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NATIONAL EXEMPLARS OF CIRCULAR PRACTICE IN THE BIOECONOMY AGRI-FOOD SECTOR

Subtask 2.2 Draft Report (Abridged Version)

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1. Introduction

This document presents a report regarding an analyse of current circular practices in the bioeconomy agri-food sector of Ireland. The overall aim of this analysis was to provide data in relation to how current policy and other activities and/or actors enhance and/or hinder circular practice in the bioeconomy agri-food sector of Ireland, in order that barriers can be removed/mitigated and sustainability pathways can be developed/enhanced. The analysis wishes to provide a holistic understanding of circularity so that it may be replicated in different contexts of rural Ireland. This was accomplished through the application of a qualitative exploratory case study applying a total of seventeen in-depth interviews with key practitioners working in the agri-food sector of Ireland. Findings from this research will contribute towards the development of a regional strategy for the bioeconomy in Ireland. The objectives of this research were to:

1) To determine how policy, the role of relevant actors and institutions, and policy provisions and financial supports enhance and/or hinders the current operation of circular practice in the bioeconomy agri-food sector of Ireland;
2) To establish how exemplar circular practices can potentially be replicated in other contexts.

First, this report will discuss the meaning of circular practice in the bioeconomy and how this relates to policy contexts. Contextual information regarding Ireland's agri-food sector will then be discussed, followed by a brief summary of the opportunities, risks and barriers associated with the bioeconomy in Ireland. Understanding the advantages and disadvantages of current and future circular practice in the bioeconomy is important in order to provide a holistic vision of bioeconomy circularity. The methodological approach of this research will then be introduced and includes details regarding the development of the interview schedule based on key themes derived from an international literature review. It is important to note that the holistic interpretation of circular practice (i.e. positive and negative aspects) is integrated within this interview schedule. This is followed by the results section, which is divided into four broad (inductive) themes, namely: 1) the meaning of circular practice; 2) the meaning of the bioeconomy; 3) circular practice and enhancement pathways; and 4) barriers to circular practice. The discussion section will then discuss the findings in more detail and in relation to international literature where appropriate. Finally, the conclusions and recommendations section will describe key recommendations for enhancing circular practice in the agri-food

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sector of the bioeconomy with the view that findings from this research will contribute towards the development of a regional strategy for the bioeconomy in Ireland.

2. Context

2.1 Circular practice in the bioeconomy

According to the European Commission (2018a) the bioeconomy can be defined as the sustainable use of renewable biomass, whereby renewable biological resources are produced and converted into a variety of bio-based products including feed, food, biochemical produce, pharmaceuticals, and bioenergy. Because the bioeconomy is based on renewable sources of energy and production, many commentators (e.g. Leipold and Petit-Boix, 2018) contend that it is intrinsically circular by virtue of its identity, the way in which it functions, and the domain in which it functions. In other words, it is based on a system of renewable resources and production within the domain of planetary ecosystems. According to Gimapietro (2019) circular activity essentially involves the dissolution of the carbon cycle in order to generate new pathways towards carbon sink capacity. This is achieved through the utilisation of biogenic carbon in the production of substances and commodities that are part of an enhanced cycle of utility (Giampietro, 2019). This process links the green economy, the circular economy, and the bioeconomy into a broader framework of sustainable economic development.

A completely circular economy needs a dramatic systemic transformation in production and consumption, whereby all waste is designed out of the production cycle and where materials are utilised until they cannot be used any longer. Likewise, Ireland's National Waste Policy 2020-2025, which is heavily influenced by the European Commission's Circular Economy Action Plan (2015), defines the circular economy as an economy where, "waste and resource use are minimised; the value of products and materials is maintained for as long as possible through good design, durability and repair; and when a product has reached the end of its life, its parts are used again and again to create further useful products" (Government of Ireland, 2020; 10). These definitions reflect the cascade principle, which is conceptually very similar to circular practice, and generally involves the sequential and successive utilisation of resources (Campbell-Johnston et al., 2020). As reflected in the policy documents previously mentioned, in the circular economy literature, the cascade principle is often cited as an approach for maintaining the 'added value' of materials until they can be used no longer, i.e. for as long as

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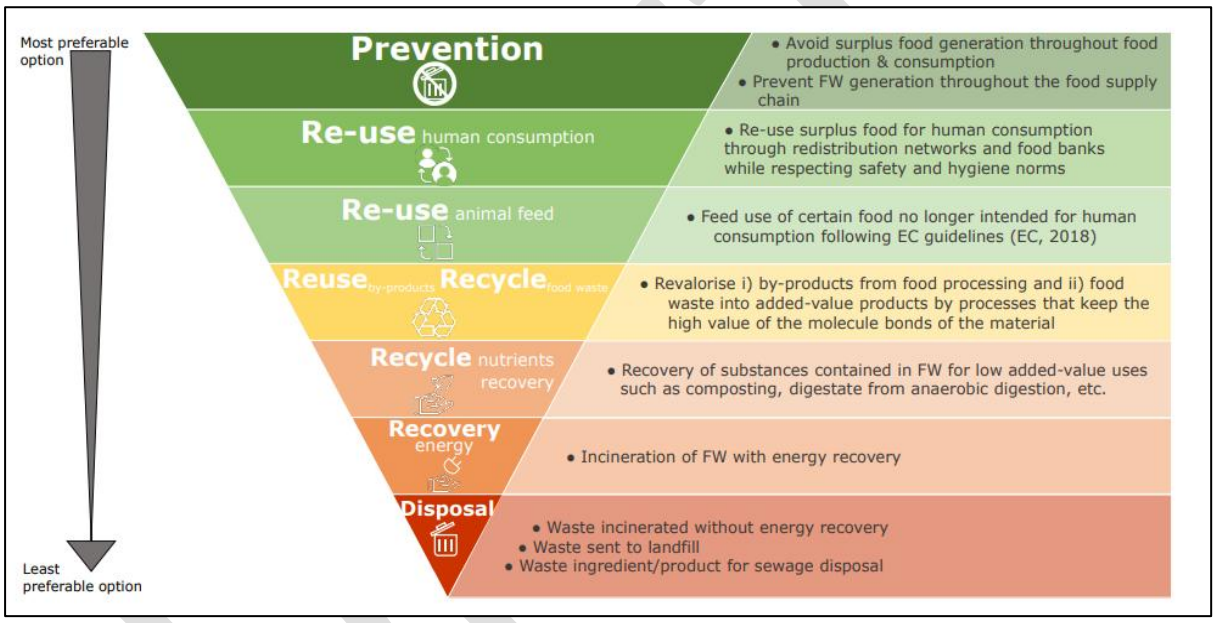
possible (Gontard et al., 2018; Mair and Stern, 2017; Bezama, 2016). Essentially, both the circular practice and the cascade principle concepts are interested in the application of sequential resource circulation in order to maximise resource efficiency (Campbell-Johnston et al., 2020). However, from an academic point of view, the cascade principle is primarily applied in relation to the timber industry (e.g. Jarre et al., 2020; Gustavsson, 2006). Hence, circular practice concept has a much broader perspective both in academic and policy contexts. In terms of agricultural production, circular practice and the cascade principle, the latter of which may be interpreted to be contained within the former, can be viewed in a general sense through the lens of the European Commission's hierarchy for prioritisation of food surplus, by-products and food waste.

Figure 1: Hierarchy for prioritisation of food surplus, by-products and food waste prevention strategies.



Source: European Commission (2020; 8). Adapted from Teigiserova et al. (2020), Papargyropoulou et al. (2014) and UNEP (2014).

This hierarchy itself has been developed from the waste hierarchy pyramid conceived in order to sequentially emphasise the management of waste (European Union, 1975). Beyond the goal of resource efficiency, it is also important to note the boarder aspirations of circular practice in agricultural production, whereby circularity aims to moderate the environmental pollution caused by the disposal of agricultural by-products and waste, recover nutrients for further agricultural production, enhance soil health, and increase food security (Amoah-Antwi et al., 2020).

More generally and in the Irish context, the development of circular practice in the bioeconomy is associated with several key policy documents, the most important of which arguably includes the Climate Action Plan 2021 (Government of Ireland, 2021a), the Whole of

Government Circular Economy Strategy 2022 (Government of Ireland, 2021b), and the Food Vision 2030 Strategy (Government of Ireland, 2021c). Examples of how the development of circular practice in the bioeconomy and how agricultural production is envisioned in such policy documents is outlined in Table 1:

Table 1: Development of Bioeconomy Circular Practice in Irish Policy

The Climate Action Plan 2021
"The circular economy offers an alternative to today's linear ('take-make-waste') model of production and consumption, in which we extract great quantities of natural resources to make things that we may use only once before throwing them away. In the circular economy, resources are kept in use for as long as possible, the maximum value is extracted from them while in use, before residual resources are then recovered and regenerated into new products and materials at the end of each lifecycle. The circular economy is, therefore, an inherently regenerative system, which minimises or avoids the emissions and other negative environmental impacts associated, by replacing a linear lifespan with a closed loop for materials." (Government of Ireland, 2021a; 182). "The high proportion of national emissions represented by agriculture means that for Ireland to meet its overall emissions reduction targets, along with all other sectors, the agriculture sector must make a positive contribution to combating climate change and supporting the transition to a climate resilient, biodiversity rich and climate neutral economy and society no later than 2050. Additionally, as other sectors decarbonise, the share of the agriculture contribution to the national emissions profile will increase" (Government of Ireland, 2021a; 159).
The Whole of Government Circular Economy Strategy 2022
"The Bioeconomy, a key facet of the Circular Economy in Ireland, encompasses a range of activities across many sectors, including agriculture, the marine, forestry, water and waste management, energy, as well as biopharmaceuticals. It is the part of our economy which uses renewable resources such as crops, forestry, and fisheries to produce food, products, as well as energy, while also reducing waste. Increasing the scope of the bioeconomy will mean diminishing our reliance on fossilbased fuels and carbon intensive resources and will boost our use of renewable biological resources." (Government of Ireland, 2021b; 27). "Increased circularity within the Agricultural sector can support lower farm costs and reduced climate and environmental footprints, through reduced use of external inputs, closing nutrient loops and minimising harmful environmental discharges. Agricultural wastes can also represent a valuable feedstock for the Bioeconomy as described previously. Further development of this Strategy should build on existing sectoral initiatives, such as the EPA/ IFA's Smart Farming programme and ensure

consistency between national policy in relation to the circular economy, the bioeconomy and climate action" (Government of Ireland, 2021b; 28).

The Food Vision 2030 Strategy

"There is scope for additional income and employment opportunities arising from embedding the agri-food sector in the circular bioeconomy. These opportunities can come from the use of raw materials from grassland, crops, forestry and bio-marine systems to develop new bio-based value chains and this Mission expands on some of these opportunities" (Government of Ireland, 2021c; 11).

Ireland will become a world leader in Sustainable Food Systems (SFS) over the next decade. This will deliver significant benefits for the Irish agri-food sector itself, for Irish society and the environment. In demonstrating the Irish agri-food sector meets the highest standards of sustainability – economic, environmental, and social – this will also provide the basis for the future competitive advantage of the sector. By adopting an integrated food systems approach, Ireland will seek to become a global leader of innovation for sustainable food and agriculture systems, producing safe, nutritious, and high-value food that tastes great, while protecting and enhancing our natural and cultural resources and contributing to vibrant rural and coastal communities and the national economy (Government of Ireland, 2021c; 1).

2.2 The bioeconomy agri-food sector in Ireland

According to O'Connor et al. (2023) circular practice in the Irish bioeconomy has huge potential due to: 1) the substantial size of Ireland's territorial waters, 2) the potential for expanding Ireland's forestry sector, and 3) its well-established and indigenous agri-food sector (O'Connor et al., 2023). The present analysis focuses on the latter potential for developing circular practice in Ireland's bioeconomy. Ireland's agri-food sector is both its earliest and largest indigenous export industry (DAFM, 2021). According to the Department of Business, Enterprise and Innovation (DBEI, 2019) it is responsible for 5.7% of Ireland's GDP, generating approximately €8.2 billion in produce originating from 137,500 farms (DAFM, 2021). Likewise, according to Matthews (2021), Ireland's food and drink sector is its most important domestic industry. From the perspective of bioeconomy activities, agricultural biomass can be classified into three primary groupings: 1) meat-related by-products and co-products; 2) biomass-orientated crops, and 3) agricultural by-products (Shirsath and Henchion, 2021; Fryda et al., 2007). Devaney and Henchion (2018) contend that there are tree agri-food value chains of particular importance for developing the agri-food bioeconomy in Ireland and they are: 1) the production of sugar crops used for feedstocks in order to produce biochemicals; 2) the production of horticultural by-products in order to produce biopolymers; and 3) the production of diary by-products and process wastes in order to produce bio-based chemicals. In relation to the latter but more

generally, Ireland's long-established dairy sector may represent a logical development from existing practices (DBEI, 2019) to circular practices and in respect to diary by-products and process wastes. Indeed, the European dairy industry currently produces whey permeate (DBEI, 2019), which undergoes a lactose (the sugar contained in diary) extraction process, whereby high-value added ingredients can be produced (de Oliveira et al., 2018). In relation to bio-based chemicals, the Department of Business, Enterprise and Innovation (DBEI, 2019) point to the AgriChemWhey biorefinery initiative, as an example of the conversion of food-processing by-products and co-products into bio-based chemicals. While in relation to the conversion of horticultural by-products into biopolymers, Monaghan Mushrooms corporation is cited as an example of the conversion of waste materials into higher value products, and the Carbery Group is cited as an example of the application of grass fibres and grass juices in order to produce biofuels and bioenergy (DBEI, 2019). From an international perspective, a recent literature review by Orozco et al. (2021) found that grass and green fodder has been successfully appliced in a broad range of bio-based products including feed protein, fertiliser, fibre boards, seeds, paper, plastics, straws, and energy. Because grassland in Ireland accounts for approximately 82.1% of all agricultural land-use according to the Central Statistics Office Ireland (CSO, 2020), grass as a source of biomass production has huge potential in the Irish context.

2.3 Opportunities, risks and barriers

Circular practice in the bioeconomy can be envisioned as an opportunity to combat the various challenges associated with climate change, the loss of biodiversity, the sustainable production of food, as well as the production of a wide-range of 'value-added' bio-based materials, chemicals and energy (Muscat et al., 2021). For Ireland, this has the potential to enhance competitiveness, increase employment, and essentially create a more adaptable economy at all spatial scales from the local through to the regional to the national (O'Connor et al., 2023). As previously intimated, circular practice essentially utilises renewable and sustainable biomass from land and sea-based activities, including meat, crops and wastes, transforming these products, co-products, and by-products into 'value-added' bio-based materials including, feed, fertiliser, proteins, oils, fats, plastics, chemicals and energy (Venkatesh, 2022). However, it is important to emphasise that most of these products are currently imported into the Irish market, generally in an unsustainable manner, and at a high economic cost (O'Connor et al., 2023). Hence, the opportunities for circular practice in the bioeconomy of Ireland are immediately apparent, whereby products can be produced sustainably by indigenous industries, using

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indigenous resources, and creating employment at local and regional levels (O'Connor et al., 2023). As such, O'Connor et al. (2023) contend that Ireland's agri-food sector exhibits significant advantage and opportunity in relation to circular practice in the bioeconomy. However, even with such enormous potential there are a multitude of challenges and barriers which can constrain, restrain and hinder its development (Salvador et al., 2022). In analysing national exemplars of circular practice in the bioeconomy agri-food sector in Ireland and in meeting the proceeding associated objectives, this analysis will focus on the various opportunities as well as the various challenges and barriers that companies operating in the agri-food sector of Ireland are currently experiencing. In this way it was deemed appropriate to focus on both the positive and negative aspects of current circular practices in the agri-food bioeconomy of Ireland in order to provide a holistic perspective regarding the various characteristics and degrees of circularity achieved in national exemplar circular practice in Ireland.

3. Methodology

3.1 Introduction

In order to analyse current circular practices in the Irish bioeconomy agri-food sector an explanatory qualitative case study analysis was applied. As previously outlined, a total of seventeen in-depth interviews with key practitioners working in the agri-food sector of Ireland was applied.

3.2 Developing the Interview Schedule

In order to develop an interview schedule for the examination of national exemplars of circular practice in the bioeconomy agri-food sector of Ireland as of 2023/4, several key themes were focused on, based on a state-of-the-art international literature review. These key themes included: 1) the application of circular practice in respect to by-products and waste recovery; 2) policy; 3) collaboration; and 4) logistics.

An additional theme found in the literature related to the promotion of public awareness. However, once interviews occurred it quickly became evident that this theme was not relevant in the Irish context. This is because the bioeconomy is still in its infancy in Ireland, and practitioners

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working in the agri-food sector do not currently consider the agri-food sector as a bioeconomy activity. The theme was therefore removed from analysis. Focusing on the remaining four key themes in developing the interview schedule was considered to contribute to meeting the two primary objectives previously outlined and repeated here for clarification:

1) To determine how policy, the role of relevant actors and institutions, and policy provisions and financial supports enhance and/or hinders the current operation of circular practices in the bioeconomy agri-food sector of Ireland.

This objective was deemed to provide an impression of the nature and extent of circular practice in the agri-food sector of Ireland's bioeconomy.

2) To establish how exemplar circular practices could possibly be replicated in other contexts.

This objective was deemed to reveal how lessons could be learned through various levels and characteristics associated with circular practice in the agri-food sector of Ireland's bioeconomy.

3.3 By-products and waste recovery

In a case study analysis of bioeconomy clusters in Europe, de Vries et al. (2021) concludes that although many elements of the European bioeconomy are interconnected, they do not necessarily operate in a circular fashion at the current time. According to Cladeira et al. (2020) this situation can be improved through efficient management and utilisation of by-products and waste materials. Sadhukhan et al. (2018) contend that the process of waste recovery is a major driver for circular practice in the bioeconomy, while for Cheng et al. (2020) the valorisation of biowaste into value-added products is seen as central for an efficient bioeconomy. In this respect, circular practice in the bioeconomy aims to utilise all categories of biomass by-product and waste including crop residues, industrial by-products and organic waste (FAO, 2019). This application is then utilised in the production of value-added products (Lange et al., 2021). But apart from the beneficial externalities which include improvements in sustainability and resource efficiency associated with the economic application of bioprocesses to generate biomaterials from waste, many argue that efficient management of by-products can also increase revenue and hence circular practice in the bioeconomy has huge economic potential (e.g. Hagman, 2023).

There is a wide range of research examining the various applications of waste in the generation of value-added products. For example, a study by Dahal et al. (2018) shows that the production of biochar from wastewater treatment can actually be used to fertilise agricultural

soil and can be used as a fuel for heating systems. Coppola et al. (2021) outlines the many uses of fish waste in the bioeconomy, whereby it can be used as fertiliser (Ahuja et al., 2020), can improve methane production in anaerobic digestion (Wu et al., 2021), and can be used as food packaging and a food additive ingredient (Coppola et al., 2021). Alexandri et al. (2020) examines the application of the by-product defatted rice bran both in respect to its application as a value-added product and eventually as a biofuel. The abundance of this by-product is noteworthy and emphasises the potential for its use in circular practice (Alexandri et al., 2021). In respect to the previously discussed concept of the cascade principle and the European Commission's hierarch for prioritisation of food surplus, by-products and food waste prevention strategies, it is important to note that biomass combustion may contain extraneous pollutants and hence, energy production from biomass should be the last step in the circular process once all other materials have been reclaimed (European Commission, 2020). In this way achieving zero waste and environmentally-sound production is the primary objective. Economically, the reduction of waste at every level of the supply chain is seen as a major advantage of circular practice from production to processing to storage, handling and transportation (Santagata et al., 2021). While environmentally and on a societal level, circular practice aims to moderate environmental pollution caused by the disposal of agricultural by-products and waste, recover nutrients for further agricultural production, enhance soil health, and increase food security (Amoah-Antwi et al., 2020).

This key theme was included as a prompt in semi-structured interviews if participates had not discussed the theme in enough detail to enable heuristic insight. In such cases participants were asked how they delt with waste and were probed in terms of potential opportunities, supports, challenges and barriers.

3.4 Policy, finance and regulation

The extent and quality of government intervention in respect to policy, financial implementation and regulation is often cited as imperative for the implementation of circular practice in the bioeconomy. Gottinger et al. (2020) argue that the main barrier to circular practice for the small to medium sized enterprise relates to the implementation of policy. In the context of developing economies, Negi et al. (2021) argue that bioeconomy policies do not provide clear instructions regarding how circular practice may be implemented (Negi et al., 2021). While in an analysis of bioeconomy clusters in Europe, Stegmann et al. (2020) found that a lack of policy and regulation

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was the main obstacle towards achieving circular practice, with other impediments relating to the small size of the bio-based markets (Stegmann et al., 2020). Kardung et al. (2021) contend that policy intervention should take place at the regional, national, and international level, and in research investigating circular activity in the Brazilian silk production sector, Barcelos et al. (2021) argues that government intervention at all levels including local, regional, and national, primarily needs to recognise the 'added-value' that circular practice can generate in order that new policies are implemented, new businesses are established, and the full potential of local resources are applied. This may be achieved through measurement. Kardung et al. (2021) emphasise the need for measuring bio-based production in order to optimise circular practice. In this respect, D'Adamo et al. (2020) also contend that the evaluation of the extent to which circular practice in the bioeconomy contributes to regional economic growth is imperative for its optimisation.

According to Giampietro (2019) circular practice within the bioeconomy cannot be successful if it is based on a model of continuous economic growth. This may be problematic from a commercial point of view as is reflected in a stakeholder analysis of biowaste management systems by Angouria-Tsorochidou et al. (2021), whereby results found that economic viability was perceived as the most important factor for circular practice in the European bioeconomy, and far more important than the quintessential social and environmental externalities associated with circular practice. Despite this, the mobilisation and availability of financial resources is seen as a major impediment for circularity in bioeconomy SNMs according to Gottinger et al. (2020). Bedoić et al. (2019) argue that circular practice involving agricultural by-products and/or agro-waste is not economically feasible at the current time without policy intervention due to high transportation and storage cost, seasonality, low quantity production, and low commodity prices. In respect to the timber industry, Husgafvel et al. (2018) and Winder and Bobar (2018) argue that the lack of government incentives for circular practice is a major barrier. While in respect to Brazilian silk industry, Barcelos et al. (2021) call on the need for financial incentives and tax exemptions to promote circular practice, which is deemed appropriate considering the many externalities associated with circularity such as economic growth for local economies and GHG emission trade-offs. For Barcelos et al. (2021), the most important policy intervention for circular practice within the Brazilian silk industry relates to the demand for capital investment in respect to business start-ups, local infrastructure, and storage capacity. Likewise, in a review of organic manure biorefinery models in China, Awasthi et al. (2019) found that new policies, and particularly financial incentives, were essential for promoting circular practice. As such, Awasthi et al. (2019) argue that financial incentives are most useful if

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they are targeted at famers in respect to the secure disposal and recycling of manure. However, it is also important to emphasise how the nature and extent of financial incentives is context specific. For example, Galagani et al. (2014) found that the process of manure recycling in respect to the application of fertiliser was financially feasible in the context of Bangladesh and Indonesia but required subsidisation in north Ghana.

For Brandão et al. (2021), government intervention is necessary in order to enhance the collaboration between research and business practice which is considered to be a challenging area at the current time. In this respect, intervention associated with assisting businesses and/or actors with scaling-up technology is considered crucial by many commentators in order to ensure economic viability of circular practice in the bioeconomy primarily. For example, Awasthi et al. (2019) discusses the need for government intervention in terms of sharing the cost of scaling-up technology for manure recycling. While for Dietz et al. (2018), government investment in technological advancement is imperative in order to mitigate any potential risks for private enterprise. More specifically, Asghar et al. (2022) contend that economic support is essential in the context of biorefinery activities. However, many current biorefinery systems are often considered inefficient and in need of financial support in terms of research and development. For example, although waste to energy centres that apply anaerobic digestion technologies are seen as central for circular practice in the bioeconomy (Pan et al., 2012), and despite the fact that anaerobic digestion is a long-established technology many commentators have pointed towards the need for improved efficiency in the process (Braguglia et al., 2018; Di Maria et al., 2018). This relates to pre-processing systems (Tabatabaei et al., 2020), reactor design (Kariyama et al., 2018), and process design and monitoring (Panigrahi and Dubey, 2019), which could all benefit from technological development. In other respects, co-digestion of various waste streams is seen as another method to improve efficiency, in this case by increasing methane production (Ingrao et al., 2018; Xu et al., 2018), which should also be incentivised by government. Generally, progress in research, innovation and technology are considered the key factors for increasing or optimising bioeconomy circular practice (Duque-Acevedo et al., 2020), with the collaboration between industry and research considered imperative for the development may provide needed for achieving a high level of circular practice in the bioeconomy. Hence, the need for state intervention in respect to financing research and development is seen as obligatory by many commentators.

For Dietz et al. (2018) financial incentives are also important in order to guarantee the competitiveness of bio-based produce. In a case study analysis of Dutch and German entrepreneurs working in the bioeconomy, Wilde and Hermans (2021) found that price

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competitiveness with traditional fossil-fuel production was the main obstacle to circular production in the bioeconomy whereby growth was severely inhibited. Likewise, Donner et al. (2021) argue that price competitiveness between biobased products compared to conventional products is as a major challenge associated with circular practice in the bioeconomy (Donner et al., 2021). Low-cost pricing is seen as key for bio-based products to compete with traditional products as well as establishing a customer base in the first place (Salvador et al., 2021a). In an analysis of perspectives from entrepreneurs working in the bioeconomy of Europe, respondents called for the implementation of CO_2 taxes for affected products in order to grow the market with the environmental impact of production also deemed a requirement within international trade regulation (Wilde and Hermans, 2021). On the other hand, traceability, high quality standards of production and environmentally sound agricultural practice also have the potential to attract consumers who are willing to pay higher prices for products derived from such processes (Donner et al., 2021). However, this only represents a certain cohort as opposed to the wider consumer-base, and hence, achieving price competitiveness seems imperative for developing successful circular practices in the bioeconomy.

Another area of contention relates to the role of regulation in bioeconomy circular practice. Stegmann et al. (2020) found that even categorising a product or material as waste actually restricts its future utility. According to Aznar-Sánchez et al. (2019) inept regulation is the primary reason why waste biomass management operates at a low level of circular practice. According to Angouria-Tsorochidou et al. (2021) regulation can either enhance or hinder technological advancement in respect to waste management and circular practice. In respect to food waste, Facchini et al. (2018) found that regulation was one of the main barriers to circularity, while Awasthi et al. (2019) found that environmental regulations were needed for optimal circular practice in the context of China. EU regulation of biowaste management heavily influences anaerobic digestion (Angouria-Tsorochidou et al., 2021), and in this regard the amended Waste Framework Directive 2018 (European Commission, 2018b) requires that source separation be obligatory from 2023. Accordingly, more efficient biowaste management systems also need to be designed (Angouria-Tsorochidou et al., 2021) and should be done so on a regulatory basis. Even in the earliest stages of product design, Fraanje (1997) points to the problem of manufacturers, in this case wood producers, being completely unaccountable in respect to the disposal of their products. In this context, Suominen et al. (2017) call on the need for labels to be introduced in such a way that circular practice is incentivised. Jarre et al. (2020) argues that

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legislation is needed in order to encourage circularity and even make it mandatory in the timber industry. As such, this approach could also be applied to the agri-food sector of the bioeconomy.

As before, this broad key theme (policy, finance, regulation) was prompted in semi-structured interviews as previously described in terms of potential opportunities, supports, challenges and barriers. As such participants were asked, if/how government policy supports or inhibits the company's circular practice. More specifically, participants were asked if/how the state financially supports their circular activities, as well as the extent to which this support is targeted towards scaling-up and technological development. Participants were also be asked if/how regulation supports and/or inhibits circular practice.

3. 5 Governance and Collaboration

Circular practice in the bioeconomy also requires a complex and extensive system of collaborative networks. This is much more apparent for circular practice relative to traditional business practice and is related to the inherent nature of the activity. For example, the collection of waste and by-product materials is an organisational challenge and requires strong collaboration between secondary and primary producers (Donner et al., 2020). This collaborative network must also operate between both interdependent and independent stakeholders (Antikainen and Valkokari, 2016). In relation to timber production, Winder and Bobar (2018) cite that the lack of collaboration between designer and manufacturer essentially leads to a product that could be easily circular but is not. Likewise, Meyer (2017) points to the general lack of coordination in the bioeconomy between energy and waste policy as highly problematic in terms of circular practice. Arora (2021) argues for government intervention in facilitating co-ordination between farming cooperatives, government bodies, NGOs, and the private sector, as well as promoting the product to the consumer. While Westerman and Bicudo (2005) highlight the importance of farming cooperatives for facilitating the transfer of manure production from livestock farming to crop production. Essentially, it seems that long-term collaboration between primary producer, secondary producer and distributor is essential, and stands as a significant challenge, in circular practice of agricultural by-products (Donner et al., 2020).

This key theme was prompted in interviews as previously discussed. Participants were asked to discuss their relationship with primary producers, how this is operationalised and how this functions in circular practice. Advantages and disadvantages associated with this relationship were probed if deemed necessary.

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3.6 Logistics

The final key theme associated with the opportunities, challenges and barriers of circular practice in the bioeconomy relates to logistics. Like all economic systems, or perhaps even more so for the bioeconomy, the importance of logistics for successful development cannot be underestimated. For Donner et al. (2020) the collection of waste and by-product materials is a logistical challenge whereby certain contingencies such as seasonality, perishability, and variability of materials must be considered. As such, Salvador et al. (2021b) suggest it may be necessary for companies to produce different products at different times throughout the year (Salvador et al., 2021b). Hence, establishing an appropriate logistics system is imperative for high level circular practice in the bioeconomy, as it is important to consider the fact that bioresource may depend on particular conditions for storage and transportation due to fast decomposition rates (Salvador et al., 2021a). Cheng et al. (2020) also highlight the issue of geographical dispersion as a major barrier in respect to bioeconomy circular practice in terms of collection, transportation and distribution of biowaste. In respect to the timber industry, Garcia and Hora (2017) regard the transportation of timber by-products from collection point to recycling point and to the various points of distribution as highly problematic due to the exorbitant transportation costs associated with the process. Indeed, Taskhiri et al. (2016) found that transport costs accounted for 89% of all logistical costs associated with circular practice within the timber industry in Germany, calling for an increase in financial incentives for circular practice and the application of the cascade principle within such practice.

In the context of biomass energy production, logistics is also seen as somewhat problematic. This is because biofuels are high-volume and low-density and cannot transported over long distances without high transportation costs (Awasthi et al., 2020). Accordingly, the application of agricultural by-product as fuel is constrained by geographical dispersion, seasonal production and lower energy material composition relative to traditional sources of energy (i.e. fossil fuels) (Tauro et al., 2018). According to Awasthi et al. (2020) it is therefore imperative that biowaste or agricultural by-products are sourced locally in order to mitigate logistical cost in the context of biofuel production. Kapoor et al. (2020) see anaerobic digestion as a cheap and simple means for generating renewable energy and considers the technology as easily scalable depending on the availability of agri-waste in the locality or region. According to Kapoor et al. (2020) agri-waste anaerobic digestion systems can be efficiently and cost-effectively distributed in a dispersed pattern in order to produce biofuel and at a small-scale level. Furthermore, Uçkun Kiran et al. (2015) argue that the high costs associated with biorefinery systems could be mitigated by using food waste since it is a relatively cheap source of waste/by-product. In

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research investigating agri-food valorisation, Klein et al. (2022) found that collaboration in bioeconomy circular practice, in this case between potato farmer, livestock farmer and biogas producer, is more cost-effective if it takes place within a relatively small radius, e.g less than 15 km. Such localised collaboration not only mitigates transportation cost, but also ensures that perishable agricultural produce maintains its integrity for application in circular activity (Klein et al., 2022). At this point it should also be stated that such arguments are context-specific, for example, if the product is highly profitable, such as in the case of rapeseed by-products that produce oil for methane reduction in dairy cattle, then collaboration can occur over large distances due to revenue far exceeding cost (Klein et al., 2022). Nevertheless, although the nature of logistics associated with circular practice is dependent on what is being produced, from a sustainability perspective, smaller more localised collaboration distances are preferable.

Again, this board key theme was prompted in interviews as previously discussed. Participants were asked about the role of logistics in their circular practice, and in terms of seasonality, perishability, and variability of materials used for their product. Storage and transportation costs, if not already discussed in the facilitating coordination (collaboration) key theme, was investigated, including the approximate distance that primary producers are located.

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3.7 The Interview Schedule

Table 2 below outlines the interview schedule based on the above literature review and informed by the research objectives (described above).

Table 2: Semi-structured Interview Schedule

Semi-structured interview schedule	
Identifying and quantitative information	○ Contact details
Open-ended questions	○ What does circular practice mean to you? ○ Please describe your company's approach to circular practice (if any)? ○ Are there any ways you think circular practice can be improved or extended in your company? ○ Are there any ways you think circular practice can be applied more generally to the entire agri-food sector?
Open-ended probing questions	○ Please describe how your company deals with waste. ○ How has this changed? What prompted this change? ○
	○ Please describe the supports, or any other mechanisms, or actors, that enhance your circular practice? ○ Please describe the barriers, or any other challenges or actors, that you think hinder your company's circular practice? ○ In your view, what are the governments priorities in this respect to circular practice and the bioeconomy?
	○ Do you have any opinions regarding the direction of EU policy in respect to the bioeconomy?
	○ How does the state financially support your company's circular practice, if at all? ○ To what extent, if any, does this financial support target scaling-up and technological development? ○ To what extent, if any, does regulation support and/or inhibit circular practice? ○ What are your views on Ireland's R&D capacity?
	○ Please describe your relationship with primary producers, how it operates, and how it functions in respect to circular practice. ○ Please describe the advantages associated with this relationship.
	○ Please describe any other kind of collaboration networks you are involved in. How were these networks initially formed? What are the benefits of these collaborations? How can these relationships be improved? Do you have any future plans to extent your current network of collaborators? ○ Please discuss your views regarding public awareness of your company's product, including level of public demand, role of state, price competitiveness.

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	○ Please described the role of logistics in your company's circular practice, including seasonality, perishability, variability of materials, storage and transportation costs. ○ What is the approximate distance of collaborative primary producers.
Probing questions	○ All of the above probed in terms of opportunities and supports as well as challenges and barriers.
Final question	○ What does the bioeconomy mean to you? ○ How is the bioeconomy related to sustainable development or is it related to sustainable development? ○ Do you have any thoughts around how we should develop the bioeconomy?
Snowball Sampling	○ So finally, could I actually just ask do you know any company would be interested in giving an interview? ○ In about a year or so we'll be doing workshops and we want what farmers who might be involved in sustainable practice to run workshops, would you know of anyone who might be interested in that?

3.8 Data collection approach

Initially, a database of agri-food companies associated with the bioeconomy in Ireland was generated based on a network analysis conducted by Kieran Harrahill and Áine Macken-Walsh in 2022 (available at: https://storymaps.arcgis.com/stories/d9a88a45154849eb9866dd262e5800e7). Second, industrial partnership information garnered from data available from Ireland's seven bioeconomy research institutes was added. This included, the *Agriculture and Bioeconomy Research Centre* in Galway, the *Bioconnect Innovation Centre* in Monaghan, the *BiOrbic Bioeconomy Research Centre* in Dublin, the *Circular Bioeconomy Cluster* in Kerry, the Irish Bioeconomy Foundation in Tipperary, *Nua na Mara Marine Innovation Development Centre* in Connemara, and *Shannon ABC Applied Biotechnology Centre* in Limerick. Using this approach a total of twenty-eight agri-food companies were identified. This number was considered too small for data collection, even if response rates were high. Therefore, an additional dataset was created based on companies registered under *An Bord Bia Origin Green* certification. This approach ensured that prospective companies were engaged in a high level of circular and sustainable practice in the agri-food sector. A total of seven interviews were conducted based on the initial approach to data collection, while the remaining ten interviews were conducted from a selection of companies registered under *Origin Green* certification. In order to provide a geographical representative impression of circular and sustainable practice in the agri-food sector of the bioeconomy in Ireland, companies were randomly selected in each of the three provinces in Ireland.

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3.9 Interview procedure

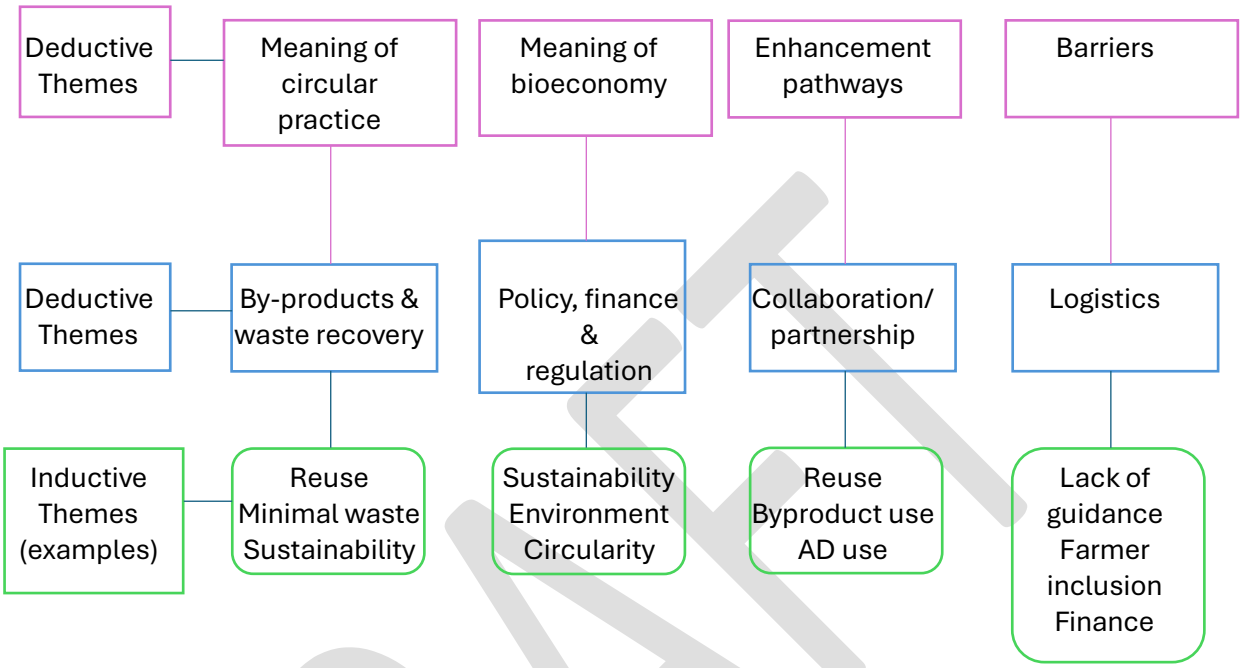
Semi-structured in-depth interviews were chosen in order to allow for a more flexible approach to data acquisition, e.g. allowing for emerging themes which may not have been identified via the interview schedule. The approach incorporates elements from both formal and informal interview approaches and allows for more natural cognition processes to occur whereby information is acquired organically and can lead to unexpected and informative results (Brinkman, 2014). Interviews took between 30 minutes to one hour and were conducted with representatives who were interested, and/or whom managed, sustainable activities within the business. Participants were initially asked to define what circular practice meant for them and then to describe the company's various approaches to circular practice. If any of the four themes and subthemes, outlined previously, were not discussed, and if appropriate, participants were prompted towards ascertaining how pertinent key themes impacted on the company's circular practice. If key themes and subthemes were discussed in a unidimensional manner, i.e. in an entirely positive (e.g. opportunities and supports) or negative (e.g. challenges and barriers) manner than participants will be probed on perspectives not discussed as appropriate. If during the pilot interview, as well as subsequent interviews, new relevant themes were discussed they were added to the final interview schedule. Based on the requirement for adequate comparative analysis and heuristic usefulness it was originally envisioned to conduct fifteen in-depth interviews, however, since additional interviews had already been organised a total of seventeen interviews were conducted. Data saturation had been reached with thirteen interviews and the pilot interview was included in the final analysis since it was deemed that the contents of the interview schedule did not change significantly in subsequent interviews, and due to the relative importance of the information provided.

3.10 Analytical approach

Interviews were transcribed verbatim and entered into Nvivo qualitative data analysis software which facilitated applied thematic analysis. The application of thematic analysis facilitated an understanding of the most important characteristics of circular practice and the most prevalent barriers and enhancement pathways to circular practice. First, relevant sections of transcripts were categorised using the overarching themes identified in the literature (previously described), and facilitated an understanding of how emerging themes are related to the literature; second, sections were categorised using a set of deductive themes emerging organically from the analysis, which facilitated an understanding of how themes and subthemes are related to one

another. Once coding was complete a review of all coding was conducted towards ensuring a consistent application of codes across all transcripts. Figure 2 describes an overview of applied (deductive) and emerging (inductive) themes derived from the in-depth qualitative analysis.

Figure 2: Overview of applied (inductive) and emerging (deductive) themes



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4. Results

4.1 The Meaning of Circular Practice

At the beginning of each interview, participants were asked what circular practice meant to them. Figure 3 describes the key inductive themes emerging from respective interviews and classified in accordance to the number of participants (interviews) that discussed these themes:

Figure 3: Meaning of Circular Practice – Frequency of Citation

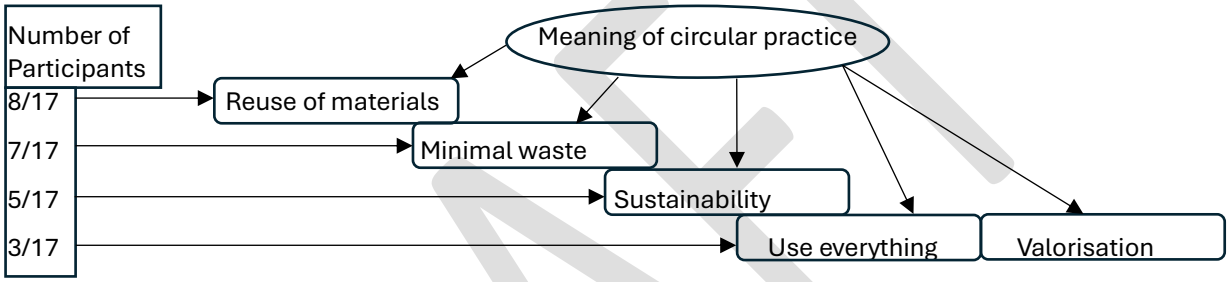

Figure 4: Meaning of Circular Practice

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Two participants were unclear what the 'circular practice' term meant. Eight participants defined circular practice in terms of reusing materials.

> *'I suppose circular practice would be reusing what you can, reusing energy or reusing whatever you can and to avoid, you know, purchasing something or getting something from elsewhere that might generate obviously more emissions. I suppose to me that's what the word that comes to my head when I think of circular is reusing'* (Participant 5).

Seven participants referenced minimal or zero waste when asked to define circular practice. Five participants defined circular practice in terms of sustainability. However, in this respect, explanations tended to be relatively non-descript, and in some cases indirect. Such descriptions may have indicated a certain difficulty with defining the concept of circular practice. One participant suggested that circular practice involves integrating sustainability into various aspects of their business operations, including supply chain management and environmental stewardship. Another participant viewed circular practice as a means to address waste streams within production processes, which are described specifically in terms of sustainability. Of the remaining participants, three associated circular practice with using everything, while three referenced valorisation. For most participants the meaning circular practice related to reusing materials, minimising waste, and ensuring that resources were used efficiently and within a closed-loop system. Circular practice was generally conceived as contributing to environmental sustainability and resource conservation.

4.2 Meaning of the Bioeconomy

Closing each interview, participants were asked what the bioeconomy meant to them. Figure 5 describes the key inductive themes emerging from respective interviews as previously described:

Figure 5: Meaning of the Bioeconomy – Frequency of Citation

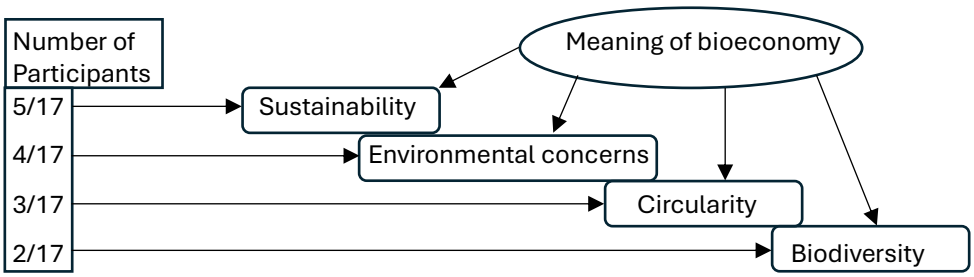

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Figure 5: Meaning of the Bioeconomy

Seven participants said they were unclear what the term 'bioeconomy' meant. However, two of such participants proceeded to associate the concept with sustainability:

> *'It doesn't mean anything at all. Just the term bioeconomy, to be fair if I'm honest, is not a term that I'm familiar with. It's not a term that I would be thinking about regularly. And the word, I can only assume, it ties into the wording, we are more looking at is sustainability'* (Participant 12).

In total five participants defined the bioeconomy in terms of sustainability. Four participations associated the meaning of the bioeconomy with environmental concern, three associated the term with circularity, and two associated the term with biodiversity. Generally, participants perceived the bioeconomy as an economic framework that integrates sustainability, circularity, renewable resources, waste management, and environmental considerations. An emphasis was placed on moving away from a linear, resource-depleting model to one that is more regenerative, efficient, and mindful of environmental impacts. Participants expressed varying degrees of familiarity and understanding of the bioeconomy concept, reflecting ongoing discussions and efforts, in policy and academic arenas, to define and implement bioeconomy principles in practical contexts.

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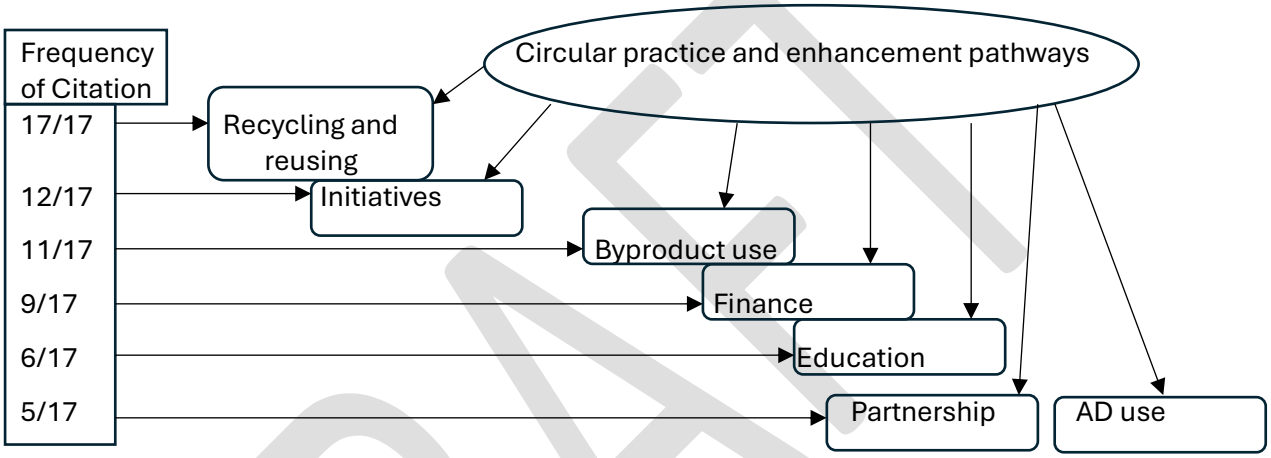
4.3 Circular Practice and Enhancement Pathways

One of the key questions participants were asked was to describe their company's circular practice, if they were engaged in such activities. This formed the basis for analysing the circular practice and enhancement pathways of companies operating in the agri-food sector of Ireland. However, this major theme was also classified in other sections of the interview discussion (i.e. in response to other questions), where appropriate. Figure 6 describes the key inductive themes emerging from respective interviews as previously described:

Figure 6: Circular Practice and Enhancement Pathways – Frequency of Citation



4.3.1 Recycling materials particularly product packaging

In respect to pathways for development, the reuse and recycling of materials dominated discussions, with all participants referencing the reuse and recycling of materials as a primary strategy.

> *'Our packaging is all fully recyclable. We have reduced the levels of plastic, as in the thickness, that we use, to what we feel is a bare minimum now. So if you can appreciate, we've a plastic film that we make our plastic bags, the one's you see in the supermarket, out of. In the past that might have done maybe 80,000 bags. Now we're getting that up between 10,000 to 15,000 bags. The level of plastic that's in them is the same, but the film is thinner'* (Participant 12).

Participants described efforts to recycle cardboard and segregate plastics for recycling, with some materials being recyclable while others were not. Strategies included managing waste streams, baling cardboard and plastic separately, and reducing plastic usage through thinner films. Reusability was emphasised, with trays and sleeves designed for reuse, and the adoption

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of reusable crates for distribution. Compostable packaging was also mentioned as an environmentally sustainable option. Some participants also expressed intentions to test recyclable packaging materials for wider adoption. Cited challenges included the complexity of implementing circular economy projects, and necessitating collaboration among multiple companies and stakeholders. Despite efforts to improve packaging recyclability, returning unused or waste product packaging was cited as a key challenge, with emphasise on limited mechanisms in place. While there was a recognition of the importance of circular economy practices, participants expressed the need for collaboration and incentives to overcome challenges and achieve widespread adoption of recycling activities in the agri-food sector more generally.

4.3.2 Sustainable development initiatives

Sustainability initiatives (e.g. Origin Green, Repak) were mentioned by twelve participants when discussing circular practice and were considered important as potential avenues for developing or improving circular practice. In relation to Bord Bia's Origin Green initiative, the following participant describes a very open system, almost unregulated:

> *'So Bord Bia conduct the annual grower audit as part of Origin Green, and within their audits there are questions asked do you recycle but there's no pressure to. There are targets that you must set as a business, that you aim to achieve. But there are no specific targets around how many tonnes of packaging has to be recycled or whatever. You set your own targets that you work to'* (Participant 13).

Whereas another participant described a more audited regime, which perhaps reflects differences between regular and gold standard membership of the programme. Participants discussed how membership of sustainability programmes improves circular practice by reducing packaging waste, setting sustainable targets for resource management, and ensuring accountability through external audits. Such initiatives were described to foster a culture of environmental responsibility within organisations, leading to tangible improvements in waste reduction and recycling rates.

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4.3.3 Alternative uses for agricultural byproduct

Eleven participants discussed alternative uses for agricultural byproduct as a key feature of circular practice, demonstrating how innovation is used to maximise the value of resources sustainably. Participants discussed initiatives such as diverting unsuitable potatoes to cattle feed, donating to food banks, and even processing products such as potato gin. The utilisation of animal byproducts was also highlighted, with a portion being consumed as food, particularly in regions outside Europe. In particular, the application of byproduct as organic fertiliser emerged as a common strategy, demonstrating an integrated approach to land management and nutrient cycling within operations.

> *So we produce a lot of [animal waste] in the form of nutrients. And moving that on to cereal or tillage farms has been a practice in the past, and it's been a bit challenging to get tillage farmers to take it because fertiliser was cheap, but recently it's become easier to do that. So moving that [animal waste] from here with us in production out to being a fertiliser* (Participant 9).

However, challenges were expressed regarding reluctance among farmers to use organic fertiliser due to convenience associated with artificial alternatives. This reluctance underscores the need for education, incentives, and infrastructural support in the area. Regulatory hurdles and logistical challenges were also emphasised, such as ensuring uniform application and quality control of organic fertilisers like slurries. Suggestions for centralised management systems and deregulation efforts highlighted potential strategies to address barriers and facilitate more efficient resource utilisation.

4.3.4 Financial aid for circular/sustainable practice

Nine participants made reference to the use of financial assistance in developing circular and sustainable practice within the company.

> *'So as members of Bord Bia we qualify to apply for the NDP Horticultural Grant, so it's the Irish National Development Plan Horticultural Grant, which is announced each year. And you can apply for specific horticultural equipment and avail of the grant funding. So that has been an excellent scheme to help relatively small-scale vegetable growers or horticultural growers to invest in all different types of machinery. Yeah, so the TAM scheme, which is a European scheme obviously, and administered through the Department of Agriculture. We have availed of that although that's more applicable to probably large -*

scale tillage growers and beef and dairy and sheep, you know. So that is probably the go-to scheme for investment funding along with that we make up the balance with our own investment then' (Participant 13).

However, some emphasised that funding initiatives tended to be more applicable to larger enterprises, with bureaucratic delays problematic. Other participants emphasised that, although funding was commonplace (e.g. from Enterprise Ireland and Inter-Trade Ireland), there was less on offer in respect to circular practice or sustainability more generally. In summation, although participants described funding opportunities as important for enhancing circular practice, many highlighted several limitations as scale, processing delays, cumbersome procedures, administrative complexities, resource allocation challenges, and limited focus on circular practices.

4.3.5 Education

Six participants discussed how educational programmes were important in facilitating circular and sustainable practice within the company:

'There's constant innovations coming out and progressions in the likes of especially AgTech, and their supports there. We actually did the Accelerator, the UCD one, the AgTech. And there's competition to get into them, which is positive and shows that there is progression and everyone's kind of looking down that route. And sustainability and tech, I think there is strong developments going on there' (Participant 1).

Participants described how training and education initiatives offered valuable opportunities for enhancing a companies' circular practice. Challenges includes limited access to programs, the resource intensive nature of participation, the relevance of certain courses, and geographic constraints. Addressing such challenges through innovative delivery methods, improved accessibility, and update content can potentially improved such initiatives.

4.3.6 Collaboration/partnership in circular and sustainable practice

Another avenue for enhancement related to a companies' promotion of circular and sustainable practice amongst primary producers. Participant 3 talked about encouraging customers (farmers) to practice circularity when buying and selling material from the company:

'We do appreciate when customers that are bringing in barley buy the spray off us and keep it going that way. And then the same in many different aspects. If we've stuff going out that it comes back in and stays, kind of, going in a circle, and stays loyal, I suppose, to customer base, and that they do the same in return and keep everything moving. And I suppose that goes across in many different aspects, whether it be dairy or beef or anything, the same with milk processors, that you take inputs and give back outputs, keeping everything moving along and everyone kind of supporting each other' (Participant 3).

Other participants discussed specifically tailored sustainability programmes which incentivise collaborating farmers to be more sustainable. Participants described promoting circular practice with farmers through encouraging return of inputs and building loyalty in order to foster long-term relationships, through setting environmental targets and prescribing supply chain requirements (e.g. Bord Bia membership), and through knowledge sharing and education (e.g. field days, open days, best practice demonstration).

4.3.7 Use of anaerobic digestion

When outlining a company's approach to circular practice five participants discussed how waste was sent to anaerobic digestion (AD) plants. Two participants emphasised that if the AD plant was not in close proximity to their facility, use of such facilities would not be feasible:

'Well, we have the AD plant, the blood and the sludge from the slaughter area goes to the local anaerobic digester unit. It's only five kilometres down the road. Yeah, we're just fortunate in that regard. And it gets converted into biogas. Yeah, methane and fertilizer. But if it wasn't close to us, it wouldn't be feasible' (Participant 10).

Another participant discussed the difficulty in initially organising the logistics of using an AD facility for their company, highlighting how the actual plant being used was located over 300 km from company headquarters. Even more interestingly, two participants discussed how their companies actually had their own AD plants but located in Northern Ireland rather than Ireland due to regulatory and planning constraints. When discussing AD, the low infrastructural development of biorefinery plants in Ireland seemed very apparent. The fact that participants describe the preferential development of AD plants in Northern Ireland over Ireland emphasises the extent of the problem. This issue will be discussed in relation to barriers to circular practice, but seems to be associated with issues around planning, finance and a general lack of incentives. Beyond such issues, it is of paramount importance that measures are taken to ensure that all

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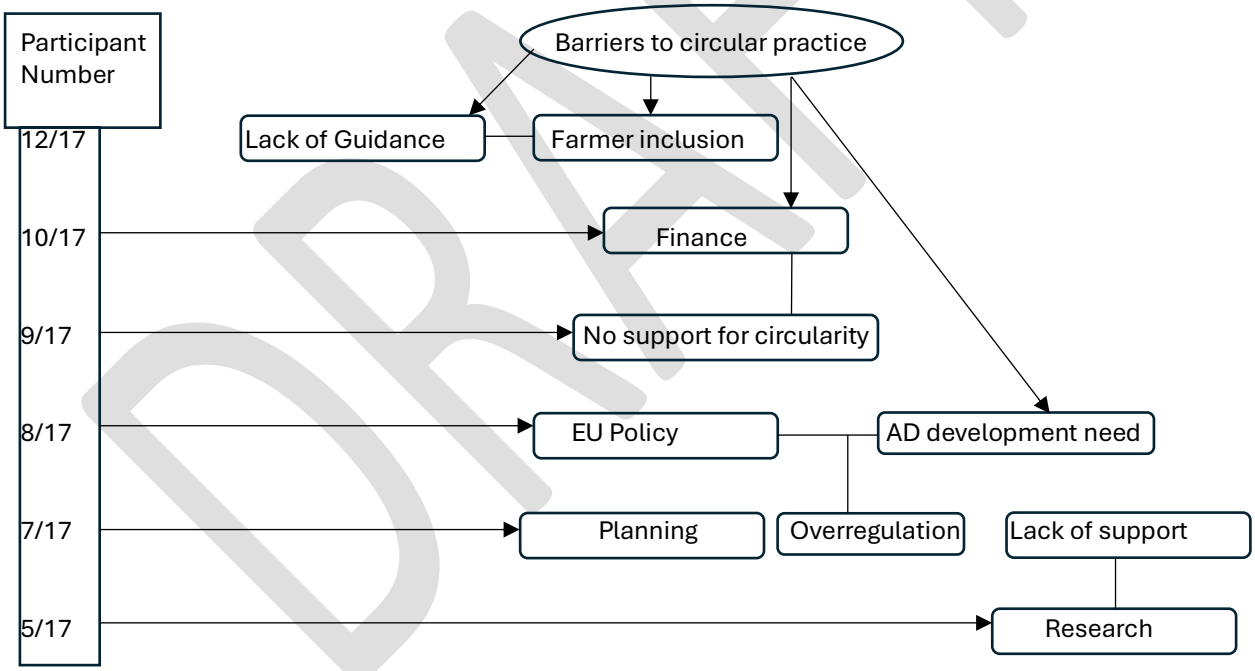
agri-food can easily integrate waste streams into biorefinery infrastructures. The most obvious point here is that biorefinery development in Ireland needs to be ramped up significantly and such infrastructures need to be more commonplace in Ireland.

4.4 Barriers to Circular Practice

The other key question participants were asked to describe regarded whether they perceived any barriers to circular practice at the current time. Once again, this major theme was also classified in other sections of the interview discussion as previously described. Figure 7 describes the key inductive themes emerging from respective interviews (also) as previously described:

Figure 7: Barriers to Circular Practice – Frequency of Citation



4.4.1 Lack of Guidance and Expertise

Lack of guidance and expertise was seen as one of the main barriers to circular practice in the agri-food sector, cited in twelve out of seventeen interviews.

> *'And a lot of people that's making the policy wouldn't have any farm background or knowledge at all, you know. See, this is it, and that's the problem. Sometimes when the*

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department releases a policy on different programmes and schemes, etc, you'd scratch your head a lot at the time, you know' (Participant 14).

Participants expressed frustration with the current suite of policies regarding circular practice. Practitioners also noted a lack of understanding of farming practices amongst policymakers, portraying a disconnect between policy-making and the on-the-ground application. Other participants emphasised the need for demonstration science and technologies to provide evidence for the feasibility of circular practice. Movement of personnel within governmental departments was also cited as a major barrier. Such movements were said to disrupt the continuity of knowledge transfer since relationships built around specific initiatives like regenerative agriculture, were said to be lost when personnel are reassigned, essentially resulting in a loss of expertise in respective areas. More generally, many participants expressed frustration with the lack of clear guidance and timelines from regulatory bodies, causing uncertainty regarding future regulations and reporting structures. Many participants expressed the feeling of being ill-equipped to navigate the complexities of current and future expectations regarding transitioning towards the bioeconomy, calling on the need for practical support, training, and financial assistance. Further developing this argument, participants expressed concerns regarding the inadequacy of support for companies to comply with emerging regulations, such as the CSRD (Corporate Sustainability Reporting Directive). Although collaboration and shared resources were thought to have potential in accelerating progress towards circular practice, the absence of common standards and tools, such as carbon calculators, was said to impede collective action. In general participants expressed a pervasive sense of frustration and a recognition of the urgent need for more practical guidance, knowledge sharing, and support mechanisms to facilitate enhanced circularity.

4.4.2 Farmer inclusion

In twelve cases participants also cited farmer inclusion, or lack thereof, as a major barrier to circular practice in the bioeconomy, emphasising a lack of inclusion in decision-making processes and policy development as problematic.

> *'And we just need to, in terms of the bio economy, I suppose, I think one important thing is to bring the growers and the primary producers along the journey in order to make everything like work and to get on the ground, you know, kind of feedback around how it could work and stuff. I just feel that we need to have a lot of buy-in from the primary producers so that all of the kind of practical considerations that might not, you*

know, that the people in labs, and whatnot, might not be aware of, are considered' (Participant 6).

The necessity of bringing farmers to the forefront of discussions and actions was heavily cited. Failure to do so was considered to lead to oversights regarding practical considerations and challenges unique to agriculture. It was stressed how farmers possess valuable insights and practical knowledge that is required for policy and initiatives to be effective. Participants advocated for bringing farmers "along the journey", thus facilitating farmer buy-in to ensure the success and practicality of proposed solutions for bioeconomy implementation.

Most participants highlighting these issues also referred to the scapegoating of farmers in respect to climate change and carbon emissions, without considering the broader context of other sectors. Participants argued that while agriculture is a leading contributor to emissions, other sectors, such as construction and aviation, also play significant roles but receive less scrutiny. This was thought to exacerbate the problem, hindering the effectiveness of circular initiatives but also leading to unfair pressure on individual farmers while ignoring the complexities of food security, and the constant and ever-increasing demand for food within production systems. Participants expressed concerns about the pressure and expectations placed on farmers, primarily regarding the demand for increased food production while simultaneously facing criticism for environmental impacts. This dynamic portrayed disconnect between societal demands for more products and the blame placed on farmers for meeting those demands. It was expressed how this perception contributes to a sense of frustration and unfair treatment within the agricultural community and stands as a major barrier to enhance circular practice. The need for a more nuanced and inclusive approach was heavily cited. An approach involving meaningful engagement, recognition of farmer contribution, and a broader perspective that considers the roles of other sectors in environmental sustainability.

4.4.3 Financial barriers and lack of support for circular practice

Financial barriers and lack of support for circular practice was also seen as a major barrier to in ten interviews.

'So we're not subsidised. We do it because we want to be part of the Origin Green sustainability thing. And because it's the right thing to do. But we don't get any financial benefit or support for it. In terms of barriers, well, it costs. That's the barrier. And sometimes it costs more to do the right thing than the wrong thing. We certify that we actually put out

our own waste food into the certified food recycling facility. And that has a cost. Whereas if we actually put it in the skip, it would be cheaper. So like it's slower. Everything's segregated and keeping everything separate, and doing the paperwork, and doing the compliance, that take time' (Participant 17).

Participants discussed how circular practice was associated with higher costs, particularly in terms of sustainable waste management and purchasing sustainable packaging. In this case it was emphasised that opting for environmentally friendly options ended up being more expensive than conventional alternatives. This financial aspect was described as potentially deterring companies, particularly if such companies needed to consider their bottom line and competitiveness. Another notable point was the need for investment and resources in circular practice solutions. Participants focused on the lack of viable alternatives and insufficient support or investment in developing sustainable packaging and infrastructure. In the absence of adequate resources, respondents described it as challenging for companies to adopt circular practice on any large scale. There was also the recognition that for widespread adoption, there needs to be a balance between environmental concerns and economic viability. Participants suggested that until financial assurance or support existed, particularly from government, the transition to the bioeconomy may be slow or limited. Interviews highlighted the complex interplay between financial considerations, resource availability, and the need for supportive frameworks to drive circular practice. While there was evidence of a willingness to engage in circular and sustainability efforts, overcoming financial barriers and ensuring viable alternatives remained a key challenge.

Related to the issue of finance, participants also pointed to the apparent lack of government support for circular practice. A desire was expressed to learn more about potential incentives and assistance available but whether such initiatives existed was questioned, with limited involvement or awareness of such programs apparent amongst all participants. A clear distinction between support received from a business perspective, such as grants for purchasing equipment or hiring staff, and support specifically targeted towards sustainability efforts was established. Participants acknowledged that while they may have received assistance for business-related activities, sustainability initiatives had not been a primary focus of these support mechanisms. Findings indicated how the absence of targeted support hinders a company's ability to invest in circular and sustainable technologies, infrastructure, and practices, thereby impeding progress towards an enhanced circularity.

4.4.4 Concerns regarding EU policy and national governance

Eight participants also expressed concerns regarding the direction of EU policy.

> *'And the European Union, I suppose is being questioned as well, is it trying to cut productivity? Is it trying to reduce productivity? Circularity is obviously important and all that, but are we looking to cut productivity? Whereas most other regions, the USA have done reports on this, are looking to see where they can optimize. Obviously, trying to mitigate emissions, and you're trying to look after the environment and protect air and water quality and soil health and biodiversity. But can't you do this without compromising productivity? Because we still need food in Africa, a lot in Ireland. We still have a lot of food insecurity, and in particular nutrient insecurity'* (Participant 1).

Such concerns primarily related to the difficulty of balancing expectations in relation to environmental sustainability whilst maintaining productivity and competitiveness in a global market. Some participants appeared uneasy in relation to whether EU regulatory frameworks might inadvertently hamper productivity and competitiveness. Interviews revealed a discernible tension between the EU's focus on circularity and environmental protection on the one hand, and a perceived negative impact on production on the other hand, with many questioning whether environmental goals can be achieved without compromising productivity, especially given the need to ensure food security, both locally and globally. The issue of global competitiveness emerged prominently. In this regard, participants expressed frustration that while EU companies adhere to stringent environmental regulations, competitors in other regions operate under less stringent rules, placing the EU at a disadvantage in respect to global markets. It was portrayed how such discrepancies raise concerns regarding fairness and competitiveness in global trade. Some participants specifically referred to the EU's Green Deal and its ambitious targets, such as increasing organic production, and how this presents significant challenges to countries such as Ireland, whose current organic production is significantly lower than other EU nations, exhibiting scepticism regarding the feasibility of achieving such targets. In respect to national (EU influenced) policy, participants felt frustration with the uncertainty surrounding government policies and regulations, which were described as hindering long-term planning and investment in sustainable and circular practice. This uncertainty, coupled with the perceived lack of acknowledgment for existing sustainable practices, was portrayed as creating a sense of unease.

4.4.5 The requirement for AD development and planning

The necessity for increasing anaerobic digestion (AD) development in Ireland was another important finding, with eight participants discussing the issue. Discussions related to the recognition of administrative barriers that need to be overcome in order to facilitate the expansion of AD infrastructure. Participants cited that the lack of financial support as a significant barrier to AD development. The need for developing new technologies to enhance the efficiency and effectiveness of AD processes was also discussed. In particular, the significant challenges posed by planning regulations and public opposition to the development of AD plants was seen as paramount. Participants expressed frustration with the planning process in this respect, citing examples of local growers facing obstacles due to objections from residents concerned about potential nuisances like odour or noise.

> *'There's a grower who put in for an AD plant just locally and he's just encountered no end of difficulty from the planning process. He's been denied, and it's actually, you know, it's down to, I think from what he, you know, from what I heard, now this isn't direct from him, it's down to a resident who's not even from the area who is worried that it's going to, like, smell or might be a little bit noisy or something like that, you know. We would be interested in sending some of our byproducts to this guy because he's very close. It would suit us, but he just ended up not to even bother doing it because of the planning problems he was encountering. So, if we're going to switch to this bioeconomy and have a nation that's teeming with AD plants that are giving us clean energy and contributing to the circularity of things, we just need to get around this. I suppose it's the same with, what was happening with the wind turbines for a long time, we just need to start the work now to kind of educate the public about like, you know, there are certain prices that you have to pay. That really, in the big scheme of things, it's great are to have renewable energy in your area. So planning would be one big thing around that to us'* (Participant 6).

These concerns, while valid, were said to result in the denial or delay of planning permissions. This highlights a key barrier to AD development, as even interested parties are deterred from pursuing AD initiatives due to planning difficulties. Participants went on to discuss the lengthy and arduous nature of the planning process for AD development. The considerable time and effort required to navigate through planning bureaucracy was discussed, underscoring the need for streamlining planning procedures to expedite the implementation of AD projects. Participants emphasised how government action is required to ease the path for AD projects, similar to efforts made for other infrastructure developments such as roads. This implies a

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need for policy changes or incentives to support the expansion of AD infrastructure and overcome planning obstacles.

4.4.6 Overregulation

Seven participants discussed how overregulation impacted negatively in achieving circular practice within the company. Participant 14 expressed frustration regarding the increasing regulatory burden and paperwork involved in farming:

> *'So I just think like when it comes back to getting all of this regulation, all of this extra work. So most of the job now seems to be like paperwork. It's paperwork and tracking all of that. And more stuff for the department and more of this and more sanctions. And I just think it's a very, very hard life to be in farming at the moment'* (Participant 14).

Other participants discussed the increasing regulatory burden on farms and emphasised the lack of financial benefits despite the extra work required to comply with regulations. Another participant discussed the feasibility of achieving certain expectations within given timeframes, highlighting the need for realistic and pragmatic approaches to achieving sustainability goals in the agri-food sector. In general, participants emphasised the challenges associated with increasing regulations, paperwork, and expectations. There was a common theme of feeling overburdened with administrative tasks and regulatory compliance without commensurate rewards or support. This highlights the need for policymakers and stakeholders to consider the practical implications and economic viability for practitioners while implementing regulatory frameworks and setting sustainability goals. Balancing regulatory requirements with adequate support and incentives for practitioners is crucial for ensuring circular and sustainable practice in the bioeconomy.

4.4.7 The need to promote (already) sustainable activity, including valorisation

Seven participants highlighted the need for government agencies to recognise and promote sustainable activity in agri-food business. One participant discussed ongoing negotiations with government agencies regarding the need to recognise materials as valuable resources (byproducts) rather than waste. Another participant highlighted the challenges faced by the poultry sector in promoting its sustainability achievements and gaining government support without overshadowing, or negatively impacting, other sectors such as the beef industry. The

participant notes that while poultry production is statistically ten times more sustainable than beef production, there are limitations imposed to openly advertising the fact on packaging or in marketing efforts:

> *'Well, the priorities of the government definitely seems to be to keep a steady state with the beef industry in particular. Statistically, we're ten times more sustainable than beef, but they don't want us advertising that. They don't want that appearing on poultry packaging, they don't want us singing and dancing. We can kind of say it quietly, but you can't go from the rooftops because nobody wants to damage the beef industry. It would be detrimental to the agri-sector as a whole, and therefore you don't want to do that. And that shouldn't be anybody's intention. But how then do we get government support to keep us up there too, as important to the economy as a whole and for people to know that we're more sustainable without doing anything? How do we get support to keep us that way and to keep everybody else?'* (Participant 9).

Another participant discussed how the idea of carbon neutrality was presented to them, prompting them to question why they are not actively promoting their carbon-neutral status. In such discussion, participants emphasised the challenges of promoting sustainable activity within the context of regulatory constraints, industry competition, and communication strategies. The government's role in promoting sustainable practice was highlighted in terms of reframing waste as byproduct, balancing sustainability promotion without undermining existing sectors, and leveraging carbon neutrality for brand image and consumer trust.

4.4.8 Lack of support for certain (smaller) sectors

Seven participants discussed how supports tend to favour larger sectors and larger enterprise. Participant 14 discussed how support received was designed for larger companies, creating practical difficulties for smaller businesses:

> *'But one complaint to the one challenge we've had with that, it [supports] was designed for their larger client base. Therefore, it's not really fit for purpose, the type of measurements they ask for. So, you know, it's not practical to look at. So, for instance, they would ask you, even just practically, they would ask you to appoint a sustainability manager to deal with it. We only have like three employees, so we can't appoint somebody to deal with it'* (Participant 14).

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Other participants discussed the challenges faced by smaller businesses in accessing funding and loans from banks, particularly through government-backed schemes designed to support them. Others outlined the challenges faced by small and medium enterprises (SMEs) in navigating government agencies and accessing support compared to larger companies, and specifically in respect to market access, the high failure rate for new products, cumbersome interactions with government agencies, and the lack of tailored support for SNMs. Participants described the systemic challenges faced by small businesses, including inadequate support structures, funding limitations, and regulatory burdens that disproportionately affect their operations and growth prospects compared to larger companies.

4.4.9 The research-led approach to bioeconomy development

Five participants discussed barriers to bioeconomy development associated with the nature of research and innovation in Ireland. One participant discussed the need to more away from research and innovation towards a readiness to engage in direct actions, indicating a sense of urgency and a desire for tangible results. Another participant suggested that while it was beneficial to have access to supports and research funding for exploring new projects, the ultimate challenge lies in translating these efforts into meaningful business outcomes. The participant highlighted the importance of having a clear endpoint or goal in mind, beyond just accessing support or funding, to ensure that efforts are aligned with achieving tangible results. Participant 2 describes frustrations experienced when working with universities whom lack perseverance in tackling challenges contributing to a culture where failure is accepted without exploring all possible avenues for success:

> *'We had financing in AD, it didn't work because of nitrogen. But the problem is that they gave up at that stage. Whereas we should have looked at how do we remove the nitrogen, how do we manipulate the system to get less than a thousand PPM amonia in the digester. So then they should have looked at that. But they didn't. So instead the technology was thrown away, which was central. It was grant aid by Europe and everything, but once they showed that it didn't work, that was that. And that's the problem with universities. I don't know. Universities love doing research. And any answer, any number, any answer they get is value to them. Even if it doesn't work. And I've done millions of other research projects with universities and I've stopped because they think, it doesn't work, is a great answer'* (Participant 2).

In respect to research and innovation, participants identified problems related to the lack of an action-orientated approach within institutions, a disconnect between research and business outcomes, and a lack of perseverance and problem-solving. Participants highlighted the importance of bridging gaps between research and practical implementation, as well as ensuring that research efforts are aligned with clear business objectives to drive meaningful innovation in the bioeconomy.

4.4.10 Issues related to Intellectual Property

When discussing research and innovation, participants also mentioned the fact that intellectual property (IP) was an issue. Participant 2 describes a sense of betrayal or disappointment in the way universities initially engage enthusiastically but then "fade away" once problems arise or the project doesn't meet expectations. This sense of betrayal is accentuated by the suggestion that universities seem to take ownership of IP rights:

> *'I've invested time and money and resources and it didn't work, which means I'm out of pocket. So failure isn't an option. And that's my biggest problem with the involvement of universities in research. They take the IP, they take control, they take your money and they don't listen to you. Once you've signed the dotted line and they all say we're only going to work together here. We're only going to get the right result. And then it goes pear-shaped. They're still around dancing around the table because they've got the money off me. They've got a load of finance off Enterprise Ireland. And I'm sitting there with my money gone and they just go off. They fade away, they were your best friend for the first three months or six months of a research project for two or three years. But then they're gone'* (Participant 2)

One participant described the complex interplay between collaboration, confidentiality, and IP protection in research and development, highlighting the challenges and importance of creating frameworks that address these concerns effectively. Another participant emphasised the importance of protecting IP while being cautious about potential risks associated with government support. Overall, participants emphasised the challenges they face in research and development environments in respect to IP protection, confidentiality, collaboration dynamics with universities, and navigating government support while safeguarding IP assets. They reflect the importance of clear IP management strategies, confidentiality agreements, trust-building in collaborations, and aligning funding sources with IP protection goals to ensure sustainable research outcomes.

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5. Discussion

5.1 The Meaning of Circular Practice

It is first important to note that two out of seventeen participants were not familiar with the term circular practice. However, in both cases participants went on to discuss the various forms of circularity taking place within their respective companies but associated such practices with sustainability rather than circularity. In general, definitions of circular practice broadly aligned with the key principles of circularity such as the reuse of materials, waste reduction, and resource efficiency. This reflects definitions found in the literature, for example, in a systematic analysis of 221 definitions of the circular economy, Kirchherr et al. (2023) found recycle (78%), reuse (73%) and reduce (52%) terminology were amongst the most cited principles associated with the concept. This alignment between practitioner and academic understandings of circular practice is both important and encouraging since it points to a clear consensus, which is an important clarification for policymaking.

Such alignment provides potential for a shared framework of assumptions and objectives and can facilitate cohesive policymaking across various political administrations, industries, and stages of product life cycle. Consensus understanding also supports alignment between a companies' circular practice initiatives and those of partners and suppliers, while also enabling researchers to engage in interdisciplinary discourse for the benefit of bioeconomy development. The broad scope and complex challenges inherent in bioeconomy transition emphasise the importance consensus on the meaning of circular practice since consensus is imperative to prevent conflicting interpretations, which have the potential to hinder bioeconomy implementation.

Nevertheless, although findings are generally encouraging, the fact that two participants were unclear what the term circular practice meant, even though they were engaged in such practices, does point to a certain deficit in terms of communication and policy engagement. The deficit, although small is fundamental, since participants were specifically selected based on their companies' association with bioeconomy research institutions in Ireland and/or their membership of the An Bord Bia Origin Green initiative. Hence this knowledge gap signals a potential need for increased awareness and education initiatives regarding circularity. As such, policymakers should consider developing targeted educational programs or resources to raise awareness about circular practices within the agri-food sector. These initiatives can ensure that all practitioners are equipped with the knowledge and vocabulary to recognise and articulate their circular efforts. Policymakers may also need to revisit existing definitions and frameworks

surrounding circular economy concepts in disseminated outputs to ensure that definitions and references are accessible and applicable, choosing clear and concise definitions to help practitioners better understand and identify circular practices within the own operations. The deficit also underscores the importance of ongoing engagement and collaboration between policymakers, industry stakeholders, and academic experts. By working together to develop and promote best practices, policymakers can support the adoption of circular practice principles more generally throughout the agri-food sector.

5.2 Meaning of the Bioeconomy

When it came to defining the bioeconomy seven out of seventeen participants were unclear what the term meant, a significant number. Participants familiar with the term, provided definitions generally in line with key themes and concepts found in the literature, such as sustainability, circularity, resource efficiency, and the integration of environmental, social, and economic factors. However, there were also instances of scepticism, uncertainty, and questioning about the practical implementation and effectiveness of bioeconomy principles.

The fact that seven participants were unfamiliar with the term, considering the cohort, is concerning, and suggests that bioeconomy activity in Ireland is in its infancy. Importantly, this gap in understanding indicates that many practitioners may not fully understand the potential of bio-based resources, processes, and products in driving sustainable economic growth. For policymakers, this lack of familiarity highlights the importance of creating policies and initiatives that promote and support bioeconomy development. This could include the integration of bioeconomy principles into broader agricultural and economic policies. The knowledge gap also suggests potential market opportunities for businesses and entrepreneurs in the bioeconomy space. With a significant portion of the industry still unaware of bioeconomy concepts, there may be untapped potential for innovative bio-based products and services in Ireland. This lack of knowledge calls on the need for greater engagement and collaboration between government agencies, industry associations, research institutions, and businesses can help drive development and adoption of bioeconomy solutions. More generally, lack of familiarity the bioeconomy highlights the importance of proactive efforts to promote awareness, educate stakeholders, and develop supportive policies to harness the potential for enhancing bioeconomy development in Ireland.

5.3 Enhancement Pathways for Circular Practice

5.3.1 Recycling and reusing materials (particularly product packaging)

As an enhancement pathway, sustainable packaging can be seen as a fundamental approach in enhancing sustainable food production in the context of climate change mitigation. This can be achieved by moving towards 100% recyclable packaging in the short-term, and as bioeconomy infrastructure becomes more sophisticated, towards 100% biodegradable packaging. Packaging itself plays a pivotal role in food waste reduction since it preserves food through regulating gas and vapor exchange with the surrounding atmosphere (Krochta, 2018). However, moves to replace oil-based packaging with renewable resources is still in its infancy, and in the meantime, it is important to choose the right alternative. Bio-sourced bioplastics currently available on the market, such as Bio-PE and bio-PET, utilise food resources like corn or sugarcane (Sid et al., 2021). However, such approaches have been criticised for exacerbating food security concerns and intensifying pressure on agricultural land (Putri, 2018), and, perhaps more importantly, for not actually being biodegradable or suitable solely for industrial composting (Emadian et al., 2017). Microbial (bio-polyesters) engineered polymers are a superior alternative since they facilitate the transformation of agricultural and food waste into biodegradable packaging (Samir et al., 2022). Of the biodegradable microbial polymers currently available, Polyhydroxyalkanoates (PHA), including the copolymer polyhydroxy (butyrate-co-valerate) P(HB-co-HV), stand out as highly promising alternatives to petroleum-derived synthetic polymers (Nhu et al., 2024). However, the effectiveness of such emerging and innovative packaging solutions are seldomly evaluated on any large-scale, and end-user information is often difficult to understand (Jahanbin, 2022). According to Monborren-Benabdillah (2015) nearly half of all food and packaging experts lack a comprehensive awareness of the latest technological developments. Similarly, consumers also lack awareness and remain sceptical regarding new products and technology related to packaging (Aday and Yener, 2015).

In alignment with circular economy principles, the next generation of biowaste-based materials is expected to create an innovative, more resilient, and productive waste-based food packaging economy by converting waste into new materials (100% biodegradable bioplastics) (di Bartolo et al., 2021). This process decouples the food packaging industry from fossil feedstocks and allows nutrients to return to the soil (*ibid*). Furthermore, utilising these organic residues in an upcycling loop through bio-conversion processes such as aerobic accumulation and anaerobic digestion is expected to facilitate the production of new materials (bioplastics), energy (to be reused for the food and packaging production steps), and ultimately, some fertilisers (Dahiya et

al., 2018). According to the Ellen MacArthur Foundation (2015), transitioning the current food and packaging industry to a circular development path could generate annual total benefits of up to €0.6 trillion in Europe. Therefore, recovering agri-food waste and by-products and developing industrial biorefinery units to process and convert such raw materials into biomaterials, with high added value and applicability for producing sustainable packaging, can be a solution for a more sustainable food packaging sector (Cristofoli et al., 2023).

Within a biorefinery model, a circular loop system is employed involving the recovery of raw materials from agri-food waste and by-products to be used as suitable packaging biomaterials (*ibid*). After being used, packages undergo further processing so they can return to nature and revert to raw materials again (zu Jeddeloh et al., 2022). These materials possess biodegradable properties, offering new end-of-life routes, such as organic recycling by aerobic or anaerobic degradation, agricultural mulching, solubilisation, or environmental biodegradation, thus reducing waste accumulation and environmental pollution (Ortega et al., 2022). Part of this loop involves the concept of food waste biorefineries, which have been at the forefront of technological development for food waste recovery in recent years (Cristóbal et al., 2018). In terms of profitability, each biorefinery has its particularities, especially in the case of food waste biorefineries. According to Jorissen et al. (2020), industrial and municipal food waste processing has slight economic advantages over the processing of agricultural waste due to its lower market value. Other associated costs, such as logistics, storage, and operational capacity, are crucial factors for economic viability (Cristofoli et al., 2023). Banerjee et al. (2022) suggest that for a biorefinery to be economically sustainable, it requires a multi-feedstock plant capable of overcoming factors such as raw material seasonality and continuous biomass supply.

Zhang et al. (2022) considers the biorefinery model as a promising, economically viable, approach for producing biomaterials for food packaging (Zhang et al., 2022). In general, agri-food wastes and by-products use to be undervalued, but they are now one of the most attractive options for raw materials to produce biodegradable packaging and improved performance (Guillard et al., 2018). The conversion of food waste usually requires a pre-treatment step where complex food waste is broken down into subcomponents (Nielsen et al., 2017). These agricultural wastes may be processed to produce fiber and polymers, which can be used in packaging applications such as bioplastic packaging, trays, containers, disposal packaging, and food coating (Abotbina et al., 2022). Using bio-derived materials is advantageous because they are derived from agricultural sources and are renewable, nontoxic, and recyclable, resulting in reduced costs (Cristofoli et al., 2023).

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However, several issues related to the recovery of agri-food waste and by-products are important to consider. Some biorefineries face challenges in handling large feedstock volumes due to the seasonality of certain products (Giuliano et al., 2016). Additionally, there are a lack of studies indicating the best way to centralise waste management (Cristofoli et al., 2023). Biorefineries may be reluctant to cover logistics costs if they exceed the added value of biomass (Xu et al., 2020). Consequently, the agroindustry often opts to dispose of waste in incinerators or landfills (Azelee et al., 2020). Furthermore, the current methods of processing and producing some biomaterials from food waste and by-products on a laboratory scale indicate low yield (Singh et al., 2019). One possible solution could be to integrate production in a multi-feedstock biorefinery model from the same bioproduct (Garcia-Ochoa et al., 2021). In general, the increasing trend of studies related to the production of sustainable packaging from agri-food waste and by-products highlights the potential of this sector (Bhat, 2021). Despite some difficulties, biodegradable, compostable, or reusable food packaging production can provide packaging suitable for sustainable bioeconomy development.

5.3.2 Sustainable development Initiatives

Findings indicated how sustainable development initiatives in the agri-food sector played a crucial role in enhancing circular practice by fostering a culture of accountability, innovation, and continuous improvement. Initiatives like Repak membership and programs such as Origin Green were described as providing platforms for companies to gather information, collaborate with stakeholders, and implement strategies aimed at reducing waste and optimising resource use. By engaging with suppliers and evaluating packaging materials, companies described being able to identify opportunities to minimise waste generation and improve packaging efficiency. Certification programs like Origin Green were portrayed as incorporating sustainability principles into business operations by setting broad goals and encouraging companies to set their own targets aligned with their sustainability objectives. The approach was described as empowering, whereby companies tailored initiatives to their specific circumstances while working towards overarching sustainability goals. Additionally, the absence of strict mandates on recycling volumes was said to foster a flexible and adaptive approach to sustainability, allowing companies to focus on holistic waste reduction strategies rather than meeting predetermined quotas. On the other hand, the auditing process was depicted as ensuring transparency, credibility, and adherence to sustainability standards. External audits conducted by independent third parties, were described as providing an objective assessment of companies' sustainability performance, reinforcing the importance of accountability and integrity in

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sustainability practices. By undergoing rigorous audits, companies seemed motivated to maintain high standards of sustainability and circularity, driving continuous improvement and innovation within the sector. In general, sustainable development initiatives were described as catalysts for advancing circular practices in the agri-food sector by promoting waste reduction, encouraging goal-setting, and ensuring accountability through rigorous auditing processes.

5.3.3 Alternative uses for agricultural byproduct

Biological materials such as compost, plant byproducts, cover crops, animal manure, and other organic substances can serve as fertiliser to enhance yield (Meddich et al., 2020). Similarly, organic waste leftovers or residues from primary industries like blood, fish emulsion, bone meal, cottonseed meal, and wood ash can all be utilised as natural fertilisers (Shaji et al., 2021). The significance of their widespread use cannot be overstated, as it enriches the organic composition of soil and provides essential organic nutrients (Chen et al., 2018). One notable difference between organic and synthetic fertilisers is the presence of carbon, which slows down the release of nutrient ions (Uzunlu, 2022). This slower release enhances the overall physical properties of the soil, ensuring sustained availability of nutrients, soil aeration, and preventing root burn and leaching losses compared to synthetic alternatives (Rashid et al., 2021). Organic fertilisers serve as an energy source for soil microorganisms, thereby enhancing soil structure and promoting plant growth (Rashid et al., 2021). They also release nitrogen, phosphate, and potash in forms easily absorbed by plants (Hue and Silva, 2000). Essentially, organic fertilisers offer long-term protection to agricultural land from the harmful effects of synthetic alternatives, which can lead to soil degradation and pollution (Verma et al., 2020). Governments and policymakers should promote the widespread use of organic fertilisers to phase out unsustainable alternatives. Education is crucial in this regard, but a centralised distribution system, as suggested in interviews, would also facilitate widespread adoption.

5.3.4 Financial support for circular and sustainable practice

Unsurprisingly, financial support was seen as crucial for enhancing circular practices in the agri-food sector. Participants described how such support provides resources and incentives for businesses to invest in sustainable initiatives and innovations. Government schemes, such as the NDP Horticultural Grant and the TAMS scheme, were described as offering financial assistance for purchasing equipment for sustainable practice. Such grants were perceived to enable small-scale growers and farmers to invest in machinery and technologies to promote circularity, such as composting equipment, renewable energy systems, or precision agriculture

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tools. Organisations like Enterprise Ireland and Inter-Trade Ireland were also described as essential in the provision of funding and assistance to develop and implement innovative solutions, extending to initiatives aimed at improving sustainability and resource efficiency within the agri-food supply chain. Whether through grants for research and development, subsidies for implementing eco-friendly practices, or assistance with market expansion, financial support from these organisations was considered important in order to explore new avenues for achieving circularity. However, challenges were also emphasised. These included delays in processing grant applications which hindered the timely implementation of projects, impacting the ability of farmers to address pressing issues such as nutrient storage. More generally, while supports were seen as available, a need for improvement was also emphasised, especially in terms of accessibility, efficiency, and adaptation to the specific needs of different types of operations, particularly for smaller-scale operations.

5.3.5 Education

Education was also seen as important in enhancing circular practice. It was described as serving as a catalyst for driving positive change and facilitating the adoption of circular practices by empowering individuals with the necessary knowledge, skills, and resources to implement sustainable solutions. In this respect educational institutions and government agencies were described as providing valuable opportunities for individuals to stay updated on the latest innovations and advancements in agricultural technology (AgTech) and sustainability practices. Education initiatives like the Acres program and Bord Bia Origin Green courses were described as platforms for disseminating information on key topics such as water quality management and sustainability standards. However, participants also emphasised the need for greater accessibility, particularly for individuals in rural areas or those with limited resources. For example, in an effort to reduce geographical barriers to participation, the expansion of online courses and resources was mentioned frequently. Offering a mix of in-person and online courses, as well as providing options for self-paced learning, was seen as important. It was also discussed how education programs needed to be regularly updated to ensure relevancy to current industry trends and challenges. Incorporating emerging topics such as water quality management and sustainable agriculture practices into course curriculums was mentioned in particular. Collaboration between educational institutions, industry experts, and government agencies were identified as a way of prioritising inclusion in educational programs. It was also highlighted how the delivery of educational programs should be flexible to accommodate different learning preferences and schedules.

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5.3.6 Collaboration

As mentioned in relation to other points of discussion, the role of collaboration was seen as pivotal in promoting circular practice. Collaboration between suppliers and customers was described as important for ensuring that resources are reused and recycled within the supply chain. The importance of returning by-products was described in respect to creating a closed-loop system where inputs and outputs are continuously circulated and reused. Such collaborative approaches were thought to promote loyalty and support among stakeholders while minimising waste and maximizing resource efficiency. Collaboration between producers and regulatory bodies, such as Bord Bia, was portrayed as driving sustainability initiatives and encouraging best practice. In this respect, participants discussed programs that incentivise farmers to adopt sustainable practices whereby targets for environmental conservation and resource efficiency are set. Collaboration between industry players and research institutions was also seen as important in facilitating innovation and knowledge exchange, leading to continuous improvement in agricultural practices. Participants highlight initiatives focused on efficiency performance, genetics, and biodiversity, which aim to reduce carbon footprint and enhance resource efficiency on farms.

5.3.7 The use of anaerobic digestion

For those whom were able to access anaerobic digestion (AD) plants, either through geographical proximity or as a component of the business itself, such facilities were described as effectively managing waste streams, converting these into valuable resources. Although AD was considered an important development pathway, it was abundantly clear from the findings that Ireland exhibits a very low biorefinery infrastructure. While some participants expressed gratitude for the proximity of their AD plant, noting that it made waste management more feasible, others faced logistical challenges due to the distance between the company's location and the AD facility. Interestingly, some companies opted to establish their own AD plants but in Northern Ireland rather than Ireland, citing regulatory incentives for electricity generation. This underscores the disparity in infrastructure between the two regions, with limitations relating to planning, finance and regulation cited as fundamental barriers. These discussions emphasise the urgent need for fast-tracking anaerobic digestion infrastructure, and biorefinery development more generally, and will be discussed further in due course and in respect to barriers to circular practice.

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5.4 Barriers to Circular Practice

5.4.1 Lack of guidance and expertise

According to Mehmood et al. (2021), governmental strategy, both directly and indirectly, impacts circular practice in the agri-food sector. However, most commentators argue that current regulations on circularity lack robustness (Bai et al., 2024). For example, no standardised framework to evaluate the effectiveness of circular practice regulations exists (Mehmood et al., 2021), and there are no legal guidelines for waste collection and treatment (Salmenperä et al., 2021). Insufficient support from government agencies, coupled with a lack of technical expertise to enforce the circular practice, is also widely criticised by commentators (Kirchherr et al., 2017; Zhu et al., 2019). Furthermore, current taxation system in Europe, as elsewhere does not align with circular principles (Zabaniotou & Kamaterou, 2019). Another fundamental barrier relates to a general uncertainty amongst stakeholders regarding the quantity, quality, mixture, timing, and location of returned goods (Alfonso-Lizarazo et al., 2013). As it stands, the majority of products sold never return to production, while the low rate of waste collection and the absence of waste treatment facilities further compounds uncertainty (Ranta et al., 2018). Such uncertainties diminish the likelihood of achieving desired economies of scale and pose significant obstacles to the implementation of circular economy initiatives (Mehmood et al., 2021). Dependable and cost-effective transportation and communication systems is also key in promoting circular practice in the agri-food sector since logistical inefficiencies affect the entire supply chain (Bernon et al., 2018). A lack of awareness and understanding of the benefits of circular economy practices, including improved commodities and network designs for circular products to promote reuse, remanufacturing, and recycling, is regular cited as major barrier to enhanced circular practice (Iacovidou et al., 2021). Although agricultural stakeholders are familiar with the term 'circular economy' they lack a deep understanding regarding its implications (Mehmood et al., 2021). In general, commentators emphasise that a lack of technical skills, expertise as well as training, currently stands as one of the major challenges to the effective adoption of circular economy initiatives within the agri-food sector (Gontard et al., 2018; Kirchherr et al., 2018).

In their examination of key European initiatives on circular practice and its implementation in Italy, Zarbà et al. (2021) discovered that it is the lack of specific regulatory instruments in the agri-food sector that leads to uncertainty. Poponi et al., (2022) argues that by establishing specific regulatory measures for the agri-food circular economy would enable operators at all levels to make choices that promote circular production. As it stands, the diverse economic activities within agri-food, because they lack targeted legislative guidelines, fail to

utilise circularity because of policy failure (Chiaraluce, 2021), preventing increased savings from reduced waste disposal costs (Pascucci, 2020; Chinnici et al., 2019; Zarbà et al., 2019).

The academic literature emphasises how practitioners need to establish guidelines when transitioning from a linear to a circular model (Borrello et al., 2016). According to Borrello et al. (2016) these guidelines can be drawn from case studies, with each challenge addressed individually. For companies seeking to adopt a circular business model, certifications such as the BS 8001 guidelines (BSI, 2017) and the XP X30-901 standard (AFNOR, 2021) have been used as points of reference. Prospectively, the development of the new ISO standard for the Circular Economy (ISO/WD 59004) will become the new standard (Poponi et al., 2022). Several studies emphasise the importance of establishing a common reference point for measuring the circular economy (Saidani et al., 2019). Despite efforts by various authors to address the issue, no universally recognised system of indicators currently exists to measure circularity (Kristensen and Mosgaard, 2020). Circular economy indicators for measurement in the agri-food sector is still in its infancy. Currently, the BS 8001:2017 (BSI, 2017) and the XP X30–901 (AFNOR, 2021) are the only recognized standards (Poponi et al., 2022), but the new ISO standard for the Circular Economy (ISO/WD 59004) is under development by Technical Committee TC/323. Poponi et al. (2022) propose a dashboard approach as a reference point for assessing the transition to a circular economy in the agri-food sector, covering environmental, economic, and social sustainability parameters across various scales. Their approach evaluates air, water, soil, energy, waste, cost, value, productivity, equality, and knowledge and innovation. The study underscores how indicators can aid in circular practice development and highlights the need for more precise and universally accepted tools. Building on such research future studies need to generate a standardised suite of circular practice indicators for agri-food which can serve to identify areas for investment and help governments and companies to assess their production systems and determine future directions.

5.4.2 Farmer exclusion in decision-making processes and policy development

Primary production in agriculture, forestry, fisheries, and aquaculture plays a vital role in the European Bioeconomy (Park and Grundmann, 2023). Beyond traditional outputs like food and feed, these sectors supply biomass that can be converted into various products, such as energy, materials, and chemicals, potentially substituting for fossil-based products (Park and Grundmann, 2023). Concerns about the potential impacts of the bioeconomy on primary production and producers persist, including issues of bargaining power inequality, competition among biomass providers (Levidow, 2015), and autonomy challenges (Hackfort, 2021). In this

respect it is important to note that international efforts are underway to identify and monitor the potential negative effect of the bioeconomy on society (e.g., Jander et al., 2020). This point is important because one of the main solution proposed to mitigate the negative impact of the bioeconomy is to adequately involve and consider the perspectives of all stakeholders (Bryden et al., 2017). Schmid et al. (2012) argues that the role of farmers in bioeconomy innovations is not sufficiently addressed in EU bioeconomy policies. Although the European Commission's (EC) updated bioeconomy strategy (2018; 52) emphasises "the deployment of inclusive bioeconomies in rural areas", it does not offer a precise definition of "inclusive", which is inherently problematic. Lühmann (2020) concludes that the updated strategy continues to prioritise growth and competition, favouring industry and research while largely neglecting the viewpoints of agricultural associations and forestry NGOs.

The importance of farmer training in circular bioeconomy practice is fundamental because well-educated and skilled farmers are vital for successful and sustainable development (Pascoli et al., 2022). To educate farmers about the bioeconomy, they need to learn about the principles and practices of efficiently and sustainably utilising biological resources to produce various goods like food, energy, and materials (Papadopoulou et al., 2023). This includes informing farmers regarding the latest developments in biotechnology, agroforestry, precision agriculture, and regenerative farming (Fava et al., 2021). Moreover, farmers should receive instruction on the economic and business aspects of the bioeconomy, including marketing, branding, and product development (Donner et al., 2021). The objective of this training is to empower farmers to play a significant role in bioeconomy transition (Papadopoulou et al., 2023). Policymakers view farmers solely as technical providers of biomass, but this perspective overlooks the broader views and concerns of farmers themselves (Rossi and Hinrichs, 2011; Schmidt et al., 2012). In reality, farmers have their own unique perspective on the suitability of new practices promoting the bioeconomy, which are frequently characterised by scepticism and uncertainty (Rossi and Hinrichs, 2011). However, the factors influencing farmer interest in circular practices are still not fully understood (White and Selfa, 2013). Balan and Zeldea (2023) discovered a significant lack of knowledge among farmers in Romania regarding the role and impact of the bioeconomy in their current activities. They also noted a lack of interest from central authorities in Romania, particularly at the Ministry of Agriculture level, in promoting the bioeconomy concept among agricultural workers (Balan and Zeldea, 2023).

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5.4.3 Financial barriers and lack of government support for circular practice

According to Prieto-Sandoval et al. (2018) a lack of financial support is the main factor preventing the adoption of advanced environmental practices in small and medium-sized enterprises (SMEs), which leads to a slower or unsuccessful uptake of the circular economy within such organisations. This is related to the fact that further processing or transformation of food waste is necessary before reuse, which requires costly changes, including research and development and infrastructure investment (Gedam et al., 2021). Additionally, evaluating and implementing available technologies to support such transformation requires significant investment (Gedam et al., 2021). Justifying such expenses is challenging, particularly because obtaining high-value products from food waste at each stage of the supply chain is currently difficult (Jaeger and Upadhyay, 2020). The circular economy model is also a novel and emerging business strategy, making it challenging for organisations to adopt it at the right position in the supply chain to reap economic benefits (Dossa et al., 2022). Furthermore, adopting circular economy practices, including new business models and recycled materials, entails high costs and financial uncertainty (Dossa et al., 2022). Public support for circular needs to be established and promoted and practitioners need to explore such supports (Gedam et al., 2021). Additionally, practitioners need to explore opportunities from sustainability collaborations, eco-industrial parks, biorefineries, resource valorisation, eco-innovations, and the adoption of cleaner technologies to develop in-house resources (Aranda-Usón et al., 2019). Businesses also need to formulate strategies for reusing and recovering used products and estimating waste (Gedam et al., 2021). Consideration of product design strategies is also important, such as eco-design for food packaging (using biodegradable materials), minimising packaging, waste reduction, and engaging in sustainability collaboration activities (Zhu et al., 2022). Active participation from consumers and suppliers is also another crucial factor. According to Gedam et al. (2021) both groups are hesitant to embrace circular products and services due to increased costs or concerns about quality. Therefore, enhancing both consumer and supplier involvement is essential for enhancing the supply, use, and purchase of sustainable products and services (Gedam et al., 2021). The success of circular economy initiatives relies on involvement and support from these external stakeholders (Singh and Giacosa, 2019).

The presence of financial resources, especially their quality, is closely tied to the level of investment (Ghisellini et al., 2016). The availability of resources, particularly at reasonable costs, is highlighted as a significant factor in the development of various circular activities undertaken by business (Aranda-Usón et al., 2019). Specifically, the quality of resources is important, as the level of collateral (guarantees) required by companies to finance circularity tends to be higher

than that required for other investments (*ibid*). Similarly, the costs associated with external funds needed for these activities are also generally higher (*ibid*). One solution relates to industrial symbiosis in respect to advanced collaboration in circularity (Daddi et al., 2017). Ghisellini et al. (2018) illustrate that companies engage in these advanced circular solutions to recoup the costs of environmental investments. In this respect, tax incentives, refund policies on resource use, and financial subsidies play a positive role in stimulating the development of industrial symbiosis (Aranda-Usón et al., 2019). Belaud et al. (2019) note that financing synergy partnerships face challenges, which limits the development of eco-industrial parks for example, and they discuss how tax incentives and government subsidies enable viable economies of scale. Similarly, Velenturf and Purnell (2017) suggests that collaborative processes fostered by the circular economy engage stakeholders in co-producing, co-deciding, and financing projects.

5.4.4 Concerns regarding the direction of EU policy

In the European Union (EU), the European Green Deal sets out to decrease net greenhouse gas (GHG) emissions by a minimum of 55% compared to 1990 levels by 2030 and to achieve net zero emissions by 2050 (European Commission, 2019). Meanwhile, Ireland's 2021 Climate Action Plan presents objectives to achieve a 51% reduction in overall GHG emissions by 2030, aiming for net zero emissions no later than 2050 (Government of Ireland, 2021). Given the significant historical role of agriculture in Ireland, it stands as the largest contributor to GHG emissions, accounting for 37.1% of emissions in 2020, in contrast to just over 10% for the EU as a whole (EPA, 2021; Mielcarek-Bocheńska & Rzeźnik, 2021). To meet reduction targets, emissions intrinsic to agricultural production, such as methane (CH4) and nitrous oxide (N2O), must be addressed (Geoghegan et al., 2023). However, concerns have been raised about the distributional impacts of policies targeting agricultural emission mitigation, particularly those based on the "polluter pays" principle, which could reduce profits and lead to farm exits (Wang et al., 2016). This also disproportionately affects lower-income households (Mosnier et al., 2017).

According to the European Environmental Agency (2021) emissions in the agricultural sector have declined by 20.5%, mainly due to a decline in cattle population (28%) and the use of synthetic (25%) and organic (13%) fertilisers. Specific subsectors like enteric fermentation and direct emissions from agricultural soils contributed to a 4.3% decline in total emissions between 1990 and 2019, making them among the sectors with the most significant emission reductions, comparable to the reduction observed in the cement, aluminium, and fluorochemical industry combined (Boix-Fayos and de Vente, 2023). However, enteric fermentation still accounts for over

40% of all agricultural emissions, while the rest are primarily related to soil management (fertilisers), crops, and residues (*ibid*).

A critical question regarding food security and the implementation of the F2F Strategy is whether a 25% increase in European organic agriculture can produce enough yields to feed the population (Boix-Fayos and de Vente, 2023). Studies have shown varying decreases in yields under organic agriculture compared to conventional farming, ranging from 20% to 35%, with some indicating lower yield stability as well (Kirchmann, 2019). Recent predictions suggest a decrease in yields of 7% to 12% with the input reductions proposed in the F2F strategy, without accounting for increased land in organic production and reduction of food waste (Beckman et al., 2020). One of the main challenges of organic agriculture is nitrogen supply due to restrictions on mineral fertilisers (Muller et al., 2017). This often necessitates rotations with legumes for biological nitrogen fixation, reducing available land for main crops and overall productivity compared to conventional agriculture (Boix-Fayos and de Vente, 2023). Expanding arable land is not considered a viable option due to environmental constraints and challenges, including increased competition for land from other human activities, the importance of ecological functions of unfarmed land, and negative effects of agriculture on biodiversity (Bernard and Lux, 2017). Instead, reducing food-competing feed from arable land, combined with decreased animal production and consumption and reduced food waste, would allow for more land allocation to organic agriculture for human consumption (Karlsson and Röös, 2019). To sustainably feed the world population by 2050, a well-designed food system incorporating increased organic agriculture, reduced animal numbers and consumption, and reduced food waste needs to be jointly addressed (Muller et al., 2017). This challenge is connected to actions aimed at maintaining land in good natural condition and promoting sustainable food production and waste reduction (Boix-Fayos and de Vente, 2023).

In Ireland, as elsewhere, agriculture varies not only in terms of income but also in spatial distribution, with soils, weather, and other agronomic conditions differing across regions, influencing farming choices and outcomes (O'Donoghue et al., 2015). Therefore, emission reduction measures affecting specific types of farming are likely to have a significant impact in regions where that type of farming is dominant. The Irish government's agri-food strategy, Food Vision 2030, commits to a minimum 10% reduction in biogenic methane by 2030 (DAFM, 2021). Due to the diverse nature of farming in Ireland, implementing a national-level target like this may have varying impacts across the country (Markkanen and Anger-Kraavi, 2019).

Research by Geoghegan et al. (2023) show that GHG mitigation measures in agriculture, such as those aimed at reducing beef production, can lead to economic losses that are almost double when multiplier effects are considered, emphasizing the strong link between the beef sector and the local economy. These findings highlight the importance of considering the distributional and spatial impacts of mitigation measures when designing policy instruments. Given the high global warming potential associated with methane, it's likely that emissions reduction efforts will target ruminant animal agricultural systems, particularly beef cattle farming, necessitating mechanisms to offset costs for those most affected (Geoghegan et al., 2023). Investments, such as the European Green Deal's Just Transition Mechanism (JSM), are essential to mitigate socioeconomic impacts, especially in areas with limited alternative employment opportunities (Filipović et al., 2022). Additionally, policy measures like an agricultural methane tax, coupled with environmental subsidies, could incentivise farmer participation and improve income distribution (Hynes et al., 2009). Furthermore, as farming in general faces challenges such as increasing age profile and competition for farmland, off-farm employment becomes increasingly important (Xu et al., 2022), and government support through schemes like the Basic Payment Scheme play a crucial role (Ciaian et al., 2015). Considering the growing environmental focus of EU policies, future agricultural payments should recognise farmers' roles in environmental stewardship and as economic pillars of local communities (McGurk et al., 2020). For the most affected sectors such as beef, organic alternatives could be an option for some, as incentives and similarities with non-organic farming exist (Bonfiglio and Arzeni, 2019).

In relation to pesticide, fertiliser, and antibiotic management, Prandecki et al. (2021) highlight how the restricted use of these substances will pose enormous organisational challenges. Each strategic goal may present significant challenges for specific farm groups; for instance, limiting pesticide use may be challenging for farms specialising in permanent crops, managing fertiliser may be difficult for farms with intensive crop production, and reducing antibiotics may pose challenges, especially for specialised farms with large-scale livestock production (i*bid*). In this respect, it remains important to emphasise that the development of organic production will be particularly challenging due to its niche significance in the agricultural market, driven by social awareness and profitability concerns (Canwat and Onakuse, 2022).

There’s little doubt within academic literature that the Green Deal is set to impact Europe's global competitiveness. According to Leonard et al. (2021) European firms may become less competitive both domestically and internationally if they have to bear regulatory costs that their

foreign competitors do not. Additionally, if the EU tries to prevent carbon leakage by imposing tariffs on carbon-intensive imports, it could face accusations of distorting international trade (Jousseaume et al., 2021). This could lead to tension with major trading partners, especially those heavily reliant on carbon, if they see a carbon border adjustment mechanism as an unlawful trade barrier (Böhringer et al., 2022). Furthermore, transitioning away from carbon in Europe alone would not significantly mitigate global warming, as Europe accounts for less than 10 percent of global greenhouse gas emissions (Leonard et al., 2021). In addition, if the Green Deal simply shifts Europe's emissions to its trading partners, it would have no impact on climate change whatsoever (*ibid*). For this reason alone, the EU is likely to strongly advocate for ambitious, enforceable multilateral agreements to address global warming, possibly prioritising this objective over others (Rayner et al., 2023).

The European Commission has actually acknowledged the need to either export its standards or establish a border adjustment mechanism to maintain European competitiveness and prevent carbon leakage (Droege and Fischer, 2020). Consequently, the EU will need to develop new trade and investment agreements, along with new approaches to international diplomacy, to encourage sustainable investment and development (Leonard et al., 2021). This international engagement will inevitably affect relationships with the United States and China, each with their own strategies for promoting sustainable development and managing climate negotiations (Belis et al., 2015). Relations with other countries, such as the Gulf states and Russia, whose export interests will be directly impacted, will also undergo transformation (van de Graaf, 2019). These foreign policy efforts will elicit various responses from the EU's international partners, ranging from cooperation on complementary climate policies to competitive actions aimed at redirecting trade and investment flows, and possibly even hostile measures to counteract the effects of the Green Deal (Gourinchas and Schwerhoff, 2023).

5.4.5 The need for accelerated AD development and issues around planning

Despite significant bioeconomy research, development, and innovation networks spread across Europe, many countries are significantly behind in developing crucial bioeconomy infrastructures, such as biorefineries (e.g., anaerobic digestion, biogas plants). According to Parisi (2018; 5-6), several countries (e.g., Ireland, Romania, Portugal) lag far behind leaders like Belgium, the Netherlands, France, and Germany in biorefinery development. This highlights a substantial imbalance in bioeconomy development across Europe. For instance, Ireland currently has only 12 anaerobic digestion (AD) facilities nationwide (Crosson et al., 2019), whereas Northern Ireland has 80 AD facilities (Halleron, 2023). Research by O'Connor et al.

(2022) indicates that planning is a significant issue in this regard, with Pender et al. (2024) pointing out that difficulties in obtaining planning permission for pilot biorefinery projects and bioenergy plants are commonly cited as major obstacles hindering development.

Anaerobic digestion (AD) has been acknowledged as an effective method for both energy production and reducing greenhouse gas (GHG) emissions (Scott and Blanchard, 2021). Despite Ireland having a sizable agriculture sector, the adoption of this technology has been minimal, ranking 20th within the EU-28 (O'Connor et al., 2022). Results from a study exploring farmer's motivations, perceived obstacles, and preferred business models revealed that approximately 41% of the 91 respondents expressed interest in installing AD on their farms within the next five years (O'Connor et al., 2021). The primary consideration hindering the implementation of AD was identified as a lack of information about the technology and high investment costs (*ibid*). Among likely adopters, a self-owned and operated plant was the preferred ownership structure, with 58% showing interest in joining a cooperative scheme (*ibid*). While economic factors primarily drove adoption, the main barrier identified was a lack of awareness and insufficient information about the technology (*ibid*). One key strategy to address this challenge is to leverage early adopters or local champions to raise awareness and highlight the positive attributes of the technology, thereby demonstrating its potential contribution to farm performance and serving as a model for other farmers to follow (Mbzibain et al., 2013). Similar initiatives implemented by policymakers have proven effective in increasing awareness and adoption rates in other countries, such as the United Kingdom, Belgium, and the Netherlands (AF BI Northern Ireland, 2013; de Dobbelaere et al., 2015; Bijnagte, 2017).

An Irish initiative following this approach is the EIP Small Biogas Demonstration Project, which aims to promote small-scale AD through informative workshops, feasibility studies, and the provision of capital grants for the construction of three biogas plants (DAFM, 2020). Other identified barriers include potentially high investment costs and uncertainty regarding the technology's financial returns. Concerns from stakeholders in terms of the economics of renewable energy (RE) enterprises have been commonly reported in existing literature (Ackrill and Abdo, 2020). To address such challenges, many governments have introduced incentives like electrical feed-in tariffs, capital grants, and heat tariffs, which can be crucial for the financial viability of such projects, particularly for early adopters (Pablo-Romero et al., 2017). In an effort to increase energy generation from renewable sources, the Irish government has recently introduced the Support Scheme for Renewable Heat (DCCAE, 2019).

Germany is a leader in this respect, and has progressed from using small, localised digesters to operating large-scale treatment facilities, which significantly contribute to the

national renewable energy quotas (Auer et al., 2016). However, these large anaerobic digestion (AD) plants are expensive to operate and require intensive farming of energy crops for feedstock (*ibid*). Current policy in Germany has shifted to supporting funding for smaller digesters while also restricting the use of energy crops (Theueri et al., 2019). In Ireland, AD, as a new technology, is affected by unclear governmental policies concerning waste and energy (Auer et al., 2016). A coherent governmental strategy supporting on-site AD processing of agricultural waste has the potential to substantially reduce Ireland's carbon footprint, enhance the safety and bioavailability of agricultural waste, and provide a domestic renewable energy source (Stevens, 2023). In 2006, Ireland introduced a Renewable Energy Feed-in Tariff programme (REFIT 1-3) under the Department of Communications, Energy and Natural Resources, aiming to support renewable energy projects (Clancy et al., 2012). REFIT 3 specifically provides dedicated funding for AD plants for up to 15 years (Böhringer et al., 2017). Under these schemes, the National Grid is mandated to purchase electricity from renewable energy producers at a fixed price (Ndiritu and Engola, 2020). Although the tariff offered to producers in Ireland is generally lower compared to other European countries, other local factors besides tariffs also contribute to the low utilization of AD (Auer et al., 2016). For example, to cover their costs, Irish AD plant operators charge waste producers gate fees ranging from €50 to 80 per 1000 kg of feedstock (*ibid*). However, these gate fees remain a significant deterrent for waste producers, such as farmers, who can simply land-spread their untreated livestock waste for free (Bedoić et al., 2019). Furthermore, the gate fees are not regulated, and their volatility discourages planning and investment in future AD plants (Nghiem et al., 2017). Despite the significant amounts of agricultural waste produced by the Irish livestock sector, the utilization of AD remains remarkably low (CSO Ireland, 2019).

In addition to providing renewable energy, the health benefits associated with spreading AD digestate, as opposed to untreated waste, can serve to encourage the development of supportive AD legislation (Healy et al., 2017). Currently, Irish policy allows farmers to land-spread their waste without prior treatment, which does little to prevent pathogen spread (Auer et al., 2016). Therefore, to take advantage of AD benefits, Ireland's governmental policy should carefully consider the appropriate levels for feed-in tariffs and gate fees (Cointe and Nadaï, 2018). Ideally, feed-in tariffs for AD plants should be set to provide a buffer for the agricultural industry against the energy market's volatility, while also promoting the efficient use of the AD biogas generated (Auer et al., 2016). Additionally, the gate fees charged to waste producers should be in line with any other type of disposal fee assessed for the respective waste type (*ibid*). The experiences of AD policy development in Germany can inform regulations in Ireland. For instance, additional legislation to promote AD development could ensure that subsidies for AD

reactors do not compete with food crops, as seen in Germany (Theuerl et al., 2019). In Ireland, providing supportive tariffs to smaller AD plants would discourage the construction of large digesters that drive the demand for energy crops (Auer et al., 2016). Adopting measures such as these would encourage the appropriate growth of the AD industry while avoiding the use of energy crops.

Anaerobic digestion (AD) is crucial for achieving greenhouse gas (GHG) mitigation and renewable energy targets in member nations, including Ireland. However, the underdevelopment of AD and its associated technologies in Ireland directly impacts the country's net GHG emissions. Bhatnagar et al. (2022) identify the main obstacles to the AD technology development as the lack of national investment and incentivisation for small to medium-scale decentralised AD plants, higher gate fees charged on organic waste, and lower REFIT (Bhatnagar et al., 2022). Additionally, the heavy reliance on largely imported fossil fuel-derived energy, despite the availability of various AD feedstocks, exacerbates the issue (Auer et al., 2017). Nonetheless, the recent establishment of the Grange Biogas plant in Co. Meath, operating on grass silage and slurry, and the Nurney biogas plant in Co. Kildare, operating on pig slurry, are positive indicators of progress (Bhatnagar et al., 2022).

Ireland has abundant biomass resources like grass silage, animal slurry, and plant biomass that can be used as AD feedstock (Tabassum et al., 2017). One such resource is cattle slurry, representing an energy-rich waste stream underutilised as an AD feedstock (Rittl et al., 2023). AD of cattle slurry offers several advantages over plant biomass, including the stabilisation of high nitrogen waste, odour reduction, reduction of pathogen load, and production of renewable methane-rich biogas, leading to GHG savings (*Ibid*). Challenges related to full-scale treatment of cattle slurry via AD have been addressed, in most cases, through pre-treatments to tackle inhibition by lignocellulosic components (Bhatnagar et al., 2022). Ammonia inhibition, another common issue with this feedstock, can be improved through co-digestion, ammonia stripping, biochar addition, and feedstock dilution (Mutegoa et al., 2020). Cattle slurry has been successfully utilised as a feedstock for large AD plants in many European countries, including Germany, Poland, Italy, the Netherlands, the United Kingdom, and Slovenia, indicating the untapped potential of cattle slurry (Bhatnagar et al., 2022). If Ireland and fellow EU nations aim to achieve climate neutrality as set out in the 2030/50 Climate Target Plan (Green Deal, EC), these alternative and renewable energy options must be thoroughly explored and implemented.

5.4.6 Overregulation

Interviews highlighted the growing burden of regulations and administrative tasks on farmers within the agricultural sector. Participants expressed concerns about the increasing amount of paperwork and regulatory requirements imposed on farmers. They perceived that a significant portion of their time and resources is dedicated to compliance with regulations rather than actual farming activities. Such instances revealed a sense of frustration with the administrative aspects of farming, which were perceived as burdensome and time-consuming. Despite the additional workload associated with regulatory compliance, participants felt that they were not receiving adequate financial compensation for their efforts. They highlighted the disconnect between increasing regulatory demands and the lack of tangible benefits or financial rewards for farmers. This suggests a growing disparity between the expectations placed on farmers and the economic realities they face. Participants questioned whether the expectations placed on farmers are realistic, particularly in terms of the timeframe given to achieve certain goals. They suggested that policymakers may be setting unrealistic targets without considering the practical constraints and challenges faced by farmers. There was a call for a more balanced approach that takes into account the complexities of agricultural production and ensures that regulatory measures are feasible and achievable within realistic timelines.

5.4.7 The need to promote (already) sustainable activity, including valorisation

Interviews highlighted how government needs to promote existing circular practice with the agri-food sector. Participants emphasised the importance of reframing agricultural waste as valuable byproduct. They rejected the notion of calling byproduct "waste" since they believe such produce has inherent value and can be used in various ways to generate income and create different products. However, government and public agency representatives were said to insist on labelling this product as waste, which was felt has damaging to the byproduct brand. Participants also expressed frustration with the lack of support in promoting the sustainability of certain sectors, particularly in comparison to beef. Despite being statistically more sustainable, participants described facing significant barriers in openly advertising sustainability aspects of respective products due to concerns over damaging the beef sector. Participants also discussed efforts to explore carbon neutrality within their operations and how it could be leveraged for branding and marketing purposes, expressing disillusionment that such carbon neutral credentials are not currently promoted by the state.

5.4.8 Lack of support for certain (smaller) sectors

Participants expressed frustration with support programs that are designed with larger businesses in mind, making them impractical or inaccessible for smaller enterprise. They cited examples where requirements such as appointing a sustainability manager or meeting extensive measurement criteria are simply not feasible for SMEs with limited resources. This highlights a need for support programs that are tailored to the specific needs and capabilities of SMEs within the agri-food sector. Participants reported facing challenges in accessing funding, particularly from banks and financial institutions. Despite the existence of state-backed schemes, participants reported difficulties in securing funding due to stringent requirements and a lack of willingness from banks to lend to smaller businesses. This financial constraint was described as hampering SMEs' ability to invest in innovation, automation, and efficiency improvements, limiting their growth potential. Participants believed a disparity in support from government agencies, with a perceived focus on larger companies at the expense of SMEs. They highlighted challenges in navigating bureaucratic processes and accessing support services, which they felt were disproportionately geared towards larger corporations. Despite complying with the same regulations as larger companies, participants from SMEs reported receiving inadequate support from government agencies, leading to feelings of frustration and disillusionment.

5.4.9 Problems with the research-led approach and issues related to Intellectual Property

Interviews revealed several issues with the research-led approach to bioeconomy development in Ireland. Participants expressed a sense of urgency in moving beyond research and innovation towards direct action. There seemed a desire to see tangible outcomes such as the establishment of new plants or the implementation of technological advancements. This highlighted the need for a more action-oriented approach to address pressing issues of bioeconomy development. While access to research funding and support was acknowledged as beneficial, participants stressed the importance of translating research efforts into meaningful business outcomes. There was a recognition that simply accessing support or funding is not sufficient if it doesn't lead to clear business objectives or tangible results. This highlights the need for a more strategic approach to align research efforts with practical business goals. Participants expressed frustration with the perceived lack of perseverance and problem-solving within research institutions, particularly universities. There was criticism regarding academic culture where failure is accepted without exploring all possible avenues for success. This highlights the importance of fostering a culture of resilience and perseverance within research institutions to drive innovation and overcome challenges in the bioeconomy development process.

Issues relating to intellectual property (IP) were also highlighted during interviews. Participants expressed a sense of betrayal or disappointment when universities seem to take control of IP rights, especially if the project didn't meet expectations or if problems arose. This highlights the need for clear agreements and expectations regarding IP ownership and collaboration dynamics between industry and academic partners. Participants discussed the delicate balance between collaboration, confidentiality, and IP protection in research and development. An emphasise was placed on the importance of creating frameworks that address these concerns effectively in order to foster trust and facilitate productive collaborations between industry and research institutions. Participants also expressed caution about potential risks associated with government support, and particularly in terms of safeguarding IP. An understanding was articulated regarding the need to balance government support with the protection of valuable IP assets in order to maintain competitiveness and value. This suggests how important it is to align funding sources with IP protection goals and implement appropriate measures to safeguard IP rights in government-supported projects.

6. Conclusions and recommendations – towards a regional bioeconomy strategy

Findings from this research will contribute towards the development of a regional strategy for the bioeconomy in Ireland. In the meantime, the following outlines key recommendations for enhancing circular practice in the agri-food sector of the bioeconomy.

6.1 Concepts

To replicate circular and sustainable practices in the agri-food sector of Ireland, it is crucial to bridge the gap in understanding and terminology among practitioners. While there is alignment between industry practices and academic definitions of circularity, there exists a lack clarity, indicating a need for increased awareness and education. Policymakers should develop targeted educational programs to equip all practitioners with the knowledge and vocabulary to recognise and articulate circular efforts. Revisiting and clarifying definitions and frameworks of circular economy concepts is essential for ensuring accessibility and applicability, fostering a shared understanding among stakeholders. Furthermore, fostering ongoing collaboration between policymakers, industry stakeholders, and academic experts is vital for developing and promoting best practices. Through these measures, policymakers can support the widespread adoption of

circular practice throughout the agri-food sector, ensuring long-term sustainability and resilience.

Proactive efforts are needed to address the significant knowledge gap surrounding the bioeconomy concept. This lack of understanding indicates a need for policies and initiatives that promote and support bioeconomy development, integrating bioeconomy principles into broader agricultural and economic policies. There are potential market opportunities for innovative bio-based products and services in Ireland, given the industry's lack of familiarity with bioeconomy concepts. Greater engagement and collaboration between government agencies, industry associations, research institutions, and businesses can help drive the development and adoption of bioeconomy solutions. Therefore, efforts to promote awareness, educate stakeholders, and develop supportive policies are crucial for enhancing bioeconomy development in Ireland.

6.2 Sustainable Packaging

To enhance circular and sustainable practice in the agri-food sector of Ireland, a fundamental approach lies in sustainable packaging. This can be achieved by gradually transitioning to 100% recyclable packaging in the short term, and ultimately aiming for 100% biodegradable packaging as bioeconomy infrastructure advances. However, in respect to packaging innovation, there is a lack of large-scale evaluation and end-user information, highlighting the need for increased awareness and education. Transitioning the agri-food industry to a circular development path, with biowaste-based materials as the cornerstone, offers significant benefits, including economic gains and environmental sustainability. Implementing a biorefinery model, where raw materials from agri-food waste are processed into biomaterials for packaging, offers a circular loop system that minimises waste accumulation and environmental pollution. However, challenges such as handling large feedstock volumes and logistics need to be addressed for these practices to be economically sustainable. Despite the challenges, sustainable packaging from agri-food waste and by-products has significant potential in driving sustainable bioeconomy development.

It is also important to leverage sustainable development initiatives that foster a culture of accountability, innovation, and continuous improvement. Programs like Repak and Origin Green provide valuable platforms for companies to collaborate, gather information, and implement strategies aimed at reducing waste and optimising resource use. By engaging with suppliers and evaluating packaging materials, companies can identify opportunities to minimise waste generation and improve packaging efficiency. Certification programs such as Origin Green incorporate sustainability principles into business operations, empowering companies to tailor

initiatives to their specific circumstances while working towards overarching sustainability goals. Sustainable development initiatives serve as catalysts for advancing circular practices in the agri-food sector, promoting waste reduction, encouraging goal setting, and ensuring accountability through auditing processes.

6.3 Organic Fertiliser

Innovative approaches must be embraced to maximise the value of agricultural byproducts while minimising waste. Utilising animal byproducts for food and organic fertiliser highlights an integrated approach to land management and nutrient cycling. However, challenges such as farmers' reluctance to adopt organic fertiliser due to convenience associated with artificial alternatives, regulatory hurdles, and logistical challenges need to be addressed. Education, incentives, and infrastructural support are crucial to overcoming these barriers. Government should promote the widespread use of organic fertiliser through education and a centralised distribution system, enabling more efficient resource utilisation and the phasing out of unsustainable alternatives.

6.4 Financial Support

To enhance circular and sustainable practices in the agri-food sector of Ireland, financial support is crucial. Finance enables small-scale business to invest in machinery and technologies that promote circularity and provides assistance for innovative solutions for improving sustainability. However, challenges such as delays in processing grant applications hinder timely implementation. Improvements are needed to enhance the accessibility, efficiency, and adaptation of supports to the specific needs of different types of operations, particularly smaller-scale ones. Efforts to streamline grant processes and tailor support to diverse agricultural operations are essential for ensuring widespread adoption of circular practice.

6.5 Education

Educational initiatives serve as catalysts for driving circular practice by empowering individuals with the knowledge, skills, and resources to implement sustainable solutions. Institutions like educational and governmental agencies provide valuable opportunities for individuals to stay updated on the latest innovations in agricultural technology and sustainability practices. However, to ensure broader accessibility, particularly for rural areas and those with limited resources, online courses and resources need expansion. Offering a mix of in-person and online courses, along with self-paced learning options, is crucial. Additionally, educational programs

should be regularly updated to remain relevant to current industry trends and challenges, incorporating emerging topics into course curriculums. Collaboration between educational institutions, industry experts, and government agencies is vital for prioritising inclusion in educational programs and ensuring flexibility in delivery to accommodate different learning preferences and schedules.

6.6 Enhanced Collaboration

In general, enhanced collaboration between suppliers and customers is crucial for ensuring resources are reused and recycled within the supply chain, creating a closed-loop system where inputs and outputs are continuously circulated and reused. This collaborative approach promotes loyalty and support among stakeholders while minimising waste and maximising resource efficiency. Collaboration between producers and regulatory bodies drives sustainability initiatives and encourages best practice adoption by incentivising farmers to adopt sustainable practices. Industry players and research institutions should collaborate to facilitate innovation and knowledge exchange, leading to continuous improvement in agricultural practices. Initiatives focused on efficiency performance, genetics, and biodiversity can reduce the carbon footprint and enhance resource efficiency on farms, highlighting the importance of collaborative efforts across the agri-food sector.

6.7 Guidance

Lack of guidance and expertise is a significant barrier in circular practice in the agri-food sector of Ireland. Current policies demonstrate a disconnect between policymakers and on-the-ground application. A critical need exists for specific regulatory instruments tailored to the agri-food sector to reduce uncertainty and promote circular production. Initiatives like the BS 8001 guidelines and XP X30-901 standard can serve as reference points, but the forthcoming ISO standard for the circular economy will be pivotal. Developing a common reference point for measuring circularity and covering environmental, economic, and social sustainability parameters, is essential. This requires generating a standardised suite of circular practice indicators for agri-food to guide investment decisions and assist governments and companies in assessing production systems. Moreover, enhancing technical skills, expertise, and training is crucial for effective adoption of circular economy initiatives. Overall, establishing targeted regulatory measures, enhancing expertise, and developing standardised indicators are essential steps towards fostering circular and sustainable practices in the agri-food sector of Ireland.

6.8 Farmer Inclusion

An inclusive approach that involves farmers in discussions and actions is needed to ensure the practicality and success of proposed solutions for the bioeconomy. It is important to acknowledge the broader context of environmental impacts beyond agriculture, such as construction and aviation. Educating farmers about the principles and practices of circular bioeconomy has the potential to empower them to play a significant role in bioeconomy transition. Training programs should cover topics like biotechnology, precision agriculture, and regenerative farming, while also addressing economic and business aspects. Policymakers need to recognise farmers not just as biomass providers but as key stakeholder with unique perspectives and concerns.

6.9 Making Circular Practice less Expensive

The higher costs associated with circular practice deters companies from adopting circularity. Lack of targeted financial support impedes investment in sustainable technologies and infrastructure. To overcome these barriers, public support for circular initiatives needs to be established and promoted. Strategies for reusing and recovering used products, along with eco-design for food packaging, are essential. Additionally, involving consumers and suppliers is crucial, as their hesitation due to increased costs or quality concerns affects the success of circular initiatives. Ensuring the availability of financial resources at reasonable costs, possibly through tax incentives, refund policies, and government subsidies, can stimulate investment in circularity. Collaborative processes fostered by the circular economy can engage stakeholders in financing projects, promoting synergy partnerships, and enabling viable economies of scale.

6.10 EU Policy

It is imperative to address concerns regarding EU policy and its impact on productivity, competitiveness, and environmental sustainability. Ireland needs to align its policies with EU directives while ensuring the balance between environmental objectives and economic viability. To mitigate the impacts, investments such as the European Green Deal's Just Transition Mechanism are crucial to offset socioeconomic effects. Policy measures like agricultural methane taxes, coupled with environmental subsidies, can incentivise participation in sustainable practices and improve income distribution. Additionally, supporting organic alternatives and recognising farmers' roles in environmental stewardship and local economies are essential. However, Ireland must also be wary of the potential impact on global competitiveness, as EU policies may lead to trade tensions and carbon leakage. Developing new

trade agreements and international engagement to encourage sustainable investment and development are necessary steps in navigating these challenges while promoting circular and sustainable practices in the agri-food sector.

6.11 Anaerobic Digestion

Ireland must develop its anaerobic digestion (AD) infrastructure as a matter of urgency. First, addressing administrative barriers to facilitate the expansion of AD developments is crucial. This includes overcoming obstacles related to planning regulations and public opposition. Streamlining planning procedures and providing government support similar to other infrastructure developments is essential to expedite AD projects. Second, raising awareness and providing information about AD technology is vital to increase adoption rates among farmers. Leveraging local champions and early adopters can help demonstrate the benefits of AD and serve as models for others. Third, addressing financial barriers is essential. Providing incentives like electrical feed-in tariffs, capital grants, and heat tariffs can significantly improve the financial viability of AD projects. Setting appropriate feed-in tariffs and gate fees for AD plants, based on experiences from countries like Germany, can encourage industry growth while avoiding overreliance on energy crops. Finally, exploring alternative feedstocks such as cattle slurry, which offers several advantages for AD, can help maximise renewable energy production and GHG savings. By implementing these recommendations, Ireland can overcome barriers and accelerate the accelerate the development of AD infrastructure.

6.12 Overregulation

It is imperative to address the burden of regulations and administrative tasks on farmers. Findings indicated a growing frustration among farmers due to increasing paperwork and regulatory requirements, which divert time and resources away from actual farming activities. Despite the additional workload, farmers feel they are not adequately compensated, highlighting a disconnect between regulatory demands and tangible benefits. To overcome this, policymakers need to adopt a more balanced approach that considers the practical constraints and challenges faced by farmers. This includes setting realistic targets and timelines for compliance with regulations, ensuring they are feasible and achievable. Additionally, providing financial incentives or support for farmers who adopt circular and sustainable practices can help bridge the gap between regulatory demands and economic realities. Streamlining administrative processes and offering training and support to farmers on compliance can also alleviate the burden and encourage greater participation in sustainable practices.

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6.13 Promotion of Circular Practice

The government needs to take proactive steps to promote existing circular practices and support sustainability efforts. The government should actively promote and support circular practices, recognise the value of agricultural byproducts, and encourage sustainability branding and marketing across all sectors, while leveraging carbon neutral credentials as a competitive advantage.

6.14 Supporting SNMs

It is crucial to address the specific challenges faced by small and medium-sized enterprises (SMEs) in the agri-food sector. It is essential to tailoring support programs to the specific needs and capabilities of SMEs. This includes simplifying requirements, such as appointing a sustainability manager or meeting extensive measurement criteria, to make them feasible for smaller enterprises. Additionally, addressing challenges in accessing funding is paramount. Government agencies need to ensure equitable support for SMEs. Simplifying bureaucratic processes and providing more accessible support services tailored to SMEs' needs will alleviate frustration and foster a more supportive environment for circular and sustainable practices in the agri-food sector.

6.15 Moving beyond Research-led Development

In order to enhance bioeconomy development in Ireland it is important to shift from a research-led approach to a more action-oriented strategy. There is a need for a strategic alignment of research efforts with practical business goals to ensure meaningful outcomes. Clear agreements and expectations regarding intellectual property (IP) ownership and collaboration dynamics between industry and academic partners are crucial. Creating frameworks that effectively address collaboration, confidentiality, and IP protection is necessary to foster trust and facilitate productive collaborations between industry and research institutions. Additionally, there's a need to balance government support with the protection of valuable IP assets to maintain competitiveness and value. Aligning funding sources with IP protection goals and implementing appropriate measures to safeguard IP rights in government-supported projects are vital steps in this process. Fostering a culture of resilience and perseverance within research institutions is also essential to drive innovation and overcome challenges in the bioeconomy development process.

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