one of the major purpose of promoting circular economy in agriculture and biobased sectors among other things is to lower global carbon emissions, it must be noted that some sub-sectors are in themselves greenhouse gas hotspots. While forestry and marine sectors are projected to be massive carbon sinks, much of agriculture industry activity remains a major greenhouse gas emission source. The agriculture sector is responsible for 10.3% of the EU's GHG emissions and 33% of Ireland's GHG emissions, with nearly 70% of those coming from the animal sector (European Environmental Agency, 2019). Ireland is one of the worst performing on greenhouse gas emissions reduction of the EU-27 in part because of this high dependence on agriculture (Figure 1).

Circular bioeconomy innovations and strategies for meeting national carbon targets in line with the Paris Climate Agreement, must therefore focus on reducing the carbon emissions from the agriculture sector on the one hand, whilst harnessing the carbon sinks from forest, oceans and maximization of urban spaces (e.g. urban forests, urban gardens, rooftop gardens etc.) on the other. Freshwater and waste management sectors are also expected to play a role in the meeting pre-determined national carbon emission reduction targets, hence the scope of this sectoral guide.



Source: Eurostat

Figure 1: Eurostat Greenhouse Gas Emissions EU 2017 (Social Justice Ireland, 2020)

1.5 Purpose and Scope of this guide

Since circular economy innovation and strategies for the Irish agriculture and biobased sectors lies within the remit of the reduction of carbon emissions from the agriculture, freshwater and waste management sectors, as well as the harnessing of carbon sinks from forestry, marine and urban spaces sectors, the case studies chosen for this sectoral guide cover all these areas. The agriculture sector in this sectoral guide is divided into the agri-food waste and agri-farming sub-sectors. The forestry sector is divided into forest production waste and forest product waste sub-sectors. Water sectors include marine and freshwater sub-sectors and the waste management sector is considered alongside the agriculture, forestry and water sectors.

To avoid overlap with a separate Food & Drinks Sectoral Guide being produced as part of this series, case studies were distinguished from those in the food and drink sectoral guide by not including agri-food examples that focus exclusively on valorizing food wastes. Agri-food waste or agri-farming case studies chosen for this sectoral guide either apply additional circular economy enabling strategies, which could be product-based or production based circular designs, biotechnology, ICT or biorefinery concepts. The wool agri-product case studies were given particular attention because of the massive unexplored opportunity existing in the sub-sector.

While forestry represents another significant circular economy opportunity for Ireland, a full sectoral guide on this top will be produced later in 2022. For this reason, we have included only two forestry case studies (one along each of the sub-sectoral divisions). One illustrating circular valorization of forestry production wastes and the other forestry product wastes. Water sub-sector case study examples included in the guide focus more on relatively unexplored but massive marine sub-sectors (comprising of marine vegetation/plant, and marine animal food waste). Case study examples from freshwater sub-sector using waste and exploiting biotechnology and biorefinery concepts are also showcased.

1.6 Methods

The report is based on information gathered using the following methods. An initial two-part scoping desktop review was conducted on:

1. the literature on circular economy in the agriculture and bio-based industries
2. policies and public-sector led initiatives in Ireland and Europe aimed at supporting circular agriculture and bio-based industries

The findings of desktop review were used to refine our Sectoral Guide objectives and were used to develop key criteria to select our case studies (using purposeful

sampling), and to develop our analytical framework. Key circular economy databases were then identified and used to identify a long list of circular agriculture and bio-based industries case studies.

In the final stage of our research, we shortlisted case studies according to the following criteria:

Circularity of the project / initiative	In order to enable comparative analysis of the processes enabling different kinds of innovation, we sought to select projects which explicitly presented themselves as a circular innovation, appeared to pursue one or more circular economy strategies, and which illustrated circularity under on or more of the following sectors: 1. Agriculture; 2. Forestry; 3. Marine; and 4. Fresh water
Impact of the project/ initiative (proven or high-potential)	"Circularity" in and of itself does not guarantee positive social, economic, and environmental performance (i.e., sustainability) (Blum et al., 2020). For this reason, we shortlisted case studies on the basis that they overtly self-identified as circular innovations, and demonstrated an effort to create impact against different social, economic and environmental impact indicators. Particular consideration was given to ensure projects and initiatives profiled demonstrated positive performance (proven or high-potential if scaled) against material waste and carbon emission reductions. That said, while we targeted examples of potential or established good practices, the aim of the case studies was not to evaluate projects or organisations - since even less 'successful' cases can yield important insights about existing barriers to implementing or scaling circular innovations.
Type of innovation and circular economy strategies employed	The case studies have been selected on the basis that they demonstrate a diversity of types of innovation – ranging from product, business model, service, technological; or system innovations. To showcase the range and variety of circular bioeconomy innovations, efforts were made to purposefully sample case studies that exemplified a diversity of circular economy strategies – such as industrial symbiosis, bio-refineries and reuse.
Technological Readiness Levels (TRLs) of the Initiative	To gather information on both emergent / cutting-edge innovations and more established, 'market ready' circular agriculture and bio-based industries innovations, we aimed to select case studies that were judged to range from TRL 6 – 9. This enabled us to gather insights about the opportunities and challenges (such as

	regulatory, scaling and replication challenges) from circular agriculture and bio-based industries innovations at different stages of maturity.
Geographic variety	To analyse the processes associated with supporting circular agriculture and bio-based industries innovations in different socio-economic and policy contexts, and in the context of different market and sectoral conditions, we aimed to select cases from a variety of regions (with a particular focus on European regions – although Asian and US based examples are included too). Particular attention has been given to spotlight a select number of good practices originating or operating in other regions, nonetheless, the Guide also endeavours to highlight good practice examples of circular innovations within Ireland.

The public sector examples profiled in **Section 3** were identified – based on a policy landscaping exercise – and used as a basis for determining and benchmarking the range of systems levers that are being used by key decisionmakers to facilitate the development of enabling market conditions and innovation ecosystems for circular agriculture and bio-based industries.

Qualitative analysis was undertaken to understand processes and approaches that have been adopted in these regions, and the insights gathered around the opportunities and gaps were used to inform the recommendations presented in Section 3 about how the agriculture and bio-based industries can be supported to transition to a circular economy in the Irish context.

Section 2 – Circular Agriculture & Biobased Industries Innovations

Next we highlight **13 case studies** (mostly from Ireland and Europe, but also Asia and the United States) - **which illustrate how circular innovations are shaping the agriculture and biobased sectors**.

The case studies profiled below are categorised by the following **4 clusters**:

2.1-Agriculture, 2.2-Forestry

2.3-Marine and 2.4-Freshwater.

Table 2.1 below provides an overview of the case studies

Bioeconomy sector	Material/ Industry	Case study name	Region(s) covered	What are the top 3 Circular Strategies?	Type of CE innovation	What is the TRL of the initiative?
Agriculture						
Agri-food waste	Agro-residue waste and bio-agricultural innovation	**Nuritas**	Dublin, Ireland	Bio-nutrient production	Product, process and ICT innovation	TRL 9
	Agro-residue waste and bio-agricultural innovation	**Hexafly**	Meath, Ireland	Bio-nutrient production and recycling	Product and process innovation	TRL 6-8
Agri-farming	Food production and circular production design	**Herfra-Refarmed**	Copenhagen, Denmark	Reuse, nutrient recovery, recycling	Process and business model innovation	TRL 6-8
	Circular food production, and biotechnology	**Balbo Group**	Brazil	Nutrient recovery, reuse, recycling	Process and business model innovation	TRL 9
	Food production and biorefinery concept	**Biorefinery Glas**	Tralee, Kerry, Ireland	Reuse, recycling, nutrient recovery and recycling	Product, process and system innovation	TRL 6-7
	Livestock production waste	**Woolcool**	London, United Kingdom	Recycling, Reduction, Substitution	Product and system innovation	TRL 9

Bioeconomy sector	Material/ Industry	Case study name	Region(s) covered	What are the top 3 Circular Strategies?	Type of CE innovation	What is the TRL of the initiative?
Forestry						
Forest waste	Forest production waste	**Sulapac Oy**	Helsinki, Finland	Recycling, reduction and substitution	Product and process innovation	TRL 8-9
	Forest product waste	**CORK-A-TEX**	Guimarães, Portugal	Recycling, Reduction and Substitution	Product and process innovation	TRL 6-8
Marine						
Marine-material	Marine vegetation	**Evoware**	Jakarta, Indonesia	Reduction, Elimination and Substitution	Product, process, service and system innovation	TRL 6-8
Marine-waste	Marine food waste	**Tidal Vision-Leigh Fibers partnership**	Wellford, South Carolina, United States	Recycling, Reduction, Substitution and waste prevention	Product and process innovation	TRL 7-8
	Marine food waste	**The Shellworks**	London, United Kingdom	Recycling, Reduction, Substitution, Nutrient recovery	Product, process and system innovation	TRL 7-8
	Marine food waste	**Nutramara-Shannon ABC**	Tralee, Kerry, Ireland	Recycling and bionutrient production	Product, process and system innovation	TRL9
Fresh water						
Fresh water waste and bioinnovation	Fresh water waste, biotechnology and biorefinery concept	**Algae factory**	Gothenburg, Sweden	Waste prevention, water reuse and recycling; Nutrient production, recovery and recycling; Substitution; Industrial Symbiosis	Product, process business model and system innovation	TRL 6-8

2.1 Agriculture

This section described case studies that focused on agri-food wastes (**Nuritas, Hexafly**), agri-farming (**Herfra-Refarmed, Balbo Group, Biorefinery Glas**) and relatively unexplored wool sub-sector (**Woolcool).**

Case Study 1: Nuritas
ICT and biotechnology for discovering, recovery and recycling of nutrients with extraordinary health benefits from food by-products and co-products
Website: Nuritas
Partner(s) involved: Seed capital funding-Enterprise Ireland (IE), Angel Investors-Ali Partov, Bono, Edge and Marc Benioff; Series A funding: Enterprise Ireland (IE); Series B funding- Wheatsheaf Group Limited (UK), CJ Corporation (SK), Cleveland Avenue (US), VisVires New Protein (SG), European Circular Bioeconomy Fund (DE), Veronorte (CO), Vertex Venture Holdings (SG), Cultivian Sandbox Ventures (US); multi-sectoral collaborations with BASF, Pharmavite and Nestle; and debt funding from EIB (LU); Multi-sectoral collaborations with BASF (DE), Pharmavite (US) and Nestle (CH).
CE Strategies used: Bio-nutrient recovery and recycling; industrial symbiosis
Type of CE innovation: Product, process and ICT innovation
Region(s) its based in: Dublin, Ireland
TRL: 9

What circular challenge / opportunity is the case study trying to address?

About one-third of global food production goes to waste. Besides food thrown away downstream the food value chain, 25-50 percent of food is discarded at the production level. About 1.3 million tonnes of food waste is being generated annually in Ireland. Food by-products and co-products however often contain billions of peptide molecules with functional health benefits. Some peptide molecules contain aantimicrobial capabilities and can thus be used as natural food preservative for enhancing safety and extending food's shelf life. Some others aid the movement of glucose into the muscle, hence preventing accumulation of body sugar and reducing the risk of diabetes. Nuritas applies novel methods that combine artificial intelligence (AI) and genomics (DNA analysis) for discovering and recovery of natural bioactive peptide ingredients with extraordinary health benefits in food by-products and co-products.

Background of the initiative

Founded in 2014. Benefited from 8 funding rounds comprising of seed capital funds, Angel funds, multi-sectoral collaborations and debt funding. This circular innovation applies biotechnology and ICT based techniques i.e. artificial intelligence (AI) and DNA analysis (genomics) for discovering, recovering and recycling nutrients (peptides) of immense health benefits in food by-products and co-products. This innovation is product based (i.e produces new products), process based (involves change in production processes with the use of AI and DNA analysis with biotechnology) and ICT based (applies ICT techniques for driving circular innovation).

Impact and maturity of the initiative
Nuritas has raised $106.5M in capital since inception. Employs about 40 people. It had its first product launch in 2020 and has launched three products for muscle building, glucose metabolism and slowing down aging processes. 0.75 tonnes of CO_2 equivalent can be avoided by valorizing the nutrient in by-products and/or co-products.

Case Study 2: Hexafly
Harnessing the power of insects for bio-nutrient production and recycling
Website: Hexafly
Partner(s) involved: Advisory inputs-Enterprise Ireland (IE). Seed capital and R&D investors and funders: SOSV (US), RebelBio (UK), Enterprise Ireland (IE), Cedas Foundation (Isle of Man), The Yield Lab (IE), IndieBio (US), Forsage Holdings (IE) and Halo Business Angel Network (IE).. Strategic partnerships with Climate-KIC (EU), European Commission (EU), Maynooth University (IE) and Google (IE) (through its Adopt A Start Up initiative)
CE Strategies used: Bio-nutrient production and recycling
Type of CE innovation: Product and process innovation
Region(s) its based in: Meath, Ireland
TRL: 6-8

What circular challenge / opportunity is the case study trying to address?
Human pressures on global natural resources (i.e. ecological footprint) has more than doubled over the last 50 years; humanity currently uses 1.75 earths and half of the earth's biocapacity is used for food production (Global footprint Network, 2022). Slowing down this overshoot and overexploitation of the earth's natural resources require exploring more sustainable alternatives for animals, plants and eventually humans. Insect farming can play a role in this. Hexafly explores this possibility by using food and other organic wastes for feeding of insect larva, extracting protein-rich nutrients from the insect larva (for aquaculture and pet feed), and using the residues for maintenance of soil health, improvement of root development and plant growth, as well as reduction of the pest infestation (aphids). The substitution effects of insect farming will significantly reduce the land use, water and carbon footprint of animal feed production, while also making much more protein available in comparison to plant and animal sources.

Background of the initiative: Founded in 2016. Industry led. Benefited from advisory inputs from Enterprise Ireland; seed capital and R&D fundings from Enterprise Ireland (IE), angel funds Cedas Foundation (Isle of Man), The Yield Lab (IE), IndieBio (US), Forsage Holdings (IE) and Halo Business Angel Network (IE); and strategic partnerships with Climate-KIC (EU), European Commission (EU), Maynooth University (IE) and Google (IE), through its Adopt A Start Up initiative. Hexafly applies biotechnology upstream and biorefinery concept downstream. Upstream, it feeds black insect larva with food and other organic wastes (i.e. recovers and recycles food and other organic wastes) and extracts digestible amino acid proteins and fatty acids for animal feed (i.e. produces nutrients biologically). Amino acids are protein replacement for soy meal and fish meal, while fatty acids are replacements for coconut and palm oil. Produced animal feed is suitable as hypoallergenic diets and increases Immune defences and gut health of animals. Downstream, residues from squeezed black soldier ant larva contains bioactives (chitin) used for maintenance of soil health, improvement of root development and plant growth, as well as reduction of the aphid pest infestation (i.e. recovers and recycles by-products of the extraction process). The innovation of the business is product based (new products are made), process based (process is cheaper with much lower land use, water and carbon footprints) and system based (as it represents a total change in production systems).

Impact and maturity of the initiative - Even though it is not fully commercialized (TRL 6-8), there are examples of same business that are fully commercialized (Agriprotein, Nasemeko) and those whose commercialization are progress (EntoGreen, Entocycle) within the EU. Insect meal makes far more protein nutrient available for use in animal feed than other plant or animal-based options. The protein bioavailability rate of insect larva is 65%, 3750-7500 times more protein can be produced per acre than poultry, 660-1320 times more protein can be produced per acre than soy, 5170 -10350 times more protein can be produced per acre than beef, 4700-9500 times more protein can be produced per acre than legumes). Replacing fishmeal with insect meal reduces CO_2 emissions by about 80%. The greenhouse gas emissions associated with insect farming is 25 times less than that of cattle production and 10 times less than that of poultry production. The Water consumption of insect farming is 21 times less than that of cattle production and 6 times less than that of poultry production. Insect farming is by far more efficient in terms of resource use.

Case Study 3: Herfra-Refarmed
Circular (zero-waste) rooftop farming design and innovation

Website: Herfra-Refarmed
Partner(s) involved: Bilka and prospective building owners willing to offer rooftop spaces
CE Strategies used: Reuse, nutrient recovery and recycling
Type of CE innovation: Process and business model innovation
Region(s) its based in: Copenhagen, Denmark
TRL: 6-8

What circular challenge / opportunity is the case study trying to address?
More than half of the world's population live in less than 3% of the earth's land surface (Arodudu et al., 2014). This imply that the larger proportion of the world's biomass flows (waste and associated carbon emission inclusive) are locked in the urban areas of the world. There is need therefore for better management of urban generated waste (organic waste and carbon emissions) on the one hand, and more efficient use of urban spaces (rooftop space inclusive) for improvement of urban food sufficiency (i.e. creation of new food sources), as well as creation of new carbon sinks (for carbon emission reduction) on the other hand. This case study uses urban roof spaces, rain harvested during precipitation events, as well as excess heat and biowaste generated within commercial and industrial buildings for crop production and mitigation of the impacts of urban infrastructure development (land conversion, urban food insecurity, carbon emission reduction, waste management etc.).

Background of the initiative
Herfra is an urban farming company (unlike Urban Farming Dublin which was ran as a social enterprise that relied on crowdsourced funding). Herfra's business model is based on circular production design i.e. production design that benefits from and ensure circular flow of production resources (space, water, heat, manure etc.) used during production process. Herfra partners with Bilka (Danish Supermarket Chain) and other commercial building rooftop space owners within the same buildng for aquaponic production of fish and plants. Residual heat from building below and rooftop solar panels is used to heat rooftop greenhouse. Compost from building below is used as soil substrate, rain harvested on rooftop is used for irrigation, as well as aquaponic production of fish and plants. Business model benefits from industrial symbiosis with Bilka and other commercial building rooftop space owners. Partnership with building occupiers/owners with rooftop spaces for establishment of very short local production and supply circuit (known as building-integrated agriculture) is currently sought for upscaling activities. Innovation is essentially process based (involves a change in process of production) and business model based business model is different from conventional farming model and only functional if industrial symbiosis partnership with prospective building owners is successfully established).

Impact and maturity of the initiative
The Herfra business model is only emergent (TRL 6-8) with rooftop space volunteers needed for scaling up. It currently operates a B2B model that sells grown produce to Bilka Supermarket below. The circular production design adopted harvests, reuses and recycles rainwater (thereby reducing irrigation water consumption); recovers and recycles excess heat energy; recovers and recycles nutrient from compost (reducing and/or eliminating mineral nutrient production and use); creates new carbon sink (sequesters and reduces carbon emissions), uses less or no mineral fertilizers and no pesticides; and share/maximizes land space. The adopted circular production designs reduce irrigation water consumption by 90% less water and carbon emissions by 0.04 kg CO2e per unit vegetable produced. Cost of production is about one-third of conventional farming (primarily due to the use of residual heat). This translates to a reduction of 46 tonnes of CO_2 less per year compared to traditional farming.

Case Study 4: Balbo Group, Brazil

Application of circular process and production designs (using residues as fertilizers and fossil energy replacement), and biotechnology (pest and disease resistant crops) for regenerative agriculture, as well as increase in productivity and profit

Website: Balbo Group
Partner(s) involved: No external partners involved.
CE Strategies used: Nutrient recovery, recycling and substitution. Fossil fuel and input substitution and reduction
Type of CE innovation: Process and business model innovation
Region(s) its based in: Brazil
TRL: 9

What circular challenge / opportunity is the case study trying to address?
Industrial agriculture model employs fossil powered machineries, mineral inputs (fertilizers and pesticides) and breeding technologies for improving crop productivity but increases carbon emissions by 3-5 times (Arodudu et al., 2017), and accelerates groundwater pollution, as well as eutrophication of nearby fresh waters sources (WRI, n.d). Balbo Group applies an agro-ecological approach combining environment-friendly biotechnology (non-GMO pest and disease resistant varieties), as well as a circular process and production design that substitutes fossil energy sources (with bioenergy from recycling of vinasse by-products) and mineral inputs (via recovery and recycling of 20 tonnes of vinasse by-products from ethanol production as fertilizers annually, and cultivation of non-GMO pest and disease resistant crops produced via biotechnology). The adopted circular process and production design also reduces the intensity of machineries and the fossil energy used for powering them (mechanical and chemical energy reduction via use of low pressure tyres for harvesters to avoid harmful compaction). This does not only translate to cost reduction, but also enhancement of productivity and profit.

Background of the initiative: Balbo Group is a transgenerational business founded in 1903. It produces sugar and ethanol on mega industrial scale. It changed from its production model from the industrial agriculture model to the agro-ecological approach by adopting a circular process and production design. It's adoption of a circular process and production design was driven by company's ambition to attain long-term sustainability (in terms of reduction in carbon emission, input cost, productivity and profit maximization, energy and nutrient cycling efficiency, waste valorization and elimination) in production systems. Internal change in production system was borne by company and resulted in reduction in production cost. Innovation is process-based (involves on-farm nutrient recovery, recycling and substitution, as well as on-farm fossil fuel and input substitution and reduction) and business model based (involves change of business model from industrial agriculture model to agroecological model). Business model benefits from application of biotechnology (cultivation of non-GMO pest and disease resistant crops).

Impact and maturity of the initiative: The innovation is commercial on a global scale. Transgenerational farming businesses in Ireland could look to replicate this. Balbo group produces 75,000 tonnes of organic sugar (34% of the world market) and 55,000m^3 of organic ethanol annually. It trains employees, offer qualifications and the chance to take more highly skilled positions in the production programme. It uses sugarcane bagasse to generate enough energy to power 100% its own operations (processing 6 million tonnes of sugar cane to ethanol), as well as extra energy enough to supply a city of 476,000 inhabitants. It has experienced Improved land productivity (by 20%) from adoption of circular and regenerative agricultural process and production design (inspired by natural processes). Organic matter is returned to the land and environment (nutrient recovery and recycling) thereby enhancing soil health. Harmful chemical fertilisers is replaced by organic fertilisation (vinasse by products) while pesticides are switched for a natural pest and disease management system (pest/disease resistant crop varieties, as well as biological and cultural control methods).

Case Study 5: Biorefinery Glas - *Circularity driven by biotechnology upstream and biorefinery concept downstream*
Partner(s) involved: Publicly funded (by EU and the National Government) academia-industry collaboration between Institute of Technology, Tralee, Barryroe Co-operative, the Carbery Group, GRASSA B.V. and University College Dublin.
CE Strategies used: Reuse, recycling, nutrient recovery
Type of CE innovation: Product, process, system and business-model innovation
Region(s) its based in: Tralee, Kerry, Ireland
TRL: 6-7

What circular challenge / opportunity is the case study trying to address?
The agriculture sector accounts for 33% of Irish greenhouse gas emissions, livestock farming is responsible for 70% of Irish agriculture sector emissions, and cattle farming represents about 65% of global livestock emissions. In terms of activities, feed production and processing (this includes land use change) and enteric fermentation from ruminants are the two major sources of livestock emissions with 45% and 39% of total emissions respectively (FAO n.d.). Implementation of changes in feed production and processing value chain can be a major contributor to significant reduction of livestock emissions. Biorefinery Glas applies biotechnology in the feed production and processing value chain and biorefinery concept downstream the value chain (for exploration of the multifunctionality in the valorization of grass for animal feed, energy, fertilizer or cosmetic applications). It targets a 40% increase in usable protein per hectare via creating a fibre press-cake fodder which improves nitrogen to milk conversion efficiency in cattle, whilst creating a second protein concentrate feed product (from the juice) suitable for monogastrics (e.g. pigs) who would otherwise not be able to access and properly process grass proteins (hence providing new indigenous pig feed products). An expected benefit of this approach includes a reduction in nitrogen and phosphorous losses (by 25%) and manure related emissions from the dairy sector (via improvement of nitrogen use efficiency in dairy), whilst simultaneously reducing indirect GHG emissions through substitution of soybean imports for use in monogastric feed.

Background of the initiative: Biorefinery Glas is a publicly funded academia-industry collaboration. It is driven by the academia and the industry as a European Innovation Partnership (EIP) Operational Group and funded by DAFM under the Regional Development Programme 2014-2020. It is a first demonstration of small-scale, low-CAPEX, farmer-operable biorefinery model in Ireland. It is funded to support new business models and farmer diversification (including validation of the route to market) which is expected to make multiple local farmer's cooperative systems own the biorefinery concept in a farm-to-farm bioeconomy symbiosis, hence changing farmers' role from suppliers of biomass to producers of finished and semi-finished products. The business model involves growing grass varieties produced via biotechnology, extracting animal protein for cattle via the making of press cake fodder (nutrient recovery), and then reusing and recycling the juice as protein concentrate in new indigenous pig feed products or in bioenergy and fertilizers, or as feed and/or cosmetic ingredients. The innovation model is product-based, process-based (maximizes previous production processes for efficiency), system-based (changes the entire farmer's production system and value chain) and business model-based.

Impact and maturity of the initiative. Currently in an emergent state (TRL 6-7-after demonstration and prototyping ongoing). Biorefinery Glas has facilitated several bioeconomy knowledge exchange activities with Irish farmers in response to demand side need for awareness raising on the bioeconomy. Recent soybean imports for Ireland was 479, 287 t for 2018, 384, 847 t in 2019 and 415, 775t in 2020. Substitution of soybean import in animal feed production will reduce the cost and carbon emissions associated with livestock production nationally (when scaled up eventually).

Case Study 6: Woolcool, United Kingdom
Circular valorization of wool for displacement of plastic packaging
Website: Woolcool
Partner(s) involved: Government Innovation funds-Technology Strategy Board (TSB) now known as Innovate UK (UK equivalent of Enterprise Ireland); University Innovation/Incubation ecosystems-University of Cambridge, Bangor University, Leeds University; UK based B2B/value chain partners-Pharmaceutical companies-The Dental Directory, Henry Schein, Pharmacy2U; food companies-The Well Hung Meat Organic Company, Paleo Ridge, The Meatbox Company, Sauce It, Eversfield Organic, the Exmoor Game co.
CE Strategies used: Recycling, Reduction, Substitution
Type of CE innovation: Product and system innovation
Region(s) its based in: London, United Kingdom
TRL: 9

What circular challenge / opportunity is the case study trying to address?
In 2017 alone, the average sheep farm in Ireland emitted approximately 139.3 tonnes CO_2 equivalents of agricultural GHG (Teagasc, 2017). While sheep farming in Ireland has primarily focused on meat production, wool represents an important circular bioeconomy opportunity to sequester carbon and contribute to the agricultural sector's carbon reduction targets. In the Material Circularity Indicator by the Ellen MacArthur Foundation, wool gets the highest score possible (Ellen McArthur, 2021). Not only is wool renewable and biodegradable, but by acting as a short-term store of atmospheric CO_2, wool prevents the stored gas from contributing to climate change while it is in productive use (Woolmark, 2021). Woolpack is a circular innovation that makes use of the material characteristics of wool, while also converting waste sheep wool into to biodegradable insulating packaging materials used for chilled food and pharma packaging. At end of life, Woolpack's packaging can be used as plant mulch, animal bedding and for weaving art pieces.

Background of the initiative
Started in 2008. Benefited from three rounds of Government Innovation funds from Technology Strategy Board (TSB), now known as Innovate UK (UK equivalent of Enterprise Ireland) to develop a proof of concept and prototype for pharma packaging 'PharmaPack' in 2010/2011 and 2013 respectively; and for prototype development for 'Bio-PCM's' phase change materials concept in 2014/2015. Benefited from University Innovation/Incubation ecosystems (R&D from University of Cambridge, Bangor University, Leeds University). Woolcool converts waste sheep wool to biodegradable insulating packaging materials used for chilled food and pharma packaging. This done by washing totally felted sheep wool in natural process, scouring them and sealing them within recyclable industry grade micro-perforated polyethylene wrap (Woolcool, n.d.). The recycling of abundant waste sheep wool as biodegradable chilled food and pharma packaging substitutes. Woolcool's major customers are food and pharmaceutical industry in the United Kingdom. Woolcool's circular innovation is product-based (leading to the production of a new product) and system based (contributes to larger societal systemic change away from plastic use). Woolcool is working on applying reverse logistics to take back some of its product from customers after use to further drive circularity. There is huge market potential for valorization of abundant waste wool resources estimated between 3, 000-48, 000 tonnes based on Irish sheep population data from DAFM and wool generation data from Moyer, 2021.

Impact and maturity of the initiative - Circular valorization of wool waste by Woolcool is matured (TRL 9) and rewarded with market success with at least 19 B2B food and pharmaceutical company customers

2.2 Forestry

This section described case studies that focused on forestry production wastes (Sulapac) and forest product wastes (Cork-A-Tex).

Case Study 7: Sulapac Oy, Finland
Circular valorization of industrial forest waste stream for displacement of plastic packaging and items

Website: Sulapac Oy
Partner(s) involved: **Initial seed capital investors -**such as Lifeline Ventures (FI) and Ardent Venture BV (NL). **Scaling investors -** including Tekes (FI) and EASME - EU Executive Agency for SMEs (EU),Planvest Oy (FI), CHANEL (FR), Sky Ocean Ventures (UK)**B2B customers and value chain partners –** various Stora Enso (FI) for straw, CHANEL (FR) for bottle cap, Haeckels (UK), Korpikuusikon Hunaja (FI), BioAroma (GK)and Ekopharma (FI) for cosmetic and personal care items packaging, Al Bayader (UAE) and Fazer (FI) for food packaging, Vida Kuulas (FI) for food supplement packaging, Unisto for Winterhilfe Schweiz (CH) for gift donation packaging .
CE Strategies used: Recycling, reduction and substitution
Type of CE innovation: Product and process innovation
Region(s) its based in: Helsinki, Finland
TRL: 9

What circular challenge / opportunity is the case study trying to address?
Ireland produced 1,124,917 tonnes of packaging waste across all materials in 2019. 319,082 tonnes of this amount was plastic packaging waste and only 28% was recycled(EPA 2021). Circular bioeconomy solutions like Sulapac Oy are attempting to tackle this circular challenge, by valorizing industrial forest wood side streams as a means to displace plastic packaging and items littering our oceans. It does this via the making of food, cosmetics and personal care items packaging, as well as items such as straw and clothing hangers.

Background of the initiative
Founded in 2016. Received initial seed capital of 1M Euros from rich individuals, angels and venture capitalists, and scaling investors funding from venture capitalists, EU Executive Agency for SMEs (EASME) and other business partners (e.g. Planvest Oy and CHANEL). Business model recycles industrial forest waste streams for reduction and substitution of plastic packaging. The innovation is product-based (leads to proodcution of new products) and process-based (enhances forest resource management processes via better utilization of industrial waste streams). It has huge market potential spanning across different Huge market potential for circular valorization of industrial forest waste streams (for reduction and substitution of plastic packaging and items littering our oceans).

Impact and maturity of the initiative
Circular valorization of industrial forest waste streams by Sulapac is very matured (TRL 9) and a success story. Sulapac has acquired a large B2B market base over its six years of existence. Benefits from both economies of scale and economies of scope as Its market cut across different product categories from straw production (Stora Enso-FI) to bottle cap production (CHANEL-FR) to cosmetic and personal care items packaging (Haeckels-UK, BioAroma-GK), to food packaging (Fazer), to food supplement packaging (Vida Kuulas-FI) to gift donation packaging (Unisto for Winterhilfe Schweiz-CH). Sulapac's market penetration has expanded beyond Europe into the Middle East (Al Bayader-UAE).

Case Study 8: Cork-A-Tex
Valorizing forest product waste (cork-based waste) for making textile fibres
Website: Cork-A-Tex
Partner(s) involved: Benefited from initial funding and co-promotion from the EU and the Portuguese government (European Regional Development Fund). Demonstrator projected benefited from industrial symbiosis and multi-sectoral collaborations between Portuguese cork-making company (Sedacor), textile company (Têxteis Penedo), research centre (Technological Center for Textiles and Clothing-CITEVE) and the University Innovation/Incubation system (Faculty of Engineering of the University of Porto-FUEP).
CE Strategies used: Waste recycling and reduction, and Substitution
Type of CE innovation: Product and process innovation
Region(s) its based in: Guimarães, Portugal
TRL: 6-8

What circular challenge / opportunity is the case study trying to address?
Synthetic fibres (mostly derived from fossil petrochemical sources) accounts for 62% of all fibres produced globally (about 68 million tonnes annually). Polyester is the most widely used fibre and China is its major producer (Common Objective, 2021). Sustainable synthetic fibres derive from recycled fibres and natural sources. Just 0.07% of overall synthetic fibre production is sustainable and an even smaller amount is used in apparel. The greenhouse gas emission associated with petro-based synthetic fibres is enormous hence the need for substitution with those from renewable natural and recycled sources. Cork-A-Tex responds to this need with the valorization (recycling) of cork based waste (stopper etc.) for making textile fibres.

Background of the initiative.
Initiated in 2016. Benefited from initial funding and co-promotion from the EU and the Portuguese government (European Regional Development Fund). Demonstrator project benefited from industrial symbiosis and multi-sectoral collaborations between Portuguese cork-making company (Sedacor), textile company (Têxteis Penedo), research centre (Technological Center for Textiles and Clothing-CITEVE) and the University Innovation/Incubation system (Faculty of Engineering of the University of Porto-FUEP). Product is an innovative, high-performance yarn that simultaneously incorporates the properties of cotton and other sustainable textile material substrates (cork waste inclusive) at the level of comfort, breathability, touch, appearance and other functional benefits of cork (i.e. natural, comfortable and warm feeling, hypoallergenic with high friction resistance and good resilience). Business model involves the recycling of cork wastes (e.g. stopper etc.) for reduction and substitution of synthetic, non-renewable textile fibre with no circular value. This innovation is product-based (new product is developed), and process-based (yarn production process is innovative)

Impact and maturity of the initiative
Innovation is emergent but near maturity (TRL 7-9) as demonstration has been completed and textile companies are beginning to adopt the new technology. Cork-A-Tex already has couple of awards to its credit including INOVATÊXTIL 2015 prize (product of the year category), selection as finalist for the Future Materials Award 2015 (Sustainability Category) and selection as finalist for the iTechStyle Awards 2019, (the product category). The substitution effects of Cork-A-Tex's innovative textile material from recycled cork can save the earth at least 1.2 kg CO_2 per kg of synthetic fibre fabric replacement (Drew & Yehounne, 2017), hence massive on a global scale (with 68 millon tonnes of synthetic fibre prodced annually).

2.3 Marine

This section described case studies that focused on marine vegetation/plant (**Evoware)** and marine animal food wastes **(Tidal Vision and Leigh Fibers partnership, The Shellworks and Nutramara)**.

Case Study 9: Evoware - *Social enterprise valorizing seaweeds as packaging materials for displacing plastics*
Website: Evoware
Partner(s) involved: DBS-NUS Social Venture Challenge Asia- An Asia-wide competition for social enterprises organized jointly by NUS Enterprise-the entrepreneurial arm of the National University of Singapore and DBS Foundation
CE Strategies used: Waste reduction and elimination, Substitution
Type of CE innovation: Product, process, service and system innovation
Region(s) its based in: Jakarta, Indonesia
TRL: 6-8

What circular challenge / opportunity is the case study trying to address? Over 300 million tonnes of plastic are produced every year for use in a wide variety of applications. At least 14 million tons of plastic end up in the ocean every year, and plastic makes up 80% of all marine debris found from surface waters to deep-sea sediments (IUCN, 2021). Marine species ingest or are entangled by plastic debris, which causes severe injuries and death. Plastic pollution threatens food safety and quality, human health, coastal tourism, and contributes to climate change. In response to this, Evo & Co. designed a circular product i.e. biodegradable and compostable sachet or packaging materials (Evoware) from seaweeds (an invasive species) to displace single use plastics, hence contributing to the slowdown of marine plastic pollution, while also improving the livelihood of seaweed farmers.

Background of the initiative
Founded as a social enterprise by Evo & Co in 2016. Evo & Co. promotes sustainability by providing plastic-free alternatives using seaweed, while at the same time improving the livelihood of seaweed farmers in Indonesia. Evo & Co benefits from economies of scope by also using other biobased materials. This includes bamboo (handmade and reusable straws and cutleries), rice and tapioca (biodegradable, compostable and edible straw), paper (straw), birch wood (biodegradable, compostable and disposable wooden cutleries), starch, vegetable oil and other non-toxic materials (shopping bags) and sugarcane bagasse (food container). Evo & co benefited from Social Venture Funding Scheme (DBS-NUS Social Venture Challenge Asia- An Asia-wide competition for social enterprises organized jointly by NUS Enterprise-the entrepreneurial arm of the National University of Singapore and DBS Foundation). Evoware sachet is a product of circular product design and the innovation can be described as product-based (product development is innovative), process-based (applies new resources in the production process i.e. from fossil based to biobased resources), service-based (rendered as stewardship to the planet, as well as a service to the community, hence improving the livelihood of seaweed farmers), and system-based (a transformation of consumption, hence halting the rate of marine plastic pollution in the oceans). It is replicable within Ireland and the potential is expected to be huge in the emerging blue economy. Evo & Co is evidence that social venture funding scheme and social enterprise (with additional societal goals aside business e.g. eradicating hunger and poverty, improving livelihood etc.) could still play a role in kick-starting circular economy businesses.

Impact and maturity of the initiative
Emergent business in the process of scaling up (TRL 6-8). Community education, involvement, inclusion and livelihood improvement rank high in its priority as a social enterprise, and this has been achieved. In recognition of its product (Evoware), Evo & Co. was a winner of the Ellen MacArthur's Circular Design Challenge. Similar seaweed-based innovation for displacement of single use plastics includes Loliware Straw (US) and Skipping Rocks Lab (UK).

Case Study 10: Tidal Vision-Leigh Fibers partnership
Industrial symbiosis for crab waste valorization

Website: **Tidal Vision-Leigh Fibers Partnership**
Partner(s) involved: Tidal Vision benefits from industrial symbiosis partnership with Leigh Fibers. Tidal Vision shares facility with Leigh Fibers. Crab waste is converted into textile fabrics primarily used in the automotive industry, bedding, caskets and furniture. Business relies on a B2B model and plans to scale based on that.
CE Strategies used: Recycling, Reduction, Substitution and waste prevention
Type of CE innovation: Product and process innovation
Region(s) its based in: Wellford, South Carolina, United States
TRL: 7-8

What circular challenge / opportunity is the case study trying to address?65% of globally produced textile fibres are of fossil origin. Their production and end of life stages (usually energy recovery) are carbon emission intensive. Disposal without energy recovery may also contribute to marine pollution. To ensure long-term sustainability of the global textile industry, there needs to be a dramatic shift from the use of fossil-based textiles to those from renewable (biodegradable and/or compostable) or recycled sources. In response to this, Tidal Vision, in collaboration with Leigh Fibers have valorized chitosan (a fibrous fibre in crab waste) for making textile fabrics usable in automotive industry, bedding, caskets and furniture. Chitosan offers fabrics antimicrobial surface property that is also fire retardant and non-allergenic. Chitosan based fabrics avoid washing out of materials (e.g. heavy metals such as silver or copper) and pollution of waterways associated with fabrics for hospital uniforms and beddings. This is particularly replicable within the context of the emerging Irish blue economy because of the availability of relatively unexploited seafood wastes (containing chitosan) from marine catches within the growing Irish seafood sector.

Background of the initiative
Industry-led industrial symbiosis partnership between Tidal Vision (a chitosan producer with manufacturing footprints in the water treatment, agriculture and textiles industry) and Leigh Fibers (a textile manufacturer). Tidal Vision shares facility with Leigh Fibers where they convert crab wastes (from sustainably managed Alaskan fisheries) into fabrics primarily used in the automotive industry, bedding, caskets and furniture. Business relies on a B2B model and plans to scale on the same. Recycles crab waste, thereby reducing and/or preventing wastes, as well as substituting fossil-based textile fibres. Innovation is product-based (leads to the manufacturing of new products) and process-based (applies new resources in the production process).

Impact and maturity of the initiative
Emergent innovation (TRL 7-8), ready to scale. New innovation will expand the value chain as well as the market of both companies in partnership (i.e. Leigh Fibers now has a new product line to sell to their customers, while Tidal Vision provides the valorization technology). The vaporization technology scales based on the ready market previously built by Leigh Fibers. At least 1.2 kg CO_2 savings should be expected per kg of fossil-based fibre replaced.

Case Study 11: The Shellworks
Marine wastes for displacement of plastic packaging

Website: The Shellworks
Partner(s) involved: Benefited from University Innovation/Incubation ecosystem (mentorship from Imperial Venture Mentoring Services of the Imperial Enterprise Lab-IVMS) and the Climate-KIC Accelerator programme.
CE Strategies used: Recycling, Reduction, Substitution, Nutrient recovery
Type of CE innovation: Product, process and system innovation
Region(s) its based in: London, United Kingdom
TRL: 7-8

What circular challenge / opportunity is the case study trying to address?
Plastic waste is an existential threat to marine life and the economic activities that builds from it. More than 14 million plastics are dumped in the ocean annually across the globe. A major strategy for drastic reduction is the displacement of single use plastics. The Shellworks respond to this demand by utilizing seafood wastes (mostly lobster waste) for making biodegradable and compostable packaging materials. Ireland can leverage on its growing seafood industry and the availability of currently unused seafood wastes to facilitating the development of such innovations within an emerging blue economy.

Background of the initiative
The Shell works is a product of university innovation/incubation ecosystem. It has benefited from Climate-KIC Accelerator programme (co-funded by the EU). The business recycles marine wastes for making biodegradable and compostable packaging, hence reducing and/or displacing single use plastics. Products can also be composted, hence returning to nature. This innovation can be said to be product-based (a new product is developed), process-based (involves change of resources used in production process) and system based (leads to systemic change in consumption patterns).

Impact and maturity of the initiative
Currently emergent (TRL 7-8) with commercialization plans on-going. Innovation has already been demonstrated and few scalable products have been manufactured and tested.

Case Study 12: Nutramara
Extraction of bioactives from marine discard (fish wastes, seaweeds and algae)

Website: Nutramara
Partner(s) involved: Shannon Applied Biotechnology Centre
CE Strategies used: Bio-nutrient recovery and recycling
Type of CE innovation: Product, process and system innovation
Region(s) its based in: Tralee, Kerry, Ireland
TRL: 9

What circular challenge / opportunity is the case study trying to address?
The ocean is a valuable source of dietary nutrients for both livestock and humans. According to the Marine Institute, Ireland has ten times more marine area than land (Marine Institute, n.d.). Despite this, Ireland is yet to tap into the full potential of its marine resources within the context of the development of a blue economy. Nutramara is one of the early movers in this space with its use of marine discard (fish wastes, seaweeds and algae) for manufacture of bioactives (e.g. fucoidan) in animal feed, human dietary supplements and cosmetics.

Background of the initiative
Founded in 2016. Nutramara had key operational expertise in seaweed and extraction, but they did not have any laboratory facilities or technical staff to validate and optimise their method for extraction of fucoidan from seaweed. Nutramara's technological validation and commercialization processes were accelerated by their partnership with Shannon Applied Biotechnology Centre (an enterprise Ireland funded Technology Gateway). Nutramara applies biotechnology upstream and plans to apply biorefinery concept downstream for optimization of marine discard resources accessible. Business model is based on bio-nutrient recovery from marine discards. Recovered bio-nutrients are recycled for manufacturing of bioactives. First for higher value applications like human dietary supplements, and later for other applications such as use in animal feed and cosmetic (when biorefinery concept is eventually introduced into the business model). This innovation is product-based (i.e. led to the development of a new product), process-based (utilizes new production processes owned by the national technology gateway) and system-based (changes the way the system's perception of marine discard resources).

Impact and maturity of the initiative
Innovation is matured (TRL 9). Nutramara's first product launch was in 2018. Product launched provides carbohydrate aids digestion, slows down metabolism and assist weight loss, boosts immune system, fight viral infections, lowers inflammation (swelling), has anti-ageing effects, works as an anti-oxidant in the body, prevent blood clots and reduces high blood pressure. Blue economy-based start-ups and other start-ups can partner with national technology gateways (e.g. enterprise Ireland funded Shannon Applied Biotechnology Centre) and national innovation partners (e.g. Irish Manufacturing Research) for acceleration of their commercialization processes.

2.4 Fresh Water

Case Study 13: Swedish Algae factory, Sweden - Biotechnology and biorefinery concept as main drivers for circular waste valorization and elimination
Website: Swedish Algae Factory
Partner(s) involved: *Chalmers School of Entrepreneurship, University of Gothenburg, Preem, Vinnova (Sweden's Innovation Agency) and Imperial College London.*
CE Strategies used: Water recovery, reuse and recycling; Nutrient production, recovery and recycling; Substitution, Waste prevention,
Type of CE innovation: Product, process, business model, service and system innovation
Region(s) it's based in: Gothenburg, Sweden
TRL: 6-8

What circular challenge / opportunity is the case study trying to address?
Wastewater treatment costs a lot and constitute an extra burden borne individually by all companies engaged in industrial production of tangibles. It is however important because the flow untreated industrial wastewater through a hydrological basin can pollute the groundwater, as well as fresh and marine water, hence causing eutrophication within the basin/area. Consequently, there is need to take responsibility for it but not at the expense of huge investment burdens. In response to this, Swedish Algae Factory is experimenting with partnership models that enable them grow algae in wastewater at low-cost and purify water for reuse and recycling. This prevents harmful emissions of nitrogen and phosphorus into our groundwater tables, rivers, lakes, seas and oceans. The grown algae traps eight times its weight in CO2 (Swedish Alage Factory, n.d.), one times its weight in nitrogen and one tenth-times its weight in phosphorous. This organic biomass can then be used in fish feed or fertilizer or for production of biocrude (for manufacture of biodiesel), and phosphorus-rich biochar (for recycling of phosphorous). The silica shell surrounding the algae are non-amorphous (insulating and antireflecting), nanoporous material usable in solar cells and batteries OR as multifunctional skincare ingredient. Wastewater is previously not perceived as a resource for valorization (value chain creation, provision of job etc). Swedish Algae Factory has set out to valorize wastewater and/or at least reduce the cost burden of its treatment on the source company.

Background of the initiative. A project conceived by two students from Chalmers School of Entrepreneurship (CSE), together with researchers from the University of Gothenburg and its Department of Marine Biology in 2012 when algae was discovered on polar ice indicating that algae could grow at such low temperature and radiation conditions. It was initially a product of University Innovation/Incubation ecosystems. Swedish Algae Factory partnered with fish farms for wastewater and space for algae cultivation. R&D collaboration with Preem, Sweden's largest fuel company was established in 2014, but discontinued later. The R&D collaboration was supported by Vinnova (Sweden's Innovation Agency) and Imperial College London (Vinnova is co-funded by the EU). This innovation has huge resource conservation and valorization potential. It takes advantage of biotechnology and biorefinery concept for circularity. Innovation is product based (produces new product), process-based (applies new production processes-biotechnology and biorefinery concept), business model-based (Swedish Algae Factory is working out its own profitable business model) for profitability, service-based (provides wastewater treatment services for industry) and system based (changes the outlook and perceptions on wastewater). Implementing Swedish Alage factory's wastewater valorization in an Irish context can benefit from University Innovation/Incubation ecosystem (at an initial stage) and industrial symbiosis (e.g. partnership with fish farms and other sites with rich nutrient wastes for establishment of algae cultivation sites).

Impact and maturity of the initiative. Emergent innovation (TRL 6-8) that needs multiple spaces with wastewater sources for expansion and growth. It is expected to save the cost of water treatment and improve the profitability of companies who volunteer to share space and provide wastewater for production.

Section 3 – Insights into increasing circularity in Ireland's Agriculture & Biobased Industries.

The examples case studied for this Guide range in maturity and technological readiness level from early-stage pilots (with Technology Readiness Levels 6 or 7), such as the Herfra-Refarmed and Swedish Alage Factory, or more mature, market ready circular bioeconomy innovations and products, such as Sulapac and Woolcool.

This range in technology readiness levels from TRL 6-9 implies that all of the cases profiled in this Guide have successfully achieved proof of concept for their innovations. Some are ready for the market while some already have their product or innovation launched in the market and have already successfully commercialised.

The international case studies included in this Guide have been purposefully selected around clusters and subsectors recognised as having good replication or adaptation potential in the Irish context (either through research-industry research collaborations, or directly by industry players looking to start new ventures or diversify into the circular economy).

3.1 Key lessons for Ireland's Agriculture and Bio-based industries

Despite evident distinctions between the case studies, the case studies profiled in this Guide exhibit a number of cross-cutting insights and features about initiating and scaling circular agriculture and bio-based innovations that is applicable to Irish entrepreneurs and industry players, these are discussed next.

3.1.1 Importance of value chain cooperation and experimentation

Many case studies in this sectoral guide benefited from industrial symbiosis and value chain partnerships (Nutramara and Shannon Applied Biotechnology Centre, Tidal vision and Leigh Fibers) and multi-sectoral collaborations (e.g. Nuritas, Sulapac, Cork-A-Tex etc.). Many of the case studies also rely on B2B model, especially at the early stages of development (Woolcool, Sulapac etc.). In industrial symbiosis partnerships and multi-sectoral collaborations, some share knowledge (e.g. Nuritas and Nestle), some share facility and resources i.e. value chain cooperation delivery (e.g. Tidal Vision and Leigh Fibers), while some help accelerate commercialization (e.g. Nutramara and Shannon Applied Biotechnology Centre). Overall, analysis of the case studies profiled suggest the circular bioeconomy market in Europe in agriculture and bio-based industries is still in a development phase in which carrying out innovation pilots, and enterprise-driven research and development – often in collaboration with research performing organisation and value chain partners - is critical to ensuring the market's continued growth.

3.1.2 Enablers of circular agriculture and bio-based industry

Based on the selected case studies, some key enabling strategies for circular agriculture and bio-based industries include circular design (which could be product based- Evoware, process based-Balbo Group or production based-Herfa-Refarmed); application of biotechnology-Hexafly, Swedish Algae Factory and Nutritas; application of the biorefinery concept-Biorefinery Glas and Hexafly; the application of technology-enabled innovations like Nutritas' AI-powered solution; the change of business model for profitability and shared prosperity (Biorefinery Glas' farmers diversification from suppliers of biomass to producers of value added products), setting up bioeconomy knowledge network for education and awareness creation (Biorefinery Glas' knowledge sharing network for piloting transition towards bioeconomy) and the use of reverse logistics to take back some products for recycling thereby reduce virgin material use (Woolcool) . The fact that some of the examples are from Ireland is an indication of the considerable maturity that circular agriculture and biobased sectors have already attained in Ireland in some subsectors like Agri-food waste valorization (e.g. Hexafly, Nuritas). An increase in application of such enabling strategies is important for circularising the Agriculture and Bio-based industries even more.

3.1.3 Funding Enterprise-led Agriculture and Bio-Based Circular Innovations

The non-European case studies profiled in this sectoral guide were either product of change in company model funded by the company (Balbo Group), industrial symbiosis and value chain partnerships (Tidal vision and Leigh Fibers), or social venture funding (Evoware). Social venture funding for social enterprise is increasingly becoming common in developing countries especially. Irish start-ups can benefit from social enterprise models already applied elsewhere in Europe, especially in the food and drink sector (e.g. Nutripeople, Ekofungi, etc.) through supports, such as Rethink Ireland's Green Transition Funds (Rethink Ireland, 2021), or Challenge Prizes such as the European Social Innovation Competition (EUSIC, 2021).

Meanwhile, virtually all European case studies profiled in this sectoral guide are products of a mix of funding sources. Some received seed capital from EU funded university incubation/innovation ecosystems partnerships (e.g. Climate KIC Accelerator Programme -Hexafly, The Shellworks; European Regional Development Fund-Cork-A-Tex, the agricultural European Innovation Partnership - Biorefinery Glas); while others received seed capital and R&D funds from EU and National Government backed innovation funds (e.g. BPI France, Enterprise Ireland, EU Horizon 2020 etc.), as well as financial backing from angel investors and venture capitalists. This implies that new ventures or established enterprises looking to move into this market should familiarise themselves with the range of funding, business supports and investment opportunities available through Local Enterprise Offices and Enterprise Ireland and others. By engaging with these agencies, entrepreneurs can access advice on deepening their organisation's circular innovation offering (e.g. via Innovation Vouchers) or assessing their investor readiness.

Other key grant and investment funding which can be used to finance circular bioeconomy initiatives include (as of 2021 are):

- Enterprise Ireland's €500 million Disruptive Technology Innovation Fund (Enterprise Ireland, 2021). The fund is geared towards mid to early-stage enterprise-driven research and development of technology-based disruptive innovations that can demonstrate commercial impacts within 3 to 7 years of project completion.
- The European Circular Bioeconomy Fund is a dedicated investment fund, with a targeted fund size of €250 million, investing in the Circular and Bio-Based Industries in Europe to help accelerate late-stage circular bioeconomy innovation (ECBF, 2022).

3.1.4 Overcoming scaling and commercialisation challenges

To overcome challenges when scaling up, several of the companies profiled have employed a range of strategies. Nutramara collaborated with national innovation partner (Shannon Applied Biotechnology Centre) for technology validation and commercialization. Pre-registration as a limited company, Nutramara was originally conceived of as a cross-agency and cross-university applied research group that brought together marine bioresources and bioscience expertise, with food science and technology expertise from different universities (University College Cork; University College Dublin; the National University of Ireland Galway; the University of Limerick and Ulster University). It commenced in 2008 and was supported by €5.2 million from the Marine Institute and the Department of Agriculture, Food and the Marine. The research programme was led by Teagasc as the head of a multi-institutional consortium.

The research-intensive requirements of many circular solutions in the sector means that universities and Research Performing Organisations have an important role to play in incubating and consequently spinning out early-stage circular bioeconomy innovations. Other examples of case studies profiled here have directly benefited from participating in incubation and accelerator programmes. Swedish Algae Factory, for example, is deemed one of the success stories of Climate-KICs Nordic Accelerator (Climate-KIC, 2020). Accelerator programmes, such as Climate-KIC's, are place-and theme-based, and are specifically focused on supporting start-ups to refine their USP and business model, finalise a first prototype and/or obtain industry feedback; to validate their idea, and to commercialise their idea by gaining access to new markets (Climate-KIC, 2018).

Meanwhile, effective industry-research collaborations can also be brokered with national innovation partners (e.g. Irish Manufacturing Research – and CIRCULÉIRE, Irish Bioeconomy Foundation etc.) by established companies too. A range of grants, regional and local incentive schemes, as well European R&I Programmes and investment funds can be used to facilitate development and scaling at different stages of the innovation lifecycle too.

Examples of incubators / accelerators which can be used to develop and scale circular bioeconomy initiatives are as follows:

- Accelerate Green is the first **equity-free scaling accelerator** in Ireland dedicated to scaling companies leading the response to climate action and sustainability by developing products and services based on green innovation (Accelerate Green, 2021).
- Green start funding support can be applied for by start-up companies towards the cost of hiring a Green consultant/trainer to undertake a short in-company assignment such as guidance on basic Environmental Management System based on 'Plan, Do, Check, Act' continuous improvement philosophy, guidance on developing a corporate sustainable strategy and aligning to national/international frameworks e.g. Origin Green, UN Environmental SDGs, CDP, guidance on Life Cycle Assessment, as well as guidance on Circular Economy thinking and transition to circular economy business models

3.2 Circular Opportunities for Agriculture & Bio-based Industries

Numerous circular opportunities abound within the Irish agriculture and biobased sectors. This section outlines 4 key opportunities to growing Ireland's circular bioeconomy in the agriculture, forestry, freshwater, marine sectors specifically.

3.2.1 Realising the circular potential of subsectors of Ireland's agriculture and bio-based industries

While acknowledging that this Guide is by no means a comprehensive review of Ireland's agriculture and bio-based sectors, the inclusion of several of the case studies in this Guide, such as AgriChemWhey, Biorefinery Glas and Nutritas, highlights how circular bioeconomy has been well exploited and developed in subsectors, such as agri-food waste and agri-farming. The agriculture sector presents sufficient volumes of crop and animal-based wastes that can be valorized. While these are already being widely explored in Ireland there is potential to further deepen their circularity via the use of enablers such as circular innovations (which could be product, process or production based), and technology (mostly biotechnology, biorefinery, etc.), and business model innovations, especially for the creation of new value chains and to support commercialisation. Several of the case studies illustrate the important technology will play as an enabler that drives circular innovations in the agriculture and bio-based sectors. As has been noted by the Department of Enterprise, Trade and Employment[1]:

> *"the enhancement of the productivity of agricultural systems, including emerging technologies such as biotechnology, precision farming, and eco-agriculture will be required in order to meet growing demand from agricultural systems without drastically increasing their environmental footprint" (DETE, 2019).*

Biorefining high value products from biomass, such as biochemicals and biomaterials, is also recognised as supporting the development of new high productivity activities within these sectors. The integration of circular economy technologies are expected to play a role in the overall prediction that Europe could grow resource productivity through circular economy practices by up to 3 percent annually, thereby generating a primary-resource benefit of as much as €0.6 trillion per year by 2030 (IDS, 2017).

3.2.2 Sheep's wool – an underexploited circular material

While sheep farming in Ireland has primarily focused on meat production, wool represents an important circular bioeconomy opportunity to sequester carbon and contribute to the agricultural sector's carbon reduction targets. In the Material Circularity Indicator by the Ellen MacArthur Foundation, wool gets the highest score possible (Ellen McArthur, 2021). Not only is wool renewable and biodegradable, but by acting as a short-term store of atmospheric CO2, wool prevents the stored gas from contributing to climate change while it is in productive use (Woolmark, 2021).

Examples of established circular innovations like Woolcool demonstrate the potential of wool to be used for viable circular bioeconomy products and solutions, valorising a material that goes to waste annually within the Irish economy. This represents a missed opportunity to sequester agricultural GHG emissions. Each kilo of cleaned wool, for example, equates to 1.8kg of CO_2e (Woolmark, 2021).

This wasted wool can be put to more productive use if the EU classification of wool from dead or slaughtered animals as a Category 3 waste prohibiting its use even as nutrients is reworked, provided health and safety concerns are not jettisoned (ICSA, 2021). This along with a hollowing out of wool processing facilities on the island of Ireland constitutes a major obstacle to the circular use of sheep wool waste in Ireland. The sheep wool sector has recently elicited interest from sectoral stakeholders and policy makers alike. Agile Executive Consortium was commissioned in 2019 by the DAFM to review the state of the industry in Ireland, develop a roadmap and shape future policies. Their report is expected first quarter of 2022.

3.2.3 Seizing the circular potential of Ireland's forests and timber industries

The forestry bioeconomy sector in Ireland has significant untapped circular opportunities that are yet to be exploited. Ireland imports most, if not all of its hardwood because most of its tree stocks are conifers (i.e. softwood). Conifers are mostly suited for applications in the pharmaceutical, paper and pulp industries. They have lesser application in more material and energy-intensive building, construction and furniture industries. Against this background, industrial forest waste streams from softwood logging and processing, as well as forest wood products (mostly imported hardwood products) are expected to be the main forest-based resources available for circular use, re-appropriation and valorization in Ireland.

Examples of circularity in the forestry sector in Europe has been reported earlier in the case study section (i.e. Sulapac Oy for industrial forest waste stream and Cork-A-Tex for valorization of forest wood product in the textile industry). The applications of circular designs (product, process or production based) and technologies (biotechnology, biorefinery, ICT etc.) as enablers of circularity and for development of new value chains in the forestry sector should be also expected for the forestry bioeconomy sector. Enterprise Ireland's Regional Technology Cluster Fund (RTCF) is currently coordinating activities to foster cross industry

collaborations, innovation and R&D activities, business development, talent and skills development, as well as identify funding opportunities around the forestry bioeconomy sector. This is expected to extend to forest-based circular bioeconomy activities going forward. Meanwhile, the significance of timber-based construction materials, such as Cross Laminated Timber and novel materials produced from salvaged rather virgin timber (InFutuREWood, 2021), being promoted as a sustainable, low-carbon construction materials in key national documents such as the Climate Action Plan 2021-2022 suggests that the national market for circular timber products is highly likely to grow as Ireland doubles down on its climate targets.

3.2.4 Seizing the circular potential of Ireland's blue and freshwater economy

While consecutive programmes and initiatives have looked to stimulate and grow Ireland's blue and freshwater economy, there remains significant opportunities to fully seize its circular potential. Here circular economy strategies and principles present key opportunities to transform our Blue and Freshwater Economy value chains, moving away from linear business models towards circular, less resource- and waste-intensive ones (EC, 2021a). According to European Commission, the Irish Blue Economy (established sectors) employs around 69,594 people and generates over €3 billion in GVA. Interestingly, as of 2018, the share of blue jobs is now at its highest level for the period under analysis (i.e. 2009 – 2018), contributing 3.2% to all employment. In absolute terms, in 2018, blue jobs increased by 77.4% compared to 2009, against 10.7% for the national employment (EC, 2021b). Ireland's blue economy thus has considerable potential to drive the transition towards a labour market that supports a green and circular just transition for Ireland, should this cohort be supported with targeted training and reskilling supports based on need.

From a bio-resource perspective, Marine weeds and marine catch waste resources (mostly animal seafood wastes) are abundant within the Irish bioeconomy (due to the Ireland's expansive seabed territories and growing seafood industry). While examples like Nutramara, Evoware, The Shellworks and Tidal Vision-Leigh Fibers partnership demonstrate the potential to create viable circular bioeconomy solutions in marine industries, there remains enormous, untapped circular potential to use marine weeds and marine catch wastes for making packaging materials, food supplements and other pharmaceuticals, as well as for manufacturing textile fibres and interior wares within the Irish bioeconomy. The freshwater sector also generates lots of resources that can be valorized in a more circular manner. Wastewater from numerous freshwater and freshwater waste sources remain a relatively undervalued resource that can be further valorized via the application of technology as described in the Swedish Algae Factory case study (where biotechnology and biorefinery concepts were applied). Much more can be achieved, such as for wastewater treatment, with the application of appropriate technologies.

3.3 Regional Examples of Circular Agriculture Supports

Elsewhere, regional, and national Governments are playing a key role in creating enabling conditions for circular innovation in the agricultural and bio-based industries. Key examples include 1) **Regional Government of Navarre, Spain**; 2) **Regional Government of Bavaria** and 3) **Flanders.**

1. Navarre (ES)

The Regional Government of Navarre, Spain, adopted several measures aimed at advancing the region's circular bioeconomy as part of its Circular Sustainability Strategy. Navarre's circular agriculture and biobased sector's future is anchored on its Navarra VISION 2030, which defines a set of scenarios where the agri-food sector will be highly competitive and specialized. In this future context climate change and resources management (i.e. use of fertilizers, pesticides, raw materials, food waste use) are identified as challenges for the regional development. The action plans listed for achieving this include promoting entrepreneurship, less regulatory burden, access to finance and access to market and internationalization. Also, important to note are the key factors that have been instrumental to the development and implementation of the regional strategy for circular agriculture and biobased sectors in the Navarre case study region are:

- **Building on the existing-existent sectoral and infrastructural framework** Circular bioeconomy growth in the Navarre case study was a product of fast-evolving and advancing primary bio-based industries, as well as the availability of research and testing facilities.

- **Financial instrument-creating new ones and taking advantage of existing ones.** Availability of financial instrument from existing sources and creation of new ones was key to Navarre's bioeconomy growth. Financial instruments are a tool starting up, expanding, commercializing and marketing circular bioeconomy products. The Navarre case study benefited from taxation through the new Regional Law on Waste (Regional Law 14/2018 of 18 June on waste and its taxation); community and international funding schemes e.g. ERA-NET COFUND MANUNET3; trans-regional cooperation programmes with local partner organizations; government innovation funding calls for financing R&D projects in companies; as well as Public support under the Rural Development Programme.

2. Bavaria

The Regional Government of Bavaria published a policy document "Future.Bioeconomy. Bavaria". The action plan listed as lever to drive the Bavarian Bioeconomy include: (i) Integration of citizens and provision of education about the benefits of the bioeconomy, e.g. by establishing targeted educational offers and fostering an intensive public discourse; (ii) initiation of necessary changes for the amendment of laws and ordinances by policy makers and administration; (iii) take on a role model function with respect to usage and consideration for climate and environmentally friendly products via public circular procurement; (iv) strengthening and offering business and industry opportunities to agriculture and forestry (as producers of renewable resources) to become a driver of innovation within the bioeconomy; (v) funding science and research as the basis for new insights and science-based bioeconomy; (vi) ensuring interdisciplinary cooperation and improved communication to promote the transfer of new insights for practical application. Key factors that have been important for the development and implementation of the regional strategy for circular agriculture and biobased sectors in the Bavaria case study region are:

- **Building on the existing-previous research and policy activities -** The strategy development process of the Bavaria case study was a product of 4-years activities including previous review of the status quo of the Bavarian Bioeconomy and past recommendations.
- **Stakeholder consultation process -** Strategy development was facilitated by exhaustive participatory process involving all relevant actors (the Bavarian Bioeconomy Council, the Interministerial Working Group on Renewable Resources and Bioeconomy, the clusters and representatives from agriculture and forestry, business, science and society). A Bavarian Bioeconomy was always the ambition of the Bavarian Bioeconomy Council, but the process started because of the strong top-down political support and high-level decision made by the state minister. The sense of urgency attached to this high-level decision drove the process to a completion over a very short one-year period of time. Strategy development process (workshops and events) was spearheaded by a national innovation partner (Bayern Innovativ). Even though the timeframe was tight, Bavaria succeeded in building a stakeholder dialogue and delivering the strategy (despite Covid-19 pandemic limitations).

3. Flanders

Flanders circular agriculture and biobased sector strategy is hinged on its Vision 2050: a long-term strategy for Flanders programme. The action plan of the programme include building partnerships for co-creation and shared ownership; providing tailored (financial) support for pioneers and pragmatic go-getters; encouraging knowledge sharing and targeted policy-relevant research assignments; making directive and supportive policies that brings alignment between administrations; fostering and accelerating innovation and entrepreneurship towards the circular economy by purposively committing the right tools; and upscaling and embedding principles and best practices in the area of the circular economy. The following key factors has helped the development and implementation of the regional strategy for circular agriculture and biobased sectors in the Flanders case study region:

- **Building from existing-strategic evolution from specific priorities to larger circular bioeconomy strategy.** Pushing to advance its circular bio-based industries (in particular biotechnology, agri-food, and chemistry) helped the Flemish region (I.e. Flanders) to position itself as a strong circular bioeconomy region.
- **Systematic (incremental) stakeholder engagement.** Even though from a governance point of view, top-down political support was crucial to making circular bioeconomy a priority in the Flanders region, the government did not act alone. Strategic collaboration among different government departments was embedded in the strategy. The range of actors brought together in the stakeholder's engagement were made as broad as possible even though engaging them all at once was very tricky. In the Flanders case study, a pragmatic approach was adopted to ensure ongoing active engagement of key stakeholders. The engagement of stakeholders and other policy departments started small on the basis of concrete grounds for collaborations. Gradually, as more and more concrete actions were being developed, additional stakeholders were brought in. This contrasted with the Bavarian example where everyone was welcomed at every event and workshop even though it was well managed by the National Innovation partner (Bayern Innovativ). The Bavarian case study also provides a broader forum at a time, thereby allowing for stirring debates and reaching conclusions on strategies and policies.

3.4 Overcoming Key Gaps/Barriers in Practice & Policy

The major gaps and barriers relevant for the development of the circular agriculture and biobased sectors within the Irish bioeconomy were taken from the two major policy documents on the Irish bioeconomy (Government of Ireland, 2018, Bioeconomy Implementation Group, 2019). This includes:

3.4.1 Lack of coherent framework for further stimulation of circular agriculture and biobased sectors There is relative imbalance between supply side and demand side measures, hence the need for alignment of activities between sectors, stakeholders/actors, networks, technologies, policies and practices leading to the growth of circular agriculture and biobased sectors. Examples of supply side measures include legal Intellectual Property Right (IPR) frameworks, international agreements, and economic incentives for bio-based industries etc.; while demand side measures include awareness raising, economic incentives for consumers, specific consumption taxes or subsidies etc.

3.4.2 Less start-up capital and expansion funding opportunities
As a result of low rural income and stagnant rural economies, people actively engaged by agriculture (i.e. farmers and farm workers) and biobased sectors such as forestry (forest managers and owners), fresh and marine water (fishermen etc.) earn low wages and profits from their employment, hence cannot take advantage of emerging circular agriculture and biobased opportunities. Start-up capital tend to go to other seemingly more formidable sectors, hence the social and economic dimensions of circular agriculture and biobased sectors (e.g. farmer's income, fair salary, working conditions etc.) are inadequately addressed.

3.4.3 Subsisting waste classification systems and handling procedures
Classification of certain wastes and legislated or regulated handling procedures hamper circular flow of resources that have the potential to generate significant value e.g. EU classification of wool from dead or slaughtered animals as a Category 3 waste prohibiting its use even as nutrients, Article 27 for by-product notification, Article 28 for end of waste determination etc.

3.5 Key Recommendations

Critical actions already identified for overcoming the key gaps and barriers to the development of the circular agriculture and biobased sectors are also contained in the 2018 National Policy Statement for the Bioeconomy, and the 2019 Bioeconomy Implementation Group Progress Report. Based on the findings of the two policy documents, this section offers suggestions on the possible role of government, industry and other stakeholders in advancing circular bioeconomy within the Irish context:

3.5.1 Greater coherence between sectoral strategies which impact bioeconomy

Whilst this is already recognised as a required action as part of the National Circular Bioeconomy Plan, regional examples, such as Navarre, offer an interesting model to outline how circular bioeconomy has been mainstreamed in several strategic plans and initiatives, in particular in relation to sustainable development, climate action, smart specialisation strategy and circular economy. Periodic monitoring and strategy meeting between multiple stakeholders are held to ensure coherence of sectoral strategies and advancing circular bioeconomy innovations.

Within the Irish circular bioeconomy context, coherence of sectoral strategies is yet to be achieved. Circular bioeconomy is strong priority within several sectoral strategies and policy frameworks (especially within the context of the programmes created for the achievement of the sustainable development goals) because of the strong position occupied by agriculture and biobased sectors within the Irish bioeconomy.

Example of sectoral strategies and policy frameworks where circular bioeconomy feature prominently include Waste Action Plan for Circular Economy 2020, Food Vision 2030, Project Ireland 2040, and the Climate Action Plan 2021. While strategy development processes for the Irish circular bioeconomy can be said to be at advanced stages, implementation, and monitoring are still at their early stages. Periodic recalibration and harmonization of sectoral strategies to ensure coherence is needed going forward. This will ensure holistic achievement of set goals ensuring current bio-based industries are supported to transition to and develop as part of a circular economy, as well as long-term sustainability. This can be brokered with the help of national circular bioeconomy innovation partners.

3.5.2 Establish industrial-public-sector network to inform the future development of Ireland's circular agriculture and bio-based industries.

As was illustrated by the approach to developing Bavaria's regional strategy for developing its circular bio-based industries, the strong coordination with which this was achieved is recommended for development of circular bioeconomy strategies in Ireland. A network interface and meeting point between representatives of commercial entities operating within the bioeconomy and relevant public bodies is still needed to drive prompt implementation and monitoring, as well as periodic recalibration and harmonization of all Irish circular bioeconomy strategies. Such network interface can provide the platform for multiple stakeholder groups to exhaustively debate and revise current circular bioeconomy development strategies, as well as legislations and policy

bottlenecks (e.g. those associated with the wastes and by products classifications and handling-Article 27, Article 28 etc.).

Actively driving such stakeholder consultation can be achieved by strong top-down political support and high-level government decision making like the case was for the Bavarian Bioeconomy case study. Even though the Department of Taoiseach provided this in adopting the value propositions of the BioÉire Project (thereby kickstarting the strategy development process), this is also needed for strong coordination and forging an inclusive stakeholder-based governance system needed to ensure the long-term sustainability of the Irish circular bioeconomy. Like in the case of the Bavarian case study, the commissioning of national innovation partners and industry oriented RPOs by the Irish Government for this task can help facilitate timely delivery on this action plan.

3.5.3 Greater balance between demand and supply side support measures

Overwhelming focus on supply side-oriented support measures e.g. legal Intellectual Property Right (IPR) frameworks, international agreements, and economic incentives for bio-based industries at the expense of demand side measures such as awareness raising, economic incentives for consumers, specific consumption taxes or subsidies etc. In response to this, there needs to be active engagement of the Irish society by the three other stakeholder groups (Government, industry and academia) recognized within the quadruple-helix collaboration model adopted by the Green Deal approach (adopted for timber and forest products management in the Netherlands) to make sure the society (the fourth and largest stakeholder group) which is on the demand side is not left behind. Misconceptions surrounding circular bioeconomy innovations should be addressed, citizens awareness and education level regarding circular bioeconomy should be escalated in a viral manner.

3.5.4 Continued public investment to close financial gaps

With regards to the effectiveness of bioeconomy policy implementation, promoting R&D for bio-based innovation has been the most effective but needs to be further enhanced. Promoting R&D for bio-based innovation is a major enabler of the Irish circular bioeconomy and it needs to be ramped up continuously by responsible agencies concerned with its facilitation. These include Government research and innovation fund agencies (e.g. Enterprise Ireland, Science Foundation Ireland, EU Horizon Europe etc.), government departments (Department of Agriculture, food and Marine; Department of Environment, Climate and Communications etc.) etc.

3.5.5 Improving social and economic impacts of circular bioeconomy innovations

While existing policies adequately address ecological/environmental sustainable development goals (carbon emission reduction, waste reduction, water conservation etc.) social and economic are still poorly addressed.. Even though circular bioeconomy has verifiable environmental (carbon emission and waste reduction/valorization) benefits, the imbalance in impact along social and economic sustainability dimensions needs to address with appropriate demand-side tools such as taxations, subsidies, etc. There needs to be improved financing comparable to those fossil fuel and other finite resource-counterparts. More direct state involvement and support in terms of provision of favourable

conditions for incubation and scaling may also help address this imbalance. Better involvement of stakeholders improved inter-ministerial policy processes as well as better communication, cooperation and integration across stakeholder groups will help foster the needed intergovernmental cooperation and coordination at international scales for stimulating circular bioeconomy growth across borders. The role of national innovation partners (e.g. Irish Manufacturing Research) in this cannot be overemphasized. This can be facilitated with the top-down political support and high-level decision-making mechanisms. The most suitable and appropriate stakeholder engagement method needs to be applied in this regard (either all-inclusive or systematic or a mix of both).

3.5.6 Exploring digital circular bioeconomy opportunities

Finally, it is important to note that while circular innovations and the funding to drive them are not lacking in the primary circular bioeconomy sectors (namely agriculture, forestry, fresh water, marine and waste management sectors), the emerging Irish digital bioeconomy sector needs to be receive much more attention.

Ireland has the potential to be a leader in this space with the successful incubation and commercialization of Nuritas' application of ICT (artificial intelligence and genomics) for unlocking natural bioactive peptide ingredients with extraordinary health benefits in food by-products. More of such innovative ventures and breakthrough applications should be expected within the emerging digital bioeconomy space if more attention is paid to development within the sphere.

Exploring cross-pollination of knowledge at the boundaries of ICT and bioeconomy i.e. digital bioeconomy (including application of artificial intelligence, robotics, internet-of-things-IOT, additive manufacturing, Industry 4.0, automation and advanced control etc. within the bioeconomy) could be Ireland's pathway to being recognized as a major global technology leader, and the heart of this is the research interface currently being explored by the Irish Manufacturing Research (IMR) and the CIRCULÉIRE network.

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