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SymbioBeer

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EPA Research Report

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Prepared for the Environmental Protection Agency
by

Irish Manufacturing Research

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The SymbioBeer innovation demonstration project would not have been possible without the engagement and commitment from our two industry partners Panelto Foods and St Mel's Brewery. The project kicked off in April 2020 during the first COVID-19 lock down and despite never meeting in person (bar for the social distanced launch of SymbioBeer Project#1 in December 2020) we managed to navigate and overcome the challenges this new operating environment has and still entails. The authors would like to extend our special thanks to Brian Guerin, Pierre Delannoy and Viraj Salvi from Panelto Foods and Liam Hanlon from St Mel's Brewery for sticking with us on this journey.

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DISCLAIMER

This report is based on research carried out/data from April 2020 to March 2021. More recent data may have become available since the research was completed.

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Executive Summary

SymbioBeer is a project which addressed the EPA Green Enterprise Fund 2019 themes of "Food Waste Prevention" by "Promoting innovative waste prevention solutions across the food production and food processing sectors". The project is a collaboration between St. Mel's Independent Brewing Company (a micro-enterprise) and Panelto Foods (an industrial bakery) facilitated by Irish Manufacturing Research (IMR). The SymbioBeer project, which ran from 2020-2021 demonstrated the possibility of industrial symbiosis synergies in the industrial area of Longford. Industrial symbiosis has proven effective in delivering economic, environmental, and social benefits and supporting the transition to a more circular economy around the world. Industrial Symbiosis involves the use by one company or sector of "… *underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer*." (CEN, 2018)

During the SymbioBeer project, we examined the feasibility and evaluated a business case for creating industrial synergies between breweries and bakeries to reduce food waste in these sectors through the re-use of bread production residues as a secondary raw material for beer production and the utilisation of by-products from beer production to create new bread products. This entailed the application of material flow analysis and value stream mapping methodologies on the one hand and conducting a demonstration pilot on the other hand. We qualified and quantified the environmental and economic impact of establishing such industrial synergies between the bakery and brewery sectors via techno-economic analysis.

In addition, we created an industrial symbiosis framework for evaluation of industrial symbiosis opportunities in the wider area of Longford (via a desk-based review of industrial symbiosis best practices, key policies, regulations, extended producer responsibility/compliance schemes and standards). We also developed a register of opportunities for potential synergies in the Longford area to inform the business case for creating further industrial synergies in the region (via mapping of industrial symbiosis opportunities and stakeholder engagement). We further identified key barriers and success factors to the wider implementation of industrial symbiosis between brewery and bakery sectors to inform insights for industry and policy making and support the implementation and scaling up of industrial symbioses in Ireland (via stakeholder engagement). Key dissemination activities included a stakeholder workshop and the development of a demonstrator case study as well as summary guides for industry and to inform policy making.

From the material flow analysis and value stream mapping, valuable production residues for potential valorisation identified included cooked dough (from Panelto Foods), brewer spent grains and yeast (from St. Mel's Brewery). From the demonstration pilot, experiments with the utilization of brewer yeast for bread production proved unsuccessful in comparison to baseline production parameters. However, a new beer from surplus bread was produced (by St Mel's Brewery) and well perceived by the market in December 2020 and brewer spent grains (BSG) was found to be feasible for use as a flour or nutritional ingredient for Panelto's bread. From the techno-economic analysis, an annual 3% reduction in greenhouse gas emissions was estimated for the proposed bakery-brewery synergy between St Mel's and Panelto Foods were the synergy to be scaled-up.

Cost comparison of baseline with the industrial symbiosis scenario(s) the pilot sought to demonstrate, however gave conflicting outlooks. While beer production from bread production residues from Panelto Food was found by St. Mel's to be marginally competitive, production of bread by Panelto Foods from brewer spent grain flour or nutritional ingredient from St Mel's were found not to be competitive (in terms of the cost of production) in comparison to baseline scenarios by Panelto Foods. This is due to the high residue transformation cost associated with drying and milling of brewer spent grain. A similarly high residue transformation cost applied to dehydrating of bread production residue for use in brewing process by St. Mel's. Despite the high residue transformation cost, bread production residues from Panelto Food's proved a good material substitute for a proportion of malted barley. Moreover, it is anticipated that improved efficiencies associated with larger volumes of bread production residues will contribute to the commercial viability of the material substitute due to the economies of scale accruable at such scales. Also, in the absence of high residue transformation costs, material and cost savings from replacement of virgin are expected.

An industrial symbiosis framework from desk-based review of industrial symbiosis best practices, key policies, regulations, extended producer responsibility/compliance schemes and standards formed the basis for mapping of industrial symbiosis opportunities in the Longford industrial area. The industrial symbiosis framework was adapted from UNE 166001 (2006) and UNE 166002 (2006) standards for innovation management systems, Jensen (2016), Domenech (2018) and Garcia (2018). The mapping of industrial symbiosis opportunities in the Longford industrial area resulted in the development of register of opportunities for higher value applications of residue streams generated in the Longford industrial area.

The stakeholder engagement generated cross-sectoral insights for scaling up the bakery-brewery industrial symbiosis and insights for local authorities and regional development actors (involved in policy making) to facilitate the implementation and scaling up of industrial symbiosis more broadly in Ireland.

These insights will help enhance industrial collaboration on one hand (e.g. improvement of information sharing mechanisms, creation of secondary raw material markets etc.) and provide policy support (e.g. demystifying the inter-related regulations (food and environmental), introducing appropriate taxation systems and incentives etc.) to ensure the meeting of government set policy targets (e.g. Waste Action Plan for Circular Economy, Sustainable Development Goals etc.) on the other. Wider dissemination of the findings of this project was done via this report, stakeholder engagement, the accompanying case study of the demonstrator, a guide for manufacturers/industry and a report for policy making (e.g. local and regional economic development actors and policy makers).

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Introduction

The concept of waste only started to emerge during the industrial revolution as mankind was mastering energy – prior to this waste generation was marginal. As machinery was introduced, production lines became increasingly standardised, companies' outputs grew, and mass production became the norm accompanied by a substantial rise in pre-consumer waste. As consumer demand and markets grew globally, the supply of raw materials for meeting market demand became more limited and expensive, motivating producers exploration of cheaper and more economical alternatives to virgin raw materials.

By 1970s, a group of private organisations in the Danish town of Kalundborg decided to work together to reuse one another's waste streams within their production chain, hence maximizing overall raw material supply and use, as well as delivering cost savings. To date the Kalundborg Symbiosis, which is still in operation, is estimated to deliver annual savings of 635,000 tonnes of CO2; 3.6 m^3 of water, 100 GWh of energy, 87, 000 tons of virgin materials; €14.1 million in socio-economic savings and €24.2 million in business economic savings ((Kalundborg Symbiosis, n.d.), (EMF, 2013). Creating synergies and transactions collaboratively in this manner which optimize flows of material, energy and capital between industrial actors at inter-firm level is referred to as Industrial Symbiosis (IS). Industrial Symbiosis has more recently been formally defined by an industry-led consortium for the EU as *"the use by one company or sector of underutilised resources from another, with the result of keeping resources in productive use for longer (underutilized resources being broadly defined to include waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials)"* (CEN, 2018).

While industrial symbiosis evolved as a strategy for economic sustainability, its environmental and social benefits have over the years been widely acknowledged. Recovering and capturing the value of various by-products (valorisation) via industrial symbiosis has not only resulted in cost reductions and savings but also greenhouse gas emission (GHG) reductions. Other benefits of industrial symbiosis include landfill diversion (environmental), increased tax revenues from increased sales and profits (economic), increased competitiveness from reduced production costs and demand-led innovation (economic), increased private investment (economic), job creation and safeguarding (social), cleaner environment (social), SME engagement (social) etc.

Industrial symbiosis has been described as an example of circular economy in action because it disrupts the conventional linear economic model (take-make-waste) and is one of a multitude of resource-life extending strategies which contribute to keeping materials in productive use in the economy (Blomsma and Brennan, 2017). At the first Industrial Symbiosis Workshop by the G7 Alliance for Resource Efficiency in 2015 UNEP identified industrial symbiosis (a valuable contributor to circular economy) as capable of contribution to six UN Sustainable Development Goals namely, Decent Work & Economic Growth (SDG 8), Industry Innovation & Infrastructure (SDG 9), Sustainable Cities (SDG 11), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13) and Partnerships (SDG 17).

Furthermore, the UNEP International Resource Panel Co-Chair and former EU Environment Commissioner Dr. Janez Potočnik argued in 2019 that resource efficiency (industrial symbiosis and circular economy being a key part 'a la' G7 Alliance for Resource Efficiency) contributes to all SDGs.

Aligned with global efforts and European leadership on the need for resource efficiency, and role of industrial symbiosis and circular economy strategies in ensuring it, the Department of Environment, Climate Action and Communication (DECC) of the Government of Ireland published the "Waste Action Plan for a Circular Economy" (DECC, 2020), which identifies opportunities for the application of circular economy principles across a range of areas such as food, where currently an estimated 1.3 million tonnes of waste and/or by-products is generated per year. It also outlines Ireland's target of halving food waste in Ireland by 2030, in accordance with the UN SDG's specific commitment under Goal 12 (Sustainable Consumption and Production-target 12.3) and emphasises the role of sustainable food waste management (part of which is valorising food waste and by-products via industrial symbiosis activities) as an effective strategy for reaching Ireland's food waste reduction/prevention target.

In the context of increasing awareness of the benefits of industrial symbiosis to valorise waste, the SymbioBeer Project, funded by the EPA sought to address the 2019 Green Enterprise Fund theme of "Food Waste Prevention" by "promoting innovative waste prevention solutions across the food production and food processing sectors". SymbioBeer was facilitated by the Irish Manufacturing Research (IMR) as an industrial symbiosis demonstration pilot (2020-2021) between Panelto Foods and St Mel's Brewery to provide insights into mainstreaming industrial symbiosis in Ireland's bakery and brewing sectors.

1. SymbioBeer - Project Overview & Objectives

Valorising bakery production residues to create beer is not new - producing beer out of bread dates to ancient Mesopotamia – and more and more examples of producing beer from surplus bread are emerging for example, ToastAle; JawBrewery and Adnams' collaboration with Marks & Spencer in the U.K. to name but a few.

The reason that creating beer from bread is attractive is because surplus bread can replace up to a third of the malted grain required for beer production (EMF, n.d.)– which not only reduces food waste but also reduces the ingredients bill (delivering costs savings) for breweries and the land and water-intensive footprint associated with grain production creating more resilience within the sector. However, despite the range of niche examples of producing beer, a gap in knowledge was identified related to the key barriers preventing the mainstream use of production residues from the bakery sector as a secondary raw material and starch substitute in beer production.

In addition, while opportunities exist to develop higher value applications/uses of residues from brewing for the bakery sector with reduced environmental impact, demonstration of these in Ireland is currently limited. The limited uptake of higher-value applications and mainstream valorisation of production residues can be attributed to firstly the fact that industrial symbiosis tends to occur between sectors, rather than within sectors and requires high-levels of collaboration. Secondly, opportunities to valorise production residues are not always self-evident and need to be uncovered.

Against this backdrop, the SymbioBeer project, sought to demonstrate the potential of industrial symbiosis as a strategy to improve the competitiveness and economic resilience of St Mel's Independent Brewing Company (a micro-enterprise) and Panelto Foods (industrial bakery firm) through new product development and product diversification (increasing revenue potential through novel revenue streams). Local sourcing of secondary raw materials / ingredients which can be used as material substitutes for virgin raw materials / ingredients not only delivers economic benefits but also contributes to reduced environmental impact, diverting waste into a resource, reducing GHG emissions associated with transportation, raw material extraction/cultivation.

The SymbioBeer project also sought to raise awareness of industrial symbiosis and circular economy, highlighting the cross-sectoral opportunities which exist for wider implementation of industrial symbiosis implementation in the Longford area as well as seeking to unpack the key barriers and success factors to implement industrial symbiosis in Ireland's brewing and bakery sectors.

1.1 Project Objectives:

This overarching project objectives of the SymbioBeer project include:

- Demonstrating the feasibility and business case for creating industrial synergies between breweries and bakeries to reduce food waste in these sectors through the re-use of bread production residues as a secondary raw material for beer production and the utilisation of by-products from beer production to create new bread products (via material flow analysis and value stream mapping, as well as demonstration pilot)
- Qualifying and quantifying the environmental and economic impact of establishing industrial synergies between bakery and brewery sectors (via techno-economic analysis).
- Creation of an industrial symbiosis framework for evaluation of industrial symbiosis opportunities in the wider area of Longford and other areas of Ireland (via a desk-based review of industrial symbiosis best practices, key policies, regulations, extended producer responsibility/compliance schemes and standards)
- Developing a register of opportunities for potential synergies in the Longford area to inform the business case for creating further industrial synergies in the region (via mapping of industrial symbiosis opportunities and stakeholder engagement).
- Identifying key barriers and success factors to the wider implementation of industrial symbiosis between brewery and bakery sectors (via stakeholder engagement).
- Developing insights for industry and policy making, to support the wider up-take of industrial symbioses in Ireland (via stakeholder engagement); and disseminating key findings (via stakeholder engagement, demonstrator case study, summary guide for industry seeking to engage in industrial symbiosis and a summary guide for policy making).

Figure 1 (Pert Chart which can be found at the end of the report) summarises the methods used to achieve the SymbioBeer project objectives as outlined above, as well as detailing the work packages and outputs associated with these objectives. In Section 2 these methods are described in more detail.

2. Project methods and approach

To achieve the SymbioBeer project objectives we employed five key methods namely (i) **material flow analysis and value stream mapping**; (ii) **demonstration pilot**; (iii) **techno-economic analysis**; (iv) **mapping of industrial symbiosis opportunities**; and (v) **stakeholder engagement** (as outlined in Figure 1).

In this section we describe the key objectives in each of the project's work packages as well as the different methods used to complete the associated tasks and deliverables Work Package 1 addressed the tasks and deliverables associated with implementing an industrial symbiosis in practice between a bakery and brewery, while Work Package 2 addressed tasks and deliverables associated with exploring how to scale industrial symbiosis at a regional level in the wider Longford region as well as how to mainstream valorisation and the implementation of industrial symbiosis within Ireland's bakery and brewing sectors.

2.1 Industrial Symbiosis in Practice (WP 1)

Work package 1 showcased industrial symbiosis in practice at a cross-sectoral level i.e. demonstrating the feasibility and business case for creating industrial synergies between St Mel's Brewery Co and Panelto Foods with a view to reducing pre-consumer food waste in these sectors through the exploration of higher-value applications and opportunities to valorise production residues as a secondary raw material. This was done via the application of **material flow analysis and value stream mapping,** as well as conducting the **demonstration pilot.**

The **material flow analysis and value stream mapping** involved (i) taking the stock of material flows (wastes and/or residues) of the two companies involved (Panelto Foods and St Mel's Brewery); (ii) quantifying and qualifying the **demand** (amount of bread waste produced by Panelto Foods) and **supply** (the amount of bread that St Mel's Brewery would require to produce beer) of by-products and/or secondary raw materials. The results of the material flow analysis and value stream mapping informed the pilot batches that St Mel's Brewery and Panelto Food tested during the demonstration pilot.

The material flow information was collected virtually via interviews and during regular project meetings using Waste Assessment Form from B CORP Impact Assessment survey (B CORP, n.d.) (a social and environmental performance certification) adapted to an Industrial Symbiosis perspective. Additional key codifications and adaptations were adapted from a Comparative Analysis of Industrial Symbiosis in a Business Network in Brazil and related Solid Waste Management Plan (Souza et al., 2020)

The demonstration pilot was a small-scale pilot for assessing the viability of the ideas for valorising production residues from the bakery and brewery sectors; and a tool to understand and manage potential barriers to industrial symbiosis. The **demonstration pilot** comprised of multiple trials and experiments by both industry partners that tested the feasibility and business case for new product development across both sectors (bakery and brewery). The demonstration pilot tested the potential of bread production residues as a secondary raw material and starch substitute in beer production. The demonstration pilot experimented with surplus bread, while aiming to utilize cooked dough (which is more available in large quantity) at mass production stage since they both have the same functional and material properties (e.g. they are both edible etc.). The choice to experiment with surplus bread rather than cooked dough was premised on the following reasons (i) surplus bread is easier to collect manually (ii) easier to transport, (iii) less perishable nature (given it is already packaged) in comparison to cooked dough, (iv) meets all necessary food regulations. The alternative valorisation pathways and decision points associated with the use of surplus bread and cooked dough at pilot and mass production stages respectively is described in Figure 2.

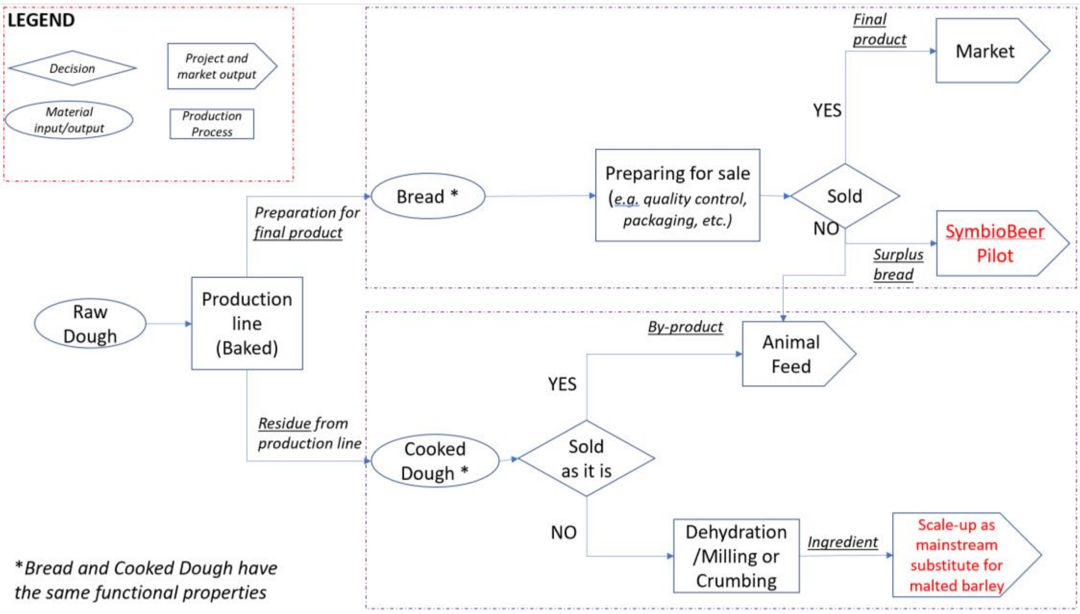

Figure 2: Valorisation pathways and decision points: surplus bread (pilot) versus cooked dough (scale-up / mainstream material substitution in mass production)

The demonstration pilot also the use of yeast by-product from beer production for leavening of bread dough; the use of brewer spent grain from beer production as a high nutritional ingredient in bread products, and the use of brewer spent grain from beer production as bread flour.

Additionally, work package 1 also qualified and quantified the environmental and economic impacts of industrial synergies tested via the demonstration pilot using **techno-economic analysis.** The **Techno-economic analysis** involved creating two scenarios for comparing the baseline and industrial synergy conditions (qualification), as well as adopting greenhouse gas emissions and economic cost as measurement indicators (for quantification). The two scenarios for qualifying the environmental and economic impacts for both companies include the baseline scenario and the industrial symbiosis (IS) scenario of successful synergies between the bakery and brewery sectors.

2.2 Industrial Symbiosis Opportunities Evaluation & Dissemination (WP2)

Work Package 2 developed an industrial symbiosis framework from a **desk-based review of industrial symbiosis best practices, and key policies, regulations, extended producer responsibility/compliance and standards.** The industrial symbiosis framework developed was used to map **industrial symbiosis opportunities. The mapping of industrial symbiosis opportunities involved** identifying additional waste reduction or prevention opportunities within the Longford geographic area. Also, to gain insight into the barriers and enablers of industrial symbiosis implementation in the industrial area of Longford and other areas of Ireland, a **stakeholder engagement** workshop was held for industry, local government, and regional development actors. The stakeholder engagement workshop was also a forum for dissemination of the findings of the SymbioBeer project (in addition to the dissemination webinar).

The industrial symbiosis framework which informed the mapping of industrial symbiosis opportunities was developed based on key principles from UNE 166601 (2006)and UNE 166602 (2006) standards for innovation management systems, Jensen (2016), Domenech (2018) and Garcia (2018). The UNE166001 (2006) standard highlights the need to have a clear picture of (a) legislations, (b) company operations and (c) risk and critical points management; and emphasises prioritizing the identification of (d) new products or processes, (e) potential markets, (f) possible economic exploitations and (f) emerging value chains. The UNE 166002 (2006) standard provides guidelines on (a) innovation process and (b) idea selection. Innovation processes may follow various interrelated (and not mutually exclusive) pathways. The main pathway can begin with the potential market identification (or 'market pull'), followed by an identification of associated problems and opportunities, providing the room for 'creativity' which is required to identify ideas that will satisfy new market needs or improve current products or processes. Ideas need to be analysed and selected accordingly based on technical and economic feasibility.

Jensen (2016) prescribes analysis of potential higher value applications for idea selection and argued that industrial symbiosis transactions may be substantially influenced the proximity (i.e. radius of resource exchange) which also depends on: 1) type of residue streams and their physical and chemical characteristics; 2) value of the residues/waste stream, since logistics and storage costs could make these secondary raw materials (such as residues and waste) more costly than virgin raw materials, hence not attractive for businesses. Aligned with Jensen (2016), Domenech (2018) found that bulky low value waste such as construction and demolition (C&D) waste and bio-waste tend to be restricted to local transactions, while low volume high value resources (e.g. cobalt) may have an international scope. Steam and waste heat valorization are therefore necessarily restricted to the local level, as they cannot be transported over long distances. Common metals such as steel and aluminium are generally traded in local/regional markets while more valuable and scarce metals and minerals (i.e. rare earths and critical metals) can travel considerable distances). Lastly, Garcia (2018) argue that industrial symbiosis adoption between two or more companies requires a full knowledge of the State of the Art, particularly for the development of new services/products.

In addition to utilising the industrial symbiosis framework to identify and evaluate industrial symbiosis opportunities within the Longford industrial area and beyond, the approach for mapping **industrial symbiosis opportunities** included the following key steps:

(i) **identifying the businesses in the Longford area and their locations by mining website information and google maps** of Longford Enterprise Office, Longford Chamber of Commerce, Templemichael Technology park and Longford Business & Technological Park;

(ii) **grouping businesses around the Longford area into ten main clusters/anchor sectors**: (a) bars & restaurants, (b) food & feedstuff manufacturers, (c) meat processors and manufacturers and relative value chain, (d) breweries and distilleries, (e) timber manufacturers, (f) constructions, (g) logistics, (h) steel manufacturers, (i) data centres and (j) healthcare

(iii) **developing a map of potential industrial symbiosis relationships based on six parameters**: (a) geography (tech park A, or B, city centre, region); (b) sectors; (c) if by-products need transformation processes (i.e. transformation potential); (d) if transactions require investments (i.e. investment requirements) (e) possible business type to match with (i.e. possible business match-up), and (f) possible products that can be created by industrial symbiosis networks (i.e. potential product creation capability and/or higher value application).

To further evaluate the industrial symbiosis opportunities of the wider Longford industrial area, and to disseminate the findings regarding such opportunities (as found within the SymbioBeer Project), a **stakeholder engagement** workshop was facilitated. Participants included industrial actors (mostly from the food and drink sector- namely Heineken, Diageo, Avoca Seafoods, Goodness Grain Bakery, Lough Ree Distillery, Biasol, Aryzta, Frylite, Adnams, Puratos, St.Mels, Panelto) and local government and regional economic development agencies (from Longford, Donegal, Derry and Strabane) was conducted in March 2021.

From the **industrial symbiosis potential mapping** and the **stakeholder engagement** a **register of industrial symbiosis opportunities** was developed; insights into **potential barriers and enablers (success factors)** for the implementation and upscaling of industrial symbiosis in the wider Longford region were also drawn.

The Stakeholder Engagement workshop had three brainstorming sessions (facilitated virtually using Miro) with participants split into three groups (two groups composed of primarily industry participants and one group composed of purely local and regional officials). The templates for engaging both groups in Miro are found in Figure 3 and 4.

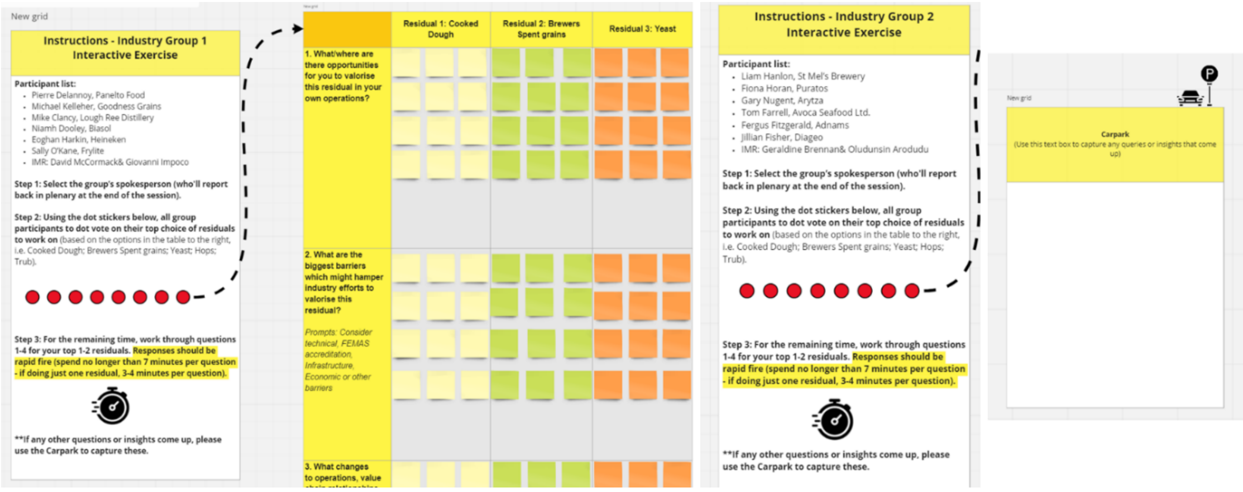

Figure 3: Miro Workshop Exercise for Brewing and Bakery Sectors and their supply-chains

To gain insights on the implementation and scalability of the industrial symbiosis within the brewing and bakery sectors in Ireland, the following questions were posed to industry participants:
(i) What residues (from cooked dough, brewers spent grain, yeast, hops and trubs) are likely to be valorised and in what forms?
(ii) What barriers will hamper efforts to valorise the residues?
(iii) What operational, value chain or procurement changes are required to valorize the residues?
(iv) What initiatives, activities or enablers will support their sectors to move beyond one-off pilots and upscale?

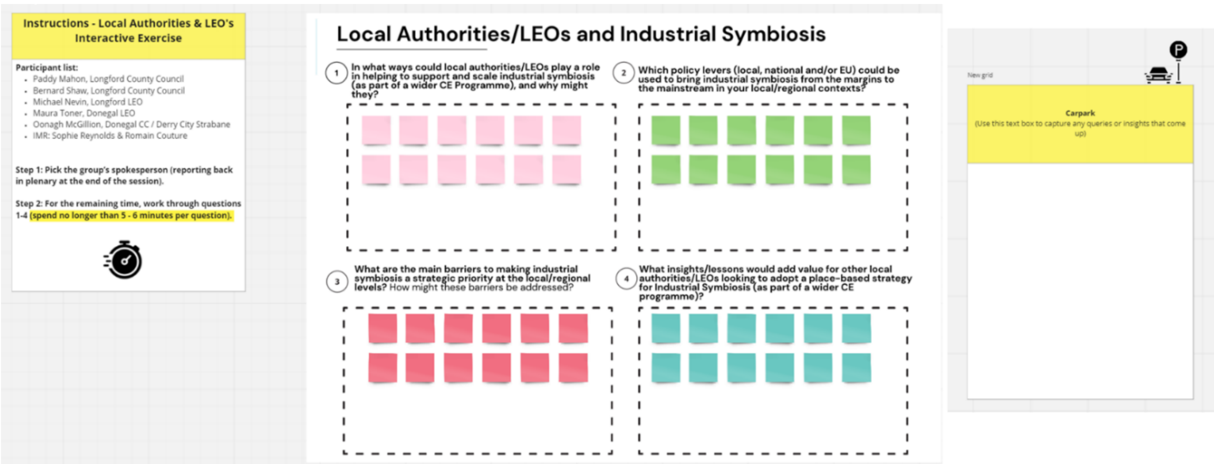

Figure 4: Miro Board Exercise for engaging local government / regional economic participants

In the same vein, the local government and economic development actors were asked the following questions:
(i) In what ways could local authorities or local environmental organizations play a role in helping to support and scale industrial symbiosis (as part of wider circular economy programme) and why might they?
(ii) Which policy levers (local, national and/or EU) could be used to bring industrial symbiosis from the margins to the mainstream in your local/regional contexts?

(iii) What are the main barriers to making industrial symbiosis a strategic priority at the local/ regional levels and how might this be addressed?
(iv)What insights/lessons would add value for other local authorities or local environmental organizations looking to adopt a place-based strategy for industrial symbiosis (as part of wider circular economy programme)?

2.2.1 Dissemination Outputs

As part of the dissemination activities for the SymbioBeer Project, the outputs of the **material flow analysis and value stream mapping**, **demonstration pilot**, **techno-economic analysis**, industrial symbiosis framework and mapping of **industrial symbiosis opportunities** and **stakeholder engagement** methods employed were synthesised to inform the following dissemination outputs:

1) a **Case Study of the Demonstrator**
2) a **Guide for Industry to engage in Industrial Symbiosis**,
3) a **Guide for policy making**

In addition, see Appendix 1 for summary of SymbioBeer Dissemination Activities, Section 3, which follows next describes the results and key findings from the SymbioBeer project.

3. Results and findings

The results and findings obtained from the industrial symbiosis methodology framework employed by the SymbioBeer project are described in line with the five methods/approaches utilised in the project namely; (i) material flow analysis and value stream mapping; (ii) demonstration pilot; (iii) techno-economic analysis; (iv) industrial symbiosis potential mapping**;** and (v) stakeholder engagement**.**

3.1 Material flow analysis and value stream mapping

The results of the material flow **analysis and value stream mapping** conducted is represented in the eSankey resource flowchart map below (Figure 5). These activities enabled the identification of production residues suitable for potential valorisation occurring in Panelto Foods' operations-cooked dough; and St Mel's operations-**brewers spent grain (BSG) and yeast**.

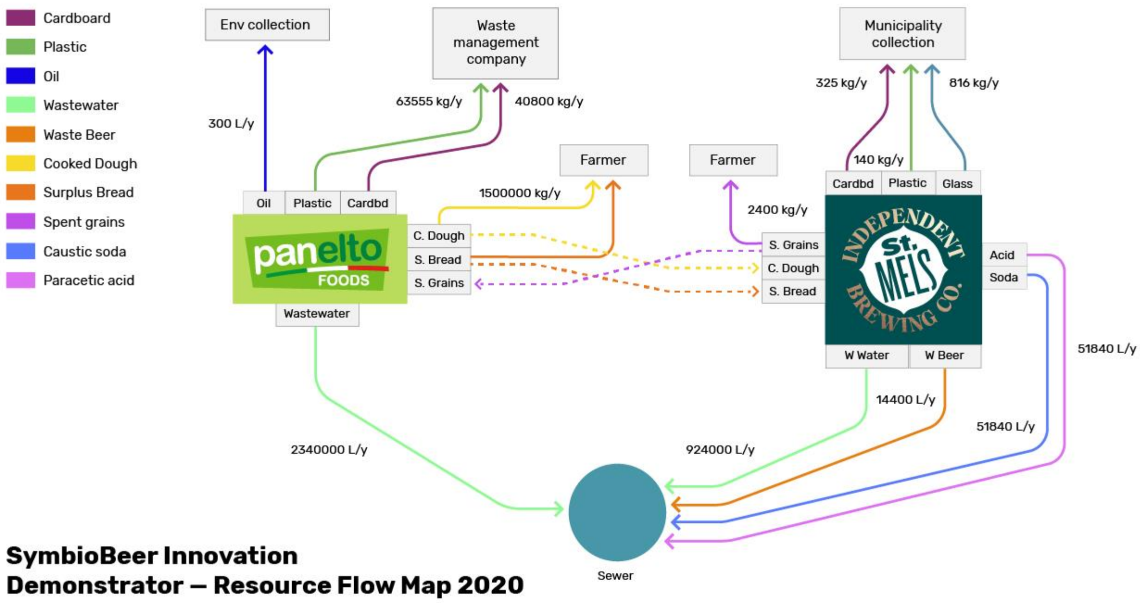

Figure 5: SymbioBeer Project Partners' residue flow (kg/y) eSankey diagram (2020)

3.2 Demonstration pilot

The demonstration pilot explored three basic possibilities (a) *a novel approach*-industrial Symbiosis between companies from different sectors (b) *new product development*-the SymbioBeer limited edition beer recipe (SymbioBeer Project#1), and (c) *a new idea*-utilisation of BSG as potential high nutritional value substitute flour. The results of explorations by the demonstration pilot are described below under three sub-headings-**trial results**, **new product and idea development** and **operational challenges**.

3.2.1 Trial results

An overview of the demonstration pilot trials for each partner company (Table 1) and the success or otherwise of the trials are reported below.

Table 1: Overview of demonstration pilot trials

Company 1: St Mel's Brewery	**Number of trials**	**Company 2: Panelto Foods**	**Number of trials**
Pilot Batches of Beer	8 batches	**Bread experiments using Brewer's Yeast**	1 experiment
Industrial Pilot of Beer (SymbioBeer Project#1)	1 batch of 1200L	**Bread experiments using Brewers Spent Grains (BSG)**	9 experiments

- St Mel's Brewery pilot batches experimented with the utilization of surplus bread as partial substitute for malted barley within its beer production operations. The exploration of a new product development (limited-edition beer) led to the successful launch of an industrial pilot in December 2020 - "SymbioBeer Project#1".

- Panelto Foods' initial experiment to use brewer's yeast from St. Mel's for their bread production was unsuccessful. They then explored the potential use of Brewers Spent Grain (BSG) as a potential high nutritional value flour substitute which was found suitable in comparison with their production parameters.

3.2.2 New product and idea development

The demonstration pilot conducted led to the development of new products and ideas. However, noteworthy also is the fact that while new products were developed on the one hand, market gaps were observed on the other hand.

1) **New product development:** St Mel's developed a new "bread to beer" recipe and in December 2020 launched a limited-edition 750ml Belgian Style Golden Ale called "SymbioBeer Project#1". The product was sold through their newly established e-commerce platform and was well perceived by the market. Substituting malted barley with surplus bread did not affect the flavour of the beer thus demonstrating it is a suitable mainstream material substitute for malted barley which can be used across St Mel's

portfolio of beers rather than just for niche products.

2) **Material traceability gap:** While experimenting with the potential to utilise BSG as a high nutritional value flour, Panelto discovered an important preliminary barrier at pilot stage which impacts their transition from experiments to an industrial pilot and new product development namely **food standard and regulatory requirements**. Panelto's suppliers must make a good quality notification to Environmental Protection Agency (EPA) on to demonstrate the compliance of their by-products with conditions for by-products test namely (i) further use of the material is certain; (ii) the material can be used directly without any further processing other than normal industrial practice; (iii) the material is produced as an integral part of a production process; and (iv) further use is lawful in that the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts. They may also need to be certified to at least British Retail Consortium (BRC) Grade A Standard to ensure conformity with the Hazard Analysis Critical Control Point (HACCP) set criteria and allow for commercialization (Section 3.4.3 and 3.4.4).

3) **Market gap:** The SymbioBeer project highlighted a market gap related to the lack of flour millers in Ireland, underlining an opportunity for either incumbent ingredients suppliers to explore the transformation of BSG into a high nutritional value flour substitute or for new market entries to fill. Addressing this market gap could contribute to making of scaling-up of this demo to mass production commercially viable.

3.2.3 Operational challenges

Both industry partners spent more time than anticipated in the new product development stage (from March to December 2020) due to operational challenges encountered which are briefly described next:

- **Crumbing and milling processes:** St. Mel's Brewery required the bread crumbed to ensure an appropriate starch and sugar reaction. Panelto Foods required the BSG dried and milled to develop a flour form of spent grains.

- **Dehydrating the dough and BSG:** The need for more infrastructure and/or services e.g. a dryer and a miller and the decision whether or not to buy equipment or contract services took some time. The Drying process was outsourced to a third-party to maintain the percentage of moisture and to ensure consistency of taste and nutritional value (in the case of spent grains 10% and in the surplus bread 20%). The dryer and miller infrastructure deficit were resolved by outsourcing these activities to Teagasc.

- **Nutritional analysis requirements**: The need for nutritional analysis for meeting product labelling requirements, in line with food regulation was also a requirement not anticipated at the onset of the project.

- **Food Safety Standard & Regulatory Requirements**: For St Mel's Brewery to supply Panelto Foods with a BSG flour, they would need to make a good quality notification to the EPA demonstrating compliance with the conditions of the by-product test (See Section 3.2.2) and/or certify this new product to at least BRC Grade A Standard – in accordance with HACCP set criteria and as a minimum requirement for supplying ingredients to food companies.

3.3 Techno-economic analysis

The results of the techno-economic analysis undertaken to qualify and quantify the environmental and economic impacts of **establishing industrial synergies between bakery and brewery sectors are described under four headings: Scenario description, Greenhouse gas emissions analysis, Economic cost analysis, and other impacts and benefits.**

3.3.1 Scenario description

The baseline and industrial symbiosis (IS) input and output scenarios of both companies for this techno-economic analysis are described next.

St. Mel's Brewery
The baseline input scenario for St. Mel's considered the greenhouse gas (GHG) emissions and cost associated with logistics and malt supply (270 km * round trip * 50 weeks), while the baseline output scenario considered GHG emissions and costs associated with logistics and spent grains transported from St. Mel's to the farmer.

Since the use of surplus bread as malted barley substitute in the pilot stage is expected to be replaced by the use of cooked dough (which is available in larger quantities) at mass production stage, the Industrial Symbiosis (IS) input scenario adopted by this analysis considered the GHG emissions and cost of the new beer recipe (80% malt and the equivalent 20% material substitute using cooked dough), as well as the additional GHG emissions and cost of residue transformation before incorporation into St Mel's production operation i.e. cost of dehydration process of cooked dough (outsourced to Teagasc and paid for by the SymbioBeer Project). The Industrial Symbiosis (IS) output scenario considers GHGs from spent grains but assumes the cost of transport to Panelto Foods to be negligible. The farmer previously supplied by St.Mel's were also assumed to find a substitute feed supply in the same radius (12km * round trip * 50 weeks).

Panelto Foods
In the case of Panelto, GHG emissions and costs from annual bread production and logistics from Panelto to the farmer (8km * 152 round trips) were taken into consideration for baseline input and output scenarios respectively, while for the IS Output scenario, only GHG emissions and costs from annual bread production were taken into consideration, since GHGs and costs related to logistics to St. Mel's are almost null. Additional pilot costs for residue transformation (i.e. drying and milling of spent grains from St. Mel's) which was outsourced to Teagasc and paid for by SymbioBeer were also considered. The IS and baseline scenarios for both companies are described in Table 2.

Table 2: SymbioBeer Product Development Pilot Scenarios: Baseline vs IS scenarios (2020)

	Baseline Scenario	
Baseline Input	**Company name**	**Baseline Output**
•Yearly Malt supply metric (15000kg) x Env. Conversion Factor	St.Mels	•Spent Grains yearly production(5400kg) x Env conversion factor
•Logistics for delivery to St.Mels (grain from Cork, 270kms * 1 round trip per 50 week) x Env. Factor		•Logistics to St.Mels' farmer contact (12 km*1 round trip per 50 weeks) x Env.Factors
	(+)	
	Panelto	•Cooked dough yearly production (900000kg) x Env conversion factor
		•Logistics to Panelto's farmer contact (8km*3 round trips *52 weeks) x Env. Conversion Factors
	Industrial Symbiosis Scenario	
Valuable composition St Mels= 80% malt + 30% c. dough	**Company name**	
IS Input		**IS Output**
•80% current input(80% yearly malt supply) x Env. Factor	St.Mels	•80% current input(80% yearly malt supply) x Env. Factor
•30% cooked dough x Env. Factor		•30% cooked bread x Env. Factor
•cooked dough drying process (64KWh) x Env. Factor		
	(+)	
	Panelto	•Cooked dough yearly production (900000kg) x Env conversion factor

Environmental conversion factors sources: From Idematapp.com - Grains/spent grains (0.57Kg CO_2 per kg), -bread (0.65kg CO_2 per kg), - industrial drying process (5.13 kg CO2 per 100 MJ, based on conversion rates (1 KWh = 3.6 MJ). From Fleetnews.co.uk- CO_2 logistics calculation, assuming a truck running at diesel (40 L diesel consumption per 100km).

3.3.2 Greenhouse gas emissions analysis

Based on 2019 data, the total combined annual GHGs from the Baseline scenario (for both Panelto and St. Mel's current practices) is 620740 Kg of CO_2, while the total combined annual estimated GHGs of the Industrial Symbiosis scenario is 601700 Kg of CO_2 (resulting in a potential reduction of 19000 kg of CO_2e -about 3% of CO_2 emissions reduction). The estimated CO_2 emissions reduction from the Industrial Symbiosis scenario is mostly due to a reduction of malt partially replaced by cooked dough in the new St. Mel's beer recipe, and due to malt related logistics from Cork (270km to Longford). Considering the relatively small amount of beer produced by St. Mel's as a microbrewery, and the 1-to-1 transaction with Panelto to source a material substitute, an industrial symbiosis scenario has the potential to bring CO_2 reduction without negatively impacting either demonstration partner's business operations.

3.3.3 Economic cost analysis

To aid clarity, we reported the economic cost of the two companies separately in this section.

<u>St Mel's Brewery</u>

Even though St Mel's slightly varied the SymbioBeer recipe between the pilot batch to the industrial batch (i.e. the SymbioBeer Limited edition brew) due to sugar extraction variation, its competitive advantage for substitution of malted barley with cooked dough was only marginal. Even though there were no additional costs associated with labour, packaging or water and energy, the pilot showed that additional pilot costs to Teagasc for extra residue transformation processes like drying, slicing and crumbing would make material substitution more expensive and affect the price of the final product disproportionately.

If this had not been a funded pilot, St Mel's would have had to pay 12-13 times more for the supply of surplus bread than equivalent malted barley. However, in the context of scaling the use of bread production residues as a mainstream substitute in the brewing sector for larger breweries acquiring volumes of cooked dough for mass production is expected to come with improved efficiencies and commercial viability obtainable from economies of scale, hence would not likely impact profitability as suggested by the pilot. In the absence of expensive residue transformation cost associated with transforming small volumes of material substitutes, significant material and cost savings from replacement of virgin ingredient with production residues is anticipated when dealing with larger volumes of production residues.

Also on a further positive note, St. Mel's recognized multiple new indirect benefits from new market segments namely: the material substitution enabled them to brew a stronger beer variety and there are benefits associated with being a brand with sustainability reputation (due to environmental benefits such as lower greenhouse gas emission potential of the SymbioBeer limited edition beer).

Panelto Foods

Similarly to St Mel's results, the additional cost associated with outsourcing the transformation of BSG (to Teagasc), from a mash with high water content (through dehydration and milling) into a flour suitable for production at pilot scale is not economically viable (estimated at somewhere in the region of 270 times more per kg of actual high fibre flour used for Panelto bread production). This would make the price of Panelto's products disproportionately higher.

While material substitution is not economically feasible at pilot level (due to the significant additional pilot cost for residue transformation), we contend that it is likely to become economically viable when scaling up to mass production. The key reasons why mainstream substitution at mass production scales are economically viable is due to the following;

i) procuring larger volumes of BSG comes with cost savings;

ii) mass production has operational efficiency gains;

iii) and flour is an imported ingredient, and there are costs savings to capture from even a percentage substitution given the increase in import taxes due to Brexit.

Additionally, utilising milled BSG as a flour substitute can also halve the amount and cost of yeast required for production. Noting that the current yeast is supplied from Belgium, a reduction in yeast imported would also reduce environmental impacts from logistics – particularly if scaled to mass production. The quantity and cost of salt usage are also anticipated to slightly decrease due to the savoury taste of spent grains. Similar to St Mel's, Panelto did not find differences in labour and packaging costs, nor water and energy usage.

Scaling from Pilot to Mass Production

Scaling from pilot to mass production is necessary for the commercial viability of industrial symbiosis transactions in Ireland's bakery and brewing sectors. In addition to potential GHG emission reduction potential, St. Mel's-Panelto Foods industrial synergy can jointly divert about 1000t of food residue annually to higher value applications, thus an added motivation for scaling.

Since additional residue transformation costs raised the cost of the pilot and the price of its final products disproportionately, a closer look at the operational cost and revision of the adopted strategy in preparation for upscaling to mass production is necessary.

Figure 6 illustrates how the SymbioBeer demonstration pilot between Panelto and St Mel’s was operationalised. Panelto sent its surplus bread (edible but not sold) to Teagasc. Teagasc transformed the surplus bread (via processes like drying, slicing and crumbling) into substitute ingredient suitable for St Mel’s beer production. Although they essentially have the same functional properties, surplus bread was chosen over cooked dough for the pilot due to its less perishable nature, ease of manual collection due to the relatively small volume, ease of transportation and alignment with food regulations. St Mel’s delivered its BSG mash to Teagasc for transformation (by drying and milling processes) into high nutritional flour for Panelto’s bread production.

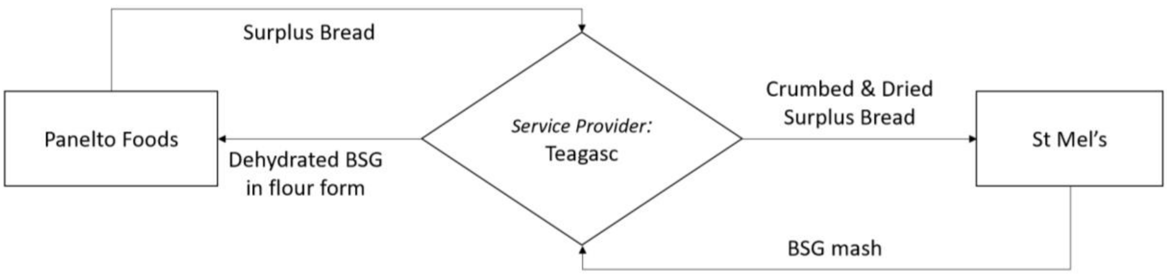

Figure 6: Flow chart of residue transformation for material substitution (at pilot level)

Based on the understanding of how the pilot was operationalised, the high cost of residue transformation processes (outsourced to Teagasc and paid for by SymbioBeer) and the need to upscale from pilot to mass production for commercial viability, breweries and bakeries alike need to either invest in equipment for transformation of their production residues or partner (in accordance with their business needs and specifications) with chosen third-party solution providers, who can fill the gap in new value-chains .This is illustrated in Figure 7 below. The choice of third-party solution providers (e.g. ingredient producers, technologists etc.) to partner with can be based on different market factors namely expected cost savings, business reputation, technology applied, quality of material substitute obtainable etc.

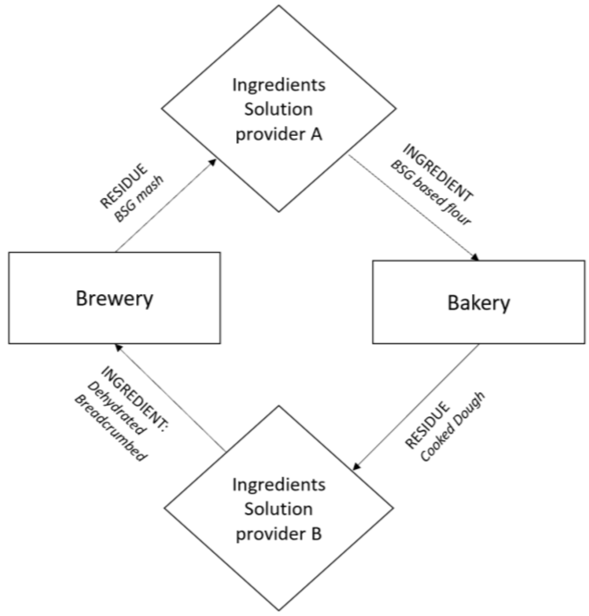

Figure 7: Scale-Up Scenario: Material transformation via Ingredient Providers

Also noteworthy is the fact that 1-2-1 transaction between a microbrewery (like St. Mel's) and an industrial bakery (like Panelto) does not make operational sense. Specifically, St. Mel's cannot provide Panelto a stable supply of spent grains with the required specifications. This is due to the nature of St. Mel's production schedule, which is characterised by small runs, driven by customers demand, and the short shelf-life of BSG. This suggests that a sectoral approach (multiple breweries collaborating with multiple bakeries) is needed to overcome barriers such as investment in new equipment / infrastructure, and to achieve the scale required to ensure consistency of the secondary raw material overtime making the use of BSG based flour an economically viable mainstream input/substitute in Ireland's bakery sector.

3.3.4 Other impacts and benefits from SymbioBeer demonstrator

Improved social awareness and willingness for industrial synergy: Aside new product development of a craft beer and the launch of a limited edition beer during a challenging operating year for micro and small businesses due to the ongoing negative impact of COVID-19, SymbioBeer's visibility via social media and coverage in the Irish Times as well as other regional press (see Dissemination table for overview) in a small community such as Longford has contributed to interest from local start-ups who are potentially interested in exploring future opportunities to collaborate.

<u>**International Engagements Impacts**</u>: Through profiling of SymbioBeer on social media, ToastAle, one of the most successful examples of "breadbeer" reached out to St Mel's Brewing Co. to set up a knowledge exchange meeting. IMR also conducted an exploratory meeting for potential collaborations and exchanges of findings with three Italian organisations: Chamber of Commerce of Bergamo, AFIL (Association of Intelligent Factories of Lombardia region) and Intellimech (mechatronic research center).

Health and Wellbeing Impacts: Industrial symbiosis is a good way to improve wider community health as it has the potential to create a greater sense of community among companies in a close geographical area illustrated by the in-depth engagement and collaboration between St Mel's and Panelto Foods which has potential to continue beyond the timeframe of this demonstration project.

3.4 Desk-based review of industrial symbiosis best practices, key policies, regulations, extended producer responsibility/compliance schemes and standards

In order to develop an industrial symbiosis framework for assessment of the industrial symbiosis opportunities in the Longford Industrial area and beyond, we conducted a desk-based review of industrial symbiosis best practices, key policies, regulations, extended producer responsibility/compliance schemes and standards (for determination of the state-of-the-art) and identified guidelines and principles suitable for creation of an industrial symbiosis framework. We presented our findings in the following sections.

3.4.1 Overview of best practice industrial symbiosis examples in Ireland

Some examples of industrial symbiosis best practice in Ireland are as follows (Table 3):

Table 3: Industrial symbiosis examples in Ireland

Organisation / Initiative	Description
Ecocem	Ground slag is a low carbon binder feasible for replacing conventional cement in concrete manufacturing. It is manufactured from the granulated blast furnace slag, a co-product in the production of pig iron which has been granulated. This way Ecocem reduces the extraction of thousands of tonnes of limestone and clay used for making conventional cement (Vision 2020; Sustainability Report, 2018)
Exergyn	Exergyn has since 2011 been developing a patented technology for converting the low-grade waste heat available in hot water into energy (electricity or motive power) and creating then value from waste hot water, following industrial symbiosis and circular economy principles.
AgriChemWhey	The AgriChemWhey EU project aims of building a first-of-a-kind bio-refinery, capable of transforming over 25,000 tonnes of excess whey permeate, de-lactosed permeate and by-products of milk processing difficult to dispose into lactic acid. This lactic acid can in turn be used to make value-added bio-based products for growing global markets, including biodegradable plastics, bio-based fertiliser and other minerals. This plastic could be used to package dairy products produced by farms, while the bio-based fertiliser could be used for mushroom cultivation.
UCC with Irish Distillers Limited	The focus of the research project "*How to achieve a carbon neutral distillery*", carried out by UCC with Irish Distillers Limited is to identify alternative uses of by-products generated during the distillation process and the potential to convert these into renewable energy. A key technology to achieve this is anaerobic digestion to produce biogas which can then replace natural gas used onsite. Assessment of the utilisation of digestate (biofertilizer) remaining after the anaerobic digestion process is also to be conducted. Additionally, calculation of potential GHG emissions

Organisation / Initiative	Description
	arising from the production of animal feed which may replace the current animal feed produced at the distillery will also be conducted. Other potential renewable energy technologies will be followed by multi criteria decision analysis to aid in the selection of an appropriate system: biomass combustion, increased electrification, and solar PV.
Tallaght District Heating Scheme	The project aims at reducing GHG emissions associated with the use of fossil fuels for heating in Tallaght, South Dublin, and valorising waste heat which currently does not generate any revenue. Waste heat from the data centre will be transferred to the network with the help of centralised large-scale heat pump, housed in an on-site pump house. It is estimated that 58% of heating in the network will be delivered from the data centre as zero-carbon waste heat, corresponding to an annual reduction of 1,441 tonnes of CO2 (Codema, 2018).

3.4.2 Key Policies

Aligned with the findings from Connolly at al. (2017) and Lyons at al. (2017)Irish policies related to resource reuse opportunities identified (and summarised in Table 4) do not represent a substantive barrier to industrial symbiosis adoption.

Table 4: Irish policies on resource reuse opportunities

Irish policies on resource use opportunities	Description
The National Waste Prevention Programme (EPA, 2004)	Operated by EPA, has been in place since 2004
A Resource Opportunity: Waste Management Policy in Ireland (DECLG, 2012)	Provides a roadmap for waste and resource planning, encouraging and promoting reuse of unwanted goods.
The Regional Waste Management Plans (RWMPs) 2015–2021 (EPA, 2015)	Emphasizes prevention, reuse and preparing for reuse, focusing on both the circular economy and the waste hierarchy as central.
National Climate Action Plan (2019)	Outlines the current state of play across key sectors. Supports industrial symbiosis.
Waste Action Plan for a Circular Economy (DECC, 2020)	Introduces ambitious new targets to tackle waste and move towards a circular economy. Supports industrial symbiosis.
Origin Green (Bord Bia, 2017)	The Bord Bia Origin Green Programme encourages all food and drink producers in Ireland to take part in the verified sustainability programme. As part of this support, companies are encouraged to take part in resource efficiency and environmental

Irish policies on resource use opportunities	Description
	management programmes under the Enterprise Ireland Lean and Green initiatives.

3.4.3 Key Regulations and extended producer responsibility/compliance schemes

Key regulations associated with resource reuse and industrial symbiosis in Ireland can be found in Table 5. A decision tree diagram describing the operationalization of the key regulations within the context of resource reuse and industrial symbiosis can be found in Figure 5. Extended producer responsibility and compliance schemes associated with key resource management regulations (including those related to resource reuse and industrial symbiosis) are also listed in Table 6.

Table 5: Waste regulations associated with resource reuse and industrial symbiosis in Ireland

Waste regulations	Descriptions
Article 5 of the Waste Framework Directive (WFD) 2008/98/EC-Regulations, transposed into Irish Law as S.I. No. 126 of 2011.	The EU Waste framework Directive (2008/98/EC-Regulations) transposed into Irish Law as S.I. No. 126 of 2011 lays out basic waste management principles for three items: by-products, hazardous wastes and end-of-waste criteria. Two of these three items are however related to resource reuse and industrial symbiosis (namely Article 27 on by-products and waste determination, and Article 28 on end-of-waste criteria).
Landfill Directive (1999/31/EC)	Legislation surrounding mineral construction and demolition (C&D) waste in the EU is largely shaped by the Waste Framework Directive. Three relevant articles (2, 6, 11) underline how important it is: 1) to reuse excavation material from construction activities, 2) to turn C&D waste into a resource for new applications, and 3) to have a minimum target of 70% of weight for reusing, recycling and recovering all non-hazardous C&D waste.
Packaging and Packaging Waste Directive (1994/62/EC)	The legislation applies to virtually all organisations in the commercial sector as these bodies will supply goods to others that are contained in packaging, and including packaging designed to be consumed at the point of sale, such as bottles, etc. All of these producers are under a legal obligation to ensure that the seven main types of packaging waste are segregated when they arise on their premises: aluminium, fibreboard, glass, paper, plastic sheeting, steel and wood.
Waste Electrical and Electronic Equipment (WEEE) directive (2002/96/EC), WEEE Directive recast (2012/19/EU) and	The purpose of this Irish law is to reduce the presence of toxic metals and other hazardous substances in electrical goods, cables and spare parts. This should, over time, make it easier to recycle and recover WEEE.

Waste regulations	Descriptions
Batteries and Accumulators Directive (2006/66/EC)	
Waste Management (Tyres and Waste Tyres) Regulations 2007:	Ireland's scheme for waste tyre recovery does not stem directly from EU legislation.
Food Waste (SI 508 of 2009)	It embraces food waste arising from large and small supermarkets, from pubs, hotels, cafés and hot food outlets. All operators of obligated premises are required by law to segregate any food waste generated, keeping it separate from contamination by other waste. It then must be separately collected or delivered directly by the producer to a composting or other similar plant.
Sewage Sludge - EU Directive 86/278-Waste Management (Use of Sewage Sludge in Agriculture) Regulations 1998	Regulations on sewage sludge covers processing residue arising from sewage treatment, plus sludge collected from septic tank maintenance. Use of sewage sludge as an agricultural fertiliser falls under the amended regulation on sewage sludge.

Table **6:** Extended producer responsibility and compliance schemes associated with resource reuse and industrial symbiosis

Extended producer responsibility/ compliance schemes	Description
Repak (EPR Scheme for Packaging)	Given the breadth of the requirements for self-compliance, most major producers of packaging have joined the sole compliance scheme in Ireland for waste packaging which is run by Repak Limited. A similar scheme operates for end-of-life vehicles. There is also an equivalent scheme for farm plastics, which in this case is operated by the Irish Farm Film Producers Group (IFFPG) and managed by Repak Limited.
Waste Electrical and Electronic Equipment (WEEE)	Two compliance schemes in Ireland which collects WEEE include WEEE Ireland and EPR Ireland.
Tyres and waste tyres	At present, there are two compliance schemes in Ireland for waste tyres: Tyre Recovery Activity Compliance Scheme (TRACS) and Tyre Waste Management Limited (TWM), and they are enforced by local authorities

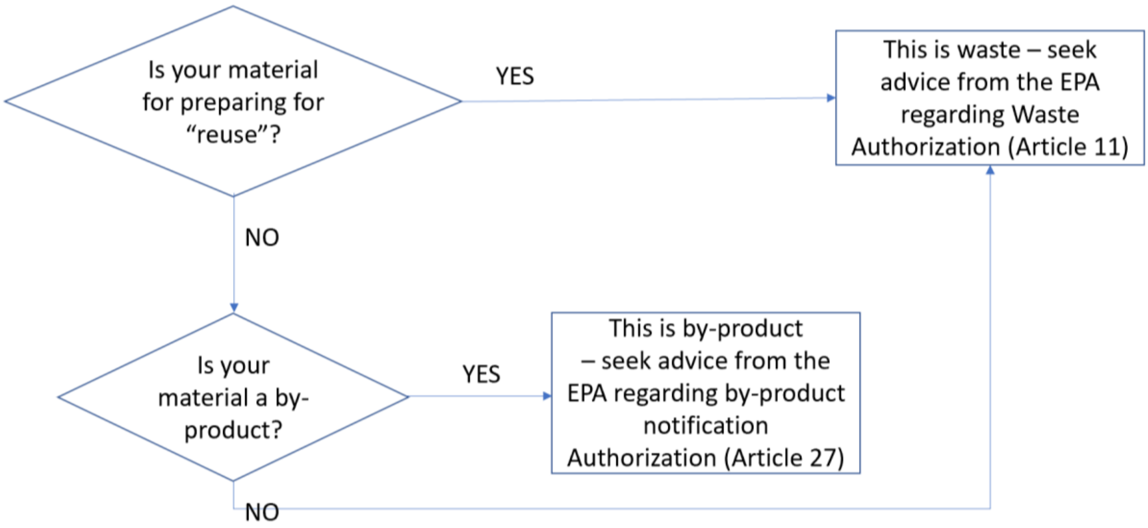

Figure 8: General waste and by-products decision tree (Source: RPS Group as published in Connolly et al, (2017))

3.4.4 Key Food Safety Standards

Key food standards associated with quality of resource usable in food and food related sectors can be found in Table 7; while a decision tree for operationalization of the key food safety standards can be found in Figure 6.

Table 7: Food Safety & Quality Standards

Food standards	Description
The (British Retail Consortium) BRC Standard for Food Safety	The BRC Global Standard for Food Safety was established in 1998 to ensure that traded products are produced according to well-defined quality standards and in compliance with minimum requirements. It can be compared to a specification that binds qualified suppliers to the distribution company. It is one of the food safety standards recognized by the Global Food Safety Initiative (GFSI).
Animal Feedstuff	By-products from breweries such as brewer's grains are a valuable source of animal feed. Breweries who are feed business operators (FBO's) are classified as "Suppliers of Feed Materials". The FBO must ensure that their Hazard Analysis Critical Control Point (HACCP) certification is amended to indicate that by-products or surplus food stuffs are not a waste but a by-product (in accordance with Article 27).
Feed Materials Assurance Scheme (FEMAS)	FEMAS aims to protect human and animal health by ensuring safe practices throughout the feed chain for food producing animals based on HACCP principles. It verifies that the industry is meeting its obligations under the appropriate feed safety related legislation and codes of practice, in maintaining safety in the feed and food chain.

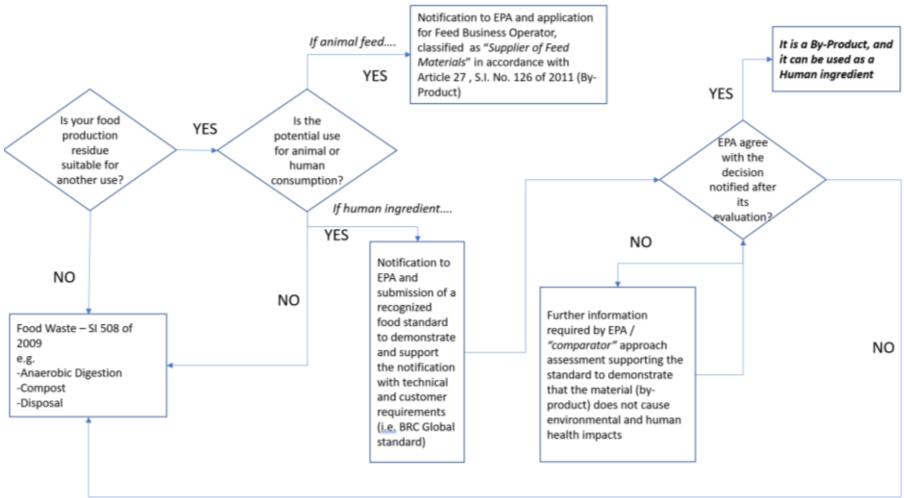

Figure 9: Waste and by-products decision tree in food & beverage sector (Source: Authors)

Table 8: Overview of EPA By-Product Notification Process

High-level overview of technical requirements to demonstrate sufficient human health and environment protection. See "Technical Requirements" in EPA (2020:11) (Step#1)
Notification to EPA and convey all relevant standards specifications and legislation applicable to the material (by-product). This entails: • identification of a national or international published standard and applicable legislation that sets out the technical product requirements (i.e. composition of material and/or other requirements); • comply with all the requirements of the selected standard or specification (i.e. tests and sampling requirements); • additional specific customer requirements defining the material characteristics and including (a) the status of the company, (b) industry body that has developed the customer specification, (c) the methodology used to develop the specification; • provide evidence that the by-product meets the relevant product standard, legislation requirements and/or specifications If technical requirements can demonstrate and provide sufficient human health and environmental protection, EPA will notify and confirm if the by-product can be used (i.e as human ingredient). If the EPA require further information to inform their decision the *"comparator"* approach can be used see Step#2
High-level overview of the "comparator" approach ("Using a comparator" in EPA (2020:17)) (Step#2)
Notification to EPA and "comparator" approach assessment to demonstrate that the material (by-product) does not cause environmental and human health impacts. This entails: Factors to consider in the "comparator" approach assessment: 1)What material specifically to be replaced; 2)Evaluation of composition of the material to be replaced; 3)Evaluation of the "comparator" material composition. Once a suitable comparator material has been identified, the company has to: 1) Compare relevant parameters, such as technical requirement and potential impacts on the environment and human health, and highlight any differences in characteristics in both materials (the material to be replaced and the comparator) 2) Explain why the properties of the comparator material will not lead to unacceptable risks EPA will evaluate and agree if a suitable comparator material has been identified and which will not lead to unacceptable risks. EPA then will notify and confirm whether or not the by-product can be used as human ingredient.

3.4.5 Industrial symbiosis framework

The industrial symbiosis framework presented next builds on guidelines from UNE 166001 (2006)and UNE 166602 (2006) standards for innovation management systems, as well as incorporates principles from Jensen (2016), Domenech (2018) and Garcia (2018) as outlined in Section 2.2 and consists of the following key steps:

• **Step 1**: Identifying concrete value chains and economic activities for industrial symbiosis and gather data to underpin the related market potential (state-of-the-art on market potential and value chain from UNE166001 (2006) standard and Garcia, (2018));

• **Step 2**: Identify key by-products and possible valorization pathway with the highest market opportunity and economic viability potential and conduct further analysis on barriers (state-of-the-art on economic exploitation, market potential, risk and critical point management from UNE166001 (2006) standard, Jensen (2016), Domenech (2018) and Garcia, (2018). This step includes an analysis of company residues, an initial exploration of residue valorisation pathways for higher value applications (in terms of market value and availability) and a synthesis of operational barriers to potential industrial symbiosis valorisation. An understanding of possible areas of material input substitution through stakeholders' engagement and interaction, and a desk research on existing case studies, data, projects and technologies enabling industrial symbiosis internationally would also be relevant for drawing a list of higher value applications.

• **Step 3:** Identify the regulatory framework for analysing the barriers to industrial symbiosis, and for evaluating the functioning of the internal market and potential lost market opportunities related to these barriers (state-of-the art on legislation, market potential from UNE166001 (2006) standard and Garcia, (2018)). This step would help to understand the regulatory and standards compliance needed for the use of residues as material substitutes in another company. Waste and by-products decision tree (Figure 5), and food waste and by-product decision tree (Figure 6) are relevant in this regard.

• **Step 4:** Identify a list of anchor sectors, possible synergies and higher value applications (from existing case studies, data, projects and technologies enabling industrial symbiosis) for technical feasibility evaluation (state-of-the-art on market potential value chain and economic exploitations from UNE166001 (2006) standard and Garcia (2018), and ideas analysis from UNE 166002 (2006)). This step requires an analysis of existing higher value applications and best practices, as well as a sense checking process that takes into consideration the geographical, and value chain context of the different companies as well as the kinds of residues they produce.

• **Step 5**: Evaluate high value application selections based on relevant criteria (from innovation process from UNE 166002 (2006), Jensen (2016) and Domenech (2018)). The criteria found relevant for this project included proximity, technology readiness, assumption of risks, existing value chains/commercial agreements, regulatory and standards compliance, and economy and higher value applications. These criteria were put into consideration in determining higher value applications and mapping the industrial symbiosis opportunities in the Longford area.

These stepwise procedures were employed to develop the mapping of industrial symbiosis opportunities for the wider area of Longford as part of the SymbioBeer project. The resulting industrial symbiosis map of opportunities provides a register of opportunities on which future synergies and business cases for potential higher value applications can be built (from ideas analysis from UNE 166002 (2006) and Jensen (2016)). Find a graphical representation of industrial symbiosis framework in Figure 10.

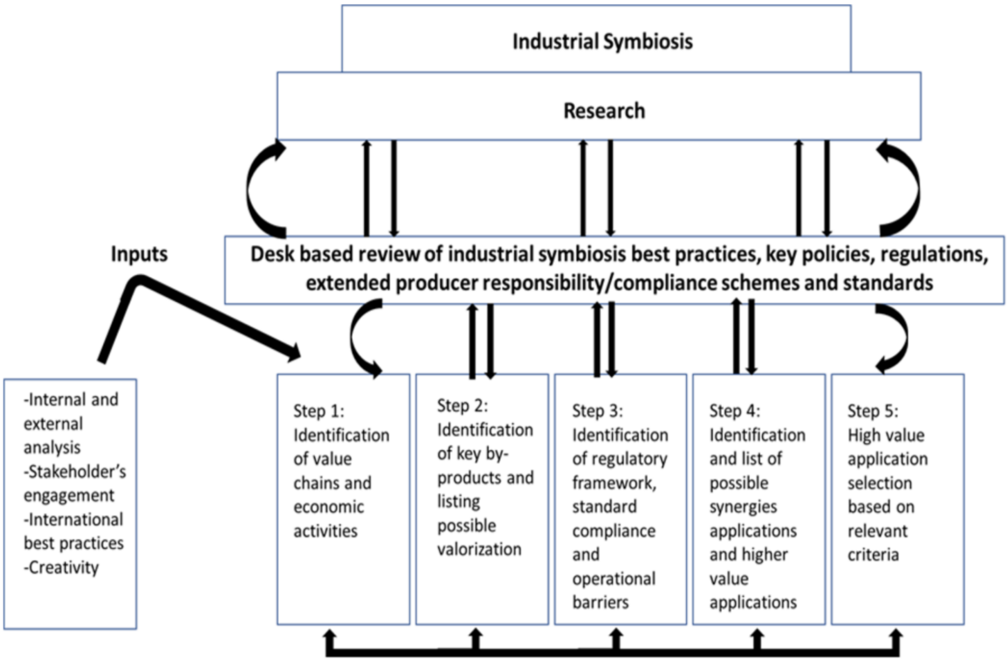

Figure 10: A graphical representation of industrial symbiosis framework (Source: Authors)

3.5 Industrial Symbiosis Opportunity Map

To explore the feasibility and business case for future industrial synergies between actors in Longford area, and develop a register of opportunities for potential synergies, we created a map of industrial symbiosis opportunities.

As part of the mapping process, an initial grouping of businesses in the Longford area into anchor sectors was implemented (Table 9). Based on the groupings and in accordance with the industrial symbiosis framework created (Section 3.4), an industrial symbiosis opportunity map was then produced. The industrial symbiosis framework created highlighted potential waste/residue materials from key anchor sectors in the Longford area, their potential use based on proximity and higher value applications locally/regionally (around Longford area and other areas of Ireland), as well as internationally (in other parts of the EU). Factors considered for determining potential use based on proximity and higher value applications include geography, sectors, transformation potential, investment requirements, possible business match-up, potential for value creation. The industrial symbiosis opportunity map for different residue flows from the Longford area and a list of potential higher value applications can be found in Figure 11 and Table 10.

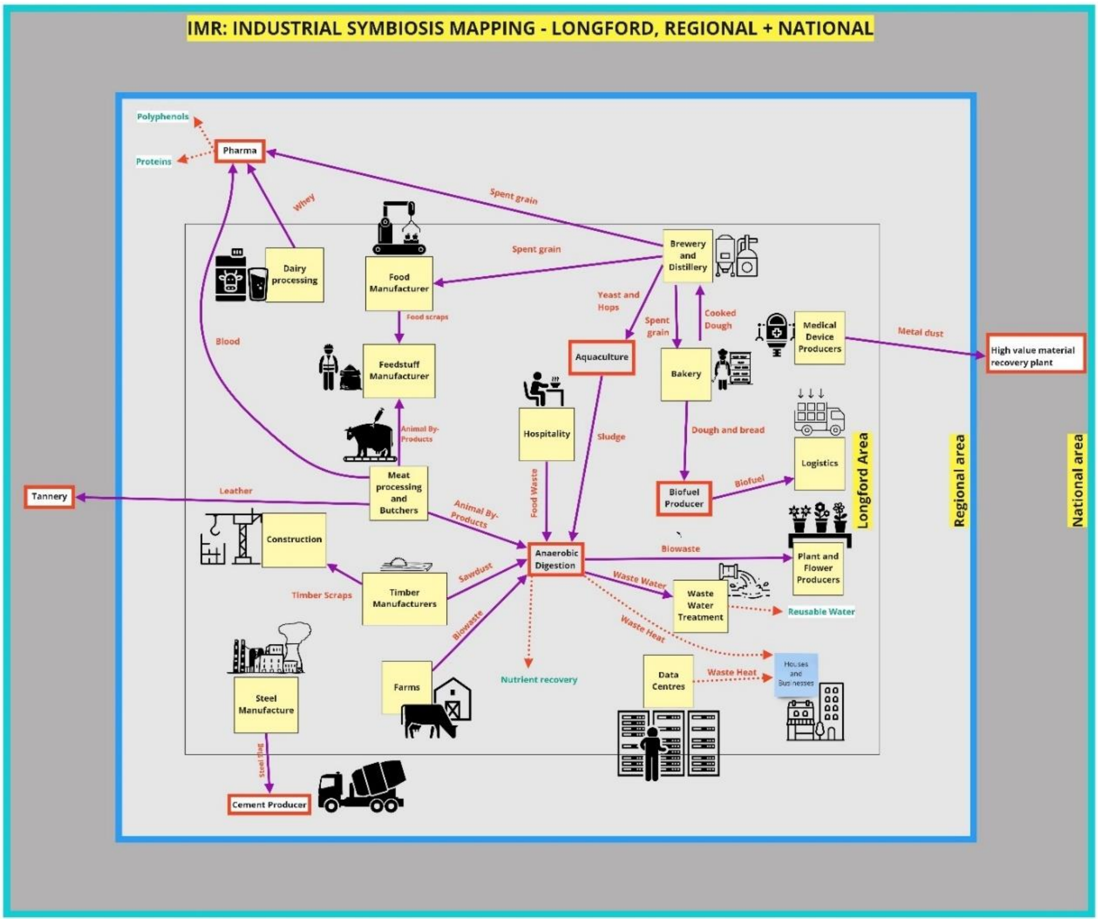

Figure 11: Map of Industrial Symbiosis Opportunities for the Longford area

Table 9: Groupings of Longford area businesses into ten main company clusters/anchor sectors

Industrial Cluster	Company Name	Company Business Type
Hospitality	Camlin Service Station	Bar
	Clarkes Bar	Bar
	Eddie Valentine - 'Valentines'	Restaurant
	JP Reillys Bar	Bar
	Kanes Bar	Bar
	Kavanaghs Bar	Bar
	Milo's Bar	Bar
	Pizza Hut	Pizzeria
	Tally-Ho Bar	Bar
	The Market Bar	Bar
	Longford Arms Hotel	Hotel
	Longford Shopping Centre	Bar
	Dial-A-Chef	Restaurant
	Mekong Asian rest	Restaurant
	Moments Restaurant	Restaurant
	Spice India	Restaurant
	Torc Café	Bar
	Uncle Bok South African Meat restaurant	Restaurant
	Vocella's	Restaurant
Food manufacturers	Green Isle Foods	Food manufacture
	C&D Foods	Food manufacture
	Goodness Grains	Gluten free food manufactures
	Panelto	Industrial bread producer
	PAT the baker	Industrial bread producer
Feedstuff manufacturers	Kiernan Milling	Animal feedstuffs producer
	Paul and Vincent	Manufacture and supply of compound animal feed
Beverage manufacturers	St. Mel's Brewing	Beer producer
	Richmount Cordial Company	Liquor producer
	Lough Ree	Distillery
Meat manufacturers	Herterich Artisan	Butcher
	Lough Bawn Organic	Meat producer
	Kepak group	Primary meat processing business
	FW Woods Ltd –	Online store with fresh meat products
Timber manufacturer	Glennon Brothers Timber Ltd	Timber manufacture
	Longford Precast	Slats for the pig and cattle sectors
	Eamon Glennon Ltd	Coffin, casket manufactures
Logistics	Protrans	Logistics
	Pulse	Logistics
Construction	GEM Group	Construction firm
	Mulleady Construction Co. Ltd	Construction firm
	OMP Ltd	Construction plant parts supplier
Steel manufacturer	Fenelon Group	Steel manufacture
	CPF Profiles Ltd	Steel profiles manufacture
	Framespace solutions	Steel Framed prefabrication
	Kiernan Structural Steel ltd	Steel manufacturers
	N and E Precision	Precision milled and turned components manufacture
Data center	ARK Energy	Data center
	Elephant smart business	Data center
Healthcare	Abbott	Healthcare products manufacture
	Finnesse Medical	Healthcare products manufacture
Wastewater treatment	Butler service	Wastewater treatment solutions

Table 10: Register of opportunities containing potential and higher value applications of waste/residue materials generated in Longford area

Sector	**Waste or residue flows**	**Potential use based on proximity**			**Higher value use**		
		Local	Regional	International	Local	Regional	International
Bakery	Dough and bread	Animal feed			Breweries and distilleries		
Breweries & Distilleries	Spent grain, yeast, hops, trubs	Animal feed and aquaculture			Bakery		
Hospitality	Food waste	Animal feed			Anaerobic digestion and nutrient recovery	Nutrient recovery	
Food manufacturing	Food scrap	Animal feed			Anaerobic digestion and nutrient recovery	Nutrient recovery	
Aquaculture	Sludge	Anaerobic digestion			Water purification and nutrient recovery	Nutrient recovery	
Dairy Processing	Whey	Baking ingredient				Polyphenols, proteins, poly lactic acids for plastics, fertilizers and other minerals, pharmaceuticals	
Meat processing & Butchery	Meat residue	Animal feed				Proteins, pharmaceuticals, Nutrient recovery	Tannery
Timber manufacturing	Timber scrap and saw dust	Construction and furniture					
Farm	Biomass waste (manure and crop residue)	Anaerobic digestion, animal feed (crop residue)			Nutrient recovery	Nutrient recovery	
Steel manufacturing	Blast furnace slag		Green cement			Green cement	
Data centres	Waste heat	Home and office heating					
Wastewater treatment	Sludge	Anaerobic digestion			Water purification and nutrient recovery	Nutrient recovery	
Medical device production	Metal dust		Metal recovery	Metal recovery		Precision metal	Precision metal

3.6 Stakeholder workshop

Responses to the questions posed to the industry participant group at the stakeholder workshop contributed insights for the implementation and upscaling of industrial symbiosis in Longford industrial area and Ireland as a whole. Similarly, responses to the questions posed to the local authority and regional development actors participant group contributed insights for the implementation and upscaling of industrial symbiosis in Longford industrial area and Ireland. Excerpts of stakeholder outputs from Miro for industry partners on the one hand, and local authorities and regional development authority actors on the other hand can be found in Figures 12 and 13 respectively.

Figure 12- Excerpts of stakeholder outputs from the two industry groups

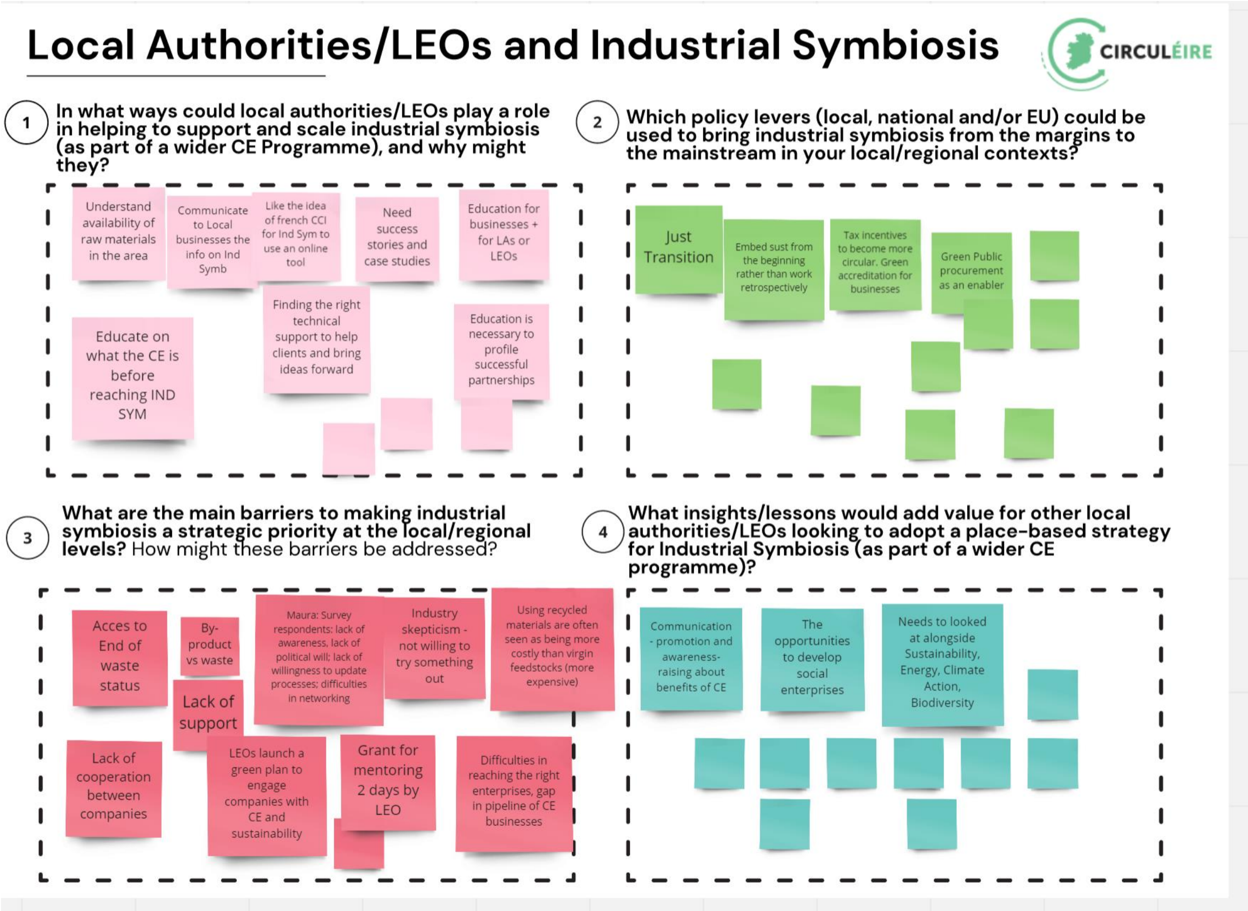

Figure 13: Excerpts of stakeholder output from the local government and regional economic development agency group

3.6.1 From the industry perspective

Selected residues (from the bakery and brewery sectors); valorisation options; as well as system (operational, value chain and procurement) changes needed for valorisation and facilitation of industrial symbiosis are highlighted in Table 9.

Table 9: Valorisation options, barriers to and systems changes for valorisation and industrial symbiosis potential of selected residues

Residues	Valorisation options	Barriers to valorisation and industrial symbiosis potential	Operational, Value Chain & Procurement Activities
Cooked dough	Beer, vodka, whiskey, gin and vodka distillate, polyphenol extract, animal feed, bioplastics, biofuel etc	Traceability, stability of supply, by-product cost, proximity, local supply availability, timely delivery of supplies, logistic cost	Addressing concerns related to safety, perishability, quality, product parameter (homogenization of ingredients), traceability, nutritional status and space/storage in accordance with HACCP set criteria and environmental waste/by-product legislation.
Brewer spent grain	Animal feed, cosmetics, high nutritional fibre content flour (flour substitute), proteins, poly lactic acid (PLA), nutritional proteins (for animal feed, aqua feed, pet food etc.), fibre ingredient, meat product replacement, polyphenol extract, material for furniture, cutlery and packaging etc.	Traceability, stability of supply, by-product cost, proximity, adequacy of local supply, logistic cost, timely delivery of supplies, perishability, need for certifications and adherence to food standards, maintaining consistency product parameter, need for nutritional fortification, risk of microbes and toxins, short shelf life, continuity of residue flow generation etc.	Addressing concerns related to safety, perishability, quality, product parameter (homogenization of ingredients), traceability, nutritional status and space/storage in accordance with HACCP set criteria.

Key initiatives, activities, and enablers of innovation scaling for industrial symbiosis highlighted by industry participants at the stakeholder workshop were as follows:
(i) clarification about added value for finished products (i.e. Different products have different unique selling points, such as nutrition, cost-savings, flavour etc.)
(ii) Microbiology of brewer spent grain for sourdough needs to be ascertained
(iii) Regional sourcing of materials will improve security of supplies
(iv) Reaching right actors for exploiting the added-value of new value chain from residues
(v) Data on residues are needed for investment considerations
(vi) Government support for residue transformation i.e. permission to receive and transform residues from HSE, food safety and environmental organizations will be needed.
(vii) facilitation of relationships among suppliers needed
(viii) education on secondary materials and marketplace needed

3.6.2. From the local / regional economic development actors' perspective

The stakeholder workshop identified potential roles for local authorities and local environmental organizations in local and regional implementation of industrial symbiosis, and in making industrial symbiosis a strategic local or regional priority. Potential role of local authorities and local environmental organizations in industrial symbiosis in Ireland discussed in the stakeholder workshop included:

(i) Educating local businesses, local authorities and local environmental organizations on industrial symbiosis by:
(a) First educating them on circular economy before introduction to industrial symbiosis
(b) Using success stories and case studies to profile successful partnerships
(ii) Facilitating the understanding of the availability of raw materials locally/regionally e.g. via application of online tool as the example from the French Chamber of Commerce and Industry (ACT'IF)
(iii) Finding the right technical support to help clients and bring ideas forward

The major policy lever for bringing industrial symbiosis from margins to mainstream locally/regionally is embedding sustainability at opening of local and regional businesses via:
(a) Establishment of green accreditation scheme for businesses;
(b) Provision of tax incentives for circularity;
(c) Endorsement and practice of green public procurement.

Identified barriers to making industrial symbiosis a strategic local and regional priority highlighted included: (a) awareness, (b) political will, (c) public sector participation, (d) networking and cooperation among local businesses, (e) willingness to update process (industry skepticism), (f) end of waste criteria specifications, (g) cost of recycled materials and difficulty in reaching right actors.

These barriers can however be addressed by:
(i) Local environmental organizations launching green plan to engage companies with circular economy and sustainability;
(ii) Local authorities providing grants for funding mentoring programmes on circular economy and sustainability to local environmental organizations. This will demonstrate the

needed political will towards tackling lack of awareness, difficulty in networking, lack of cooperation between companies and industry skepticism;
(iii) A channel for communication on flows delineated as residues/by-products and/or waste should be provided by the regulator for effective facilitation of industrial symbiosis;
(iv) Incentives that make recycling more attractive than using virgin materials need be put in place.

Also, from the stakeholder workshop, insights identified for adoption of place-based strategy for industrial symbiosis, include:
(i) Communication, promotion, and awareness raising about the benefits of circular economy and the importance of the role of industrial symbiosis in achieving it;
(ii) Exploring opportunities for social enterprise;
(iii) Identify accompanying sustainability, energy, climate action and biodiversity needs to avoid conflicts.

4. Insights for industry and policy making

Specific insights garnered during the SymbioBeer project for implementation and scaling of industrial symbiosis activities are presented in the following sections. Section 4.1 discusses insights for upscaling bakery-brewery industrial symbiosis from pilot scale to mass production; Section 4.2 discusses insights for industry (mostly food, beverage and ingredients industries) to harness the potential of implementing and scaling up industrial symbiosis, while Section 4.3 discusses the insights for facilitation of the implementation and the scaling up of industrial symbiosis activities by the policy making stakeholders (e.g. local authorities and regional development actors amongst others).

4.1 Insights for upscaling bakery-brewery industrial symbiosis from pilot scale to mass production (from SymbioBeer Demonstration pilot)

The commercial viability of a demonstration pilot differs from that of scaling-up from pilot to mass production, hence the need to identify key barriers and enablers for scaling-up the use of production residues as material substitutes to mass production. Key barriers and enablers for scaling up the use of production residues as material substitutes (from pilot scale to mass production) within the bakery and brewery sectors as observed in the SymbioBeer demonstration pilot are as follows:

<u>Barriers</u>

• **New equipment/infrastructure requirements** - a dryer and a milling equipment were required to transform the by-products into material substitutes suitable for production of an industrial-scale batch of beer (using surplus bread) and bread (using BSG as nutritional ingredient or flour). While the drying and crumbing of the surplus bread, and the drying and milling of the BSG was outsourced to Teagasc, scaling up their use for mass production would require St Mel’s and or Panelto Foods to invest in the equipment or partner with a third party to transform their residues into material substitute.

• **Food Safety & Regulatory Requirements** - For St Mel's Brewery to supply Panelto Foods with a BSG flour beyond the pilot, they would need a good quality notification to the Environmental Protection Agency (EPA) demonstrating compliance with by-product classification requirements (namely certainty of use, direct use without further processing requirements other than normal industrial practice; being an integral part of a production process; and lawful further use i.e. in compliance with the product, environmental and health protection requirements for specific uses, and on avoidance of overall adverse environmental or human health impacts). They might also need to certify this new product to at least BRC Global Standard for Food Safety (Grade A), to ensure conformity with set HACCP criteria and for the purpose of commercialization.

•**Economies of scale** - 1-2-1 by-product transaction is insufficient to achieve economies of scale required for mass production. A cross-sectoral approach (a collaboration between multiple breweries and multiple industrial bakery) is necessary to achieve consistency in quality of material substitutes overtime (given variances in production residues) and necessary to make their mainstream application economically viable. Also, economies of scale may be relatively difficult because bakery and brewery production residues are high volume residues with relatively low value.

•**Lack of data on and visibility of production residues available in regions** (for facilitation of demand and supply) is an additional barrier to scaling-up from limited edition pilots (utilising production residues) to mainstreaming material substitution in the brewing and bakery sectors.

Enablers

• **Proximity** - Close proximity aids 1-2-1 by-product exchanges, facilitates collaboration and reduces logistics costs for the material substitute relative to virgin materials.

• **Replication of International Best Practices and High technology readiness level to transform by-products** – Drawing on international best practice regarding valorisation of production residues in the bakery and brewing sectors (as done by the SymbioBeer demonstration pilot) will help identify multiple potential higher value applications. Also, technological readiness (i.e. availability of industrial dryers & milling machines) required to transform the residues into material substitutes is key for mainstreaming their use in these sectors.

• **Role for facilitator, tailored instruments and online tools** – An existing cross-sectoral synergy outside traditional supply-chains is an enabler of industrial symbiosis activities. A national innovation partner (e.g. IMR) might be needed to facilitate this if not previously in existence. The identification of new product development opportunities and the facilitation of new collaborations (including technical support) using tailored instruments and online tools will also make the availability and demands for production residues more visible. All these are key to scaling-up implementation of industrial symbiosis.

•**Scalable substitution** - Another enabler of industrial symbiosis between the bakery and brewery sectors is the availability of multiple valorisation pathways for higher value applications and the high potential for mainstream substitution. The barriers and enablers of upscaling the use of production residues as material substitutes in the bakery and brewery sectors are illustrated in Figure 14.

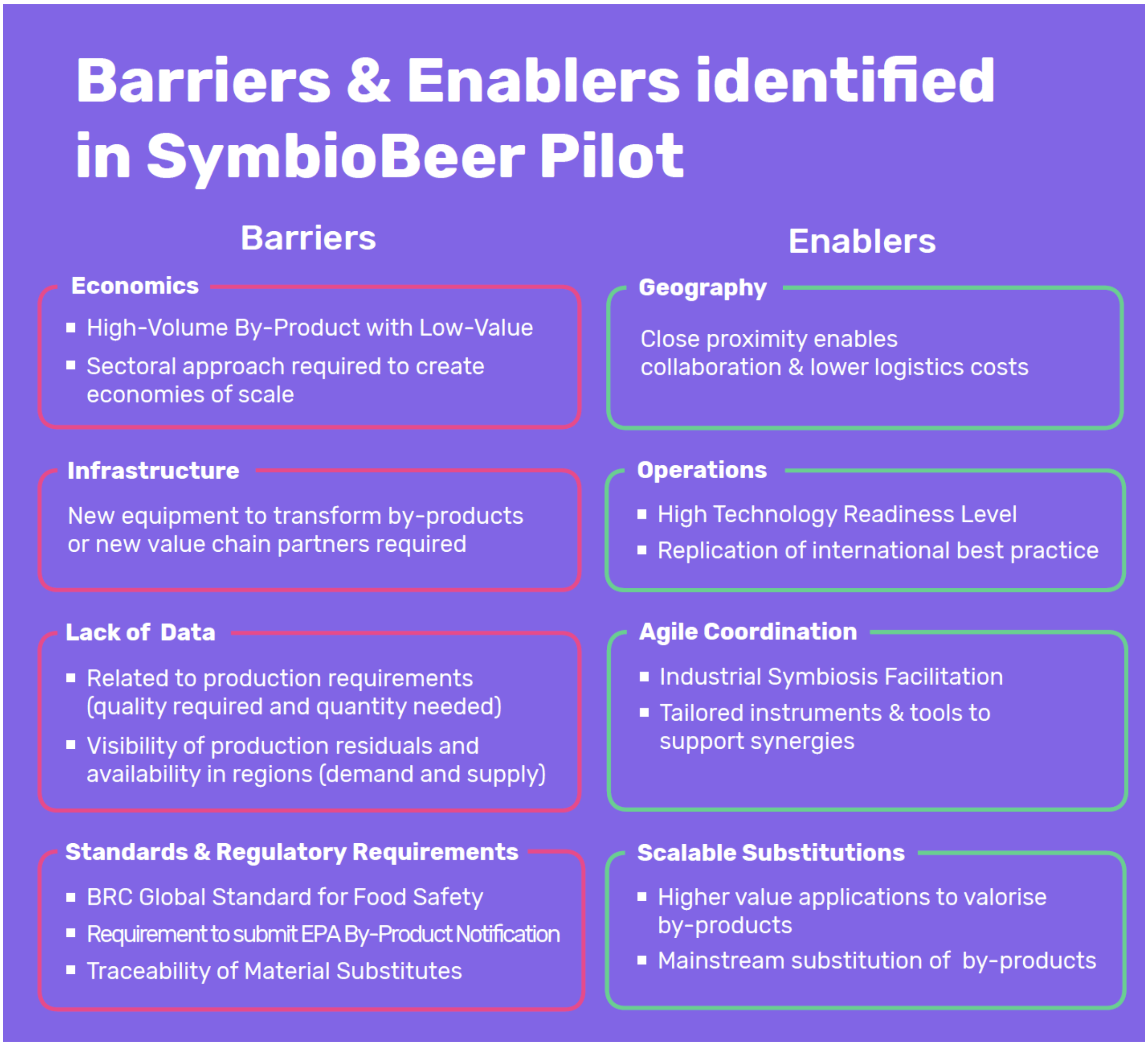

Figure 14: Summary of insights for industry (also included in the SymbioBeer Infographic)

4.2 Insights for industry

Building on the insights from upscaling industrial symbiosis activities from pilot to mass production for the bakery and brewery sectors, this section discusses industry insights (mostly for food and beverage sectors) for facilitating the implementation and scaling up of industrial symbiosis in Ireland.

Industry representatives (mostly from the food and beverage sectors) engaged during the SymbioBeer project highlighted the two major types of barriers to the implementation and scaling up of industrial symbiosis in Ireland: (a) **operational challenges** and (b) **licensing, standards and regulatory procedures/compliance schemes.**

Operational challenges highlighted either relate to;

1) **Supply of and demand for production residues** for material substitution;

OR

2) the **infrastructures and supply chain relationships** required to enable industrial symbiosis transactions.

Operational challenges related to the supply of and demand for production residues for material substitution include (a) data availability and willingness to share information on residue availability and production/material substitution requirements, and (b) need for visibility of production residues and facilitation of use for higher value applications. While the operational challenges related to infrastructures and supply chain relationships required to facilitate industrial symbiosis transactions are characterized as (c) the need for sectoral approaches and new value chains.

Even though there are no Irish regulations explicitly in conflict with industrial symbiosis transactions, there are still **licensing, standards and regulatory procedures/compliance schemes** that companies seeking to establish industrial synergies need to be comply with.

This section explains how these barriers hinder the implementation and scaling of industrial symbiosis, while also offering individual and/or combinations of insights (in form of sectoral approaches, change of mindset, financial instruments, as well as assistance from policy makers and/or external actors) for navigation around or through them.

On a more general note, all the proposed insights for implementation and scaling up of industrial symbiosis are only workable if companies' managers are willing to re-evaluate and change their mindset to embrace industrial symbiosis and be open-minded to new collaborations despite the need to stay competitive.

Table 11: Summary of Key Insights for Industry

Operational Challenges related to supply of and demand for production residues for material substitution **<u>1)</u>** **<u>Data availability and information sharing:</u>** Informing companies about industrial symbiosis possibilities is a key driver for its implementation. Determining actual industrial symbiosis possibilities are however closely linked to data availability and accessibility (i.e. information sharing) which is currently limited. Important data and information such as data on companies' size, structure and functions; and information on the quantity and quality of company's resource streams) are often rarely available. From an economic point of view, lack of access to relevant data makes the projection of potential economic return and subsequent implementation difficult. It also makes many waste/residues streams escape controlled paths, making the tracking of supply and demand, as well as the establishment of secondary raw material marketplaces almost impossible. **<u>2)</u>** **<u>Need for visibility of production residues and facilitation of use for higher value applications:</u>** For a successful industrial synergy where production residues can be used as material substitutes, they need to be available at a viable scale (quantity) and at suitable states/conditions (quality). However, in reality, there is often a mismatch between the quantity and quality of production residues generated by a company or a sector and the scale at which they are needed as material substitutes at the secondary raw material market. This is attributable to an inherent lack of visibility of the flow of supply of production residues from source companies or sectors on the one hand, and the demand for them as material substitute in destination or receiving companies or sectors on the other hand. Often, lack of visibility of production residues from the food and beverage sector leads to outright wastage and/or use of production residues for lower value applications (e.g., animal feed, anaerobic digestion, composting and landfill disposal). From an operational and economic point of view, improving the visibility of the quantity and the quality of production residue available and ascertaining the scale at which they are needed for successful material substitution and industrial symbiosis will be crucial for lowering production cost and mitigating high taxation cost of imported ingredients by Irish food and beverage sector (due to post-Brexit implications) The above operational challenges related to supply of and demand for production resides for material substitution (i.e. data availability and information sharing, as well as visibility for production residues and use for higher value applications) can be addressed through the assistance of and collaboration with policy making stakeholders and relevant institutions. Companies' representatives and associations (i.e. chamber of commerce), as well as policy making stakeholders and/or regulatory bodies (e.g. EPA) can work together to: i) develop and/or adopt shared approaches and methodologies for data collection and information sharing, (on production residues availability, potential higher value use and prospective secondary users) via public channels or platforms (e.g. online reporting tool or regularly updated online statistical database) as it is already done with waste statistics; ii) recognise standards as one of the sources for data collection and as a tracking tool to ascertain availability and quality of production residues to be used as material substitutes; iii) apply policy instruments and financial tools (e.g. taxation) as drivers for facilitating and diverting the use of production residues to higher value applications on the one hand (e.g.

those prioritizing human nutrition), and discouraging lower value applications on the other hand (in accordance with the EPA Food Waste Hierarchy);

iv) initiate connections and facilitate partnerships between owners of production residues and potential secondary users through an industrial symbiosis facilitator or national innovation partner like IMR (based on available and shared data).

Operational challenges related to infrastructures and supply chain relationships required for facilitation of industrial symbiosis transactions

Need for sectoral approaches and new value chains

Creating sectoral approaches and new value chains are key steps for solving the infrastructural deficits and facilitating supply chain relationships for scaling industrial symbiosis transactions and lowering related product's unit costs. From a company prospective, there are many challenges to transitioning from pilot/market niche stage to mainstream adoption of industrial symbiosis. Investments in infrastructures and application of appropriate incentives for de-risking new value chains will help drive industrial symbiosis, especially in the food and beverage sectors where the value of residues are low and sourcing of raw ingredients from other virgin sources can even be cheaper.

Overcoming operational challenges related to infrastructures and supply chain relationships needed for industrial symbiosis facilitation can be addressed if companies' representative/associations (i.e. chamber of commerce) and policy making/regulatory bodies (i.e. EPA) can work together to:

(i) devise financial plans tailored towards reducing high set up costs, lowering high risks associated with new investments, and creating new players (e.g. start-ups, new partnerships etc.) for filling existing market gaps for implementation and scaling up of industrial symbiosis activities.

(ii) formulate financial instruments (e.g. taxation system) suitable for facilitating the use of residues for new higher value applications.

Licensing, standards, and regulatory procedure compliance requirements

Compliance with relevant licensing, standards and regulatory procedures/compliance schemes are obligations that need to be fulfilled for industrial symbiosis transactions to occur. Guidelines for protection of human and animal food chains and safeguarding of human and animal health must be adhered to. Safe practices need to be implemented throughout the human and animal food production and use chains. This can be done by enforcing the integrity, legality and traceability requirements and protocols of production processes, and by ensuring alignment with regulations on the quality of final products.

Regulatory procedures binding the use of by-products and production residues within the human food production chains (food and beverage sectors) of Ireland include:

(i) the HACCP certification criteria set by the Food Safety Authority of Ireland-in line with the Regulation 2004/852/EC of the European Commission, and

(ii) the EPA by-product notification procedure-in line with Article 27 (on by-products and waste determination) and Article 28 (end-of-waste criteria) of the Waste Framework Directive i.e. S.I. No. 126 of 2011 of Ireland and Regulation 2008/98/EC of the European Commission.

(iii) For the Irish animal food production chains, licensing as a Feed Business Operator (FBO) and classification as "Suppliers of Feed Materials" by the Department of

Agriculture, Food and the Marine (DAFM), verification of HACCP compliance via the FEMAS and EPA by-product notification (in accordance with Article 27 of Waste Framework Directive on by-products and waste determination-S.I. No. 126 of 2011) are important requirements to guarantee the safety and protection of animal health and production chains .

(iv) For retailers, the BRC Food Safety Standard is a well-recognized certification system that tests the compliance of traded food products on the retail market against set HACCP criteria. Compliance with licensing, standards and regulatory procedures/compliance schemes for food and beverage sectors are rigorous and time consuming and can therefore impact industrial symbiosis.

In an attempt to streamline the time invested by industry in licensing, standards and regulatory procedure compliance and facilitate industrial symbiosis company representatives from the food and beverage sectors, food standards bodies and regulatory bodies (i.e. EPA) could explore the role of:

(i) demystifying the inter-related licensing, standards and regulatory procedures/compliance schemes as one of the tools needed for industrial symbiosis adoption in Ireland;
(ii) recognising licensing, standards and regulatory procedures/compliance schemes as one of the sources for data collection;
(iii) recognising and aligning licensing, standards and regulatory procedures/compliance schemes as one of the steps or processes in the fulfilment of their traceability requirements and protocols, and
(iv) working together on the collection of data on the quantity and/or quality of potentially available residues/material substitutes, in order to ease compliance with standards.

4.3 Insight for policy making (local authorities, regional economic development agencies etc.)

Policy making stakeholders (local authorities and regional economic development agencies) and bodies can play important roles in facilitating the implementation and scaling up of industrial symbiosis activities in the food and beverage sectors of Ireland. This section discusses their potential roles.

Ireland has so far aimed to decrease landfill rates and to achieve recycling rates established by the EU. It has also made efforts to create a higher sensitization for eco-designs through producer's responsibility initiatives (EEA, 2016). The life cycle approach adopted for implementation of this sustainability effort does not constitute an obstacle to industrial symbiosis adoption. It is also not a driver, nor does it incentivise synergistic transactions. In this regulatory context, local government/regional development actors can play a key role in encouraging and supporting industrial symbiosis collaboration between companies.

In particular, local government and regional development actors have the potential to develop/deploy instruments and/or tools tailored towards supporting synergies within the context of facilitated industrial symbiosis transitions. Such tailored instruments and/or tools can include:

(i) financial instruments;

(ii) licensing, standards and regulatory procedures/compliance schemes;

(iii) educational support (to facilitate change of mindset);

(iv) and provision of public data reporting tools (for data collection and analysis) and information sharing/dissemination channels.

The role of policy making stakeholders (i.e. local authorities and regional development agencies) in devising and implementing the listed tailored instruments and tools are further explained in Table 12 below.

Table 12: Summary of Key Insights for Policy Making

Financial instruments Policy making stakeholders (e.g. local authorities and regional development agencies) and regulatory bodies (e.g. EPA) can collaborate with company representative/associations (e.g. chamber of commerce, sectoral associations etc.) to facilitate industrial symbiosis adoption by devising financial instruments tailored towards: • reducing companies' high set up costs, • lowering high risks associated with new investments, • and supporting the creation of new players to fill existing market gaps (e.g. start-ups, new partnerships etc.) for implementation and scaling up of industrial symbiosis activities. • Other financial instruments (e.g. taxation) could be used as a driver for facilitating the use of companies' residues for higher value applications, for example higher taxes for companies who choose lower step/value applications as listed in the EPA Food Waste Hierarchy (i.e. landfill disposal, anaerobic digestion, composting). • Policy making stakeholders and regulatory bodies can also encourage industrial symbiosis by favouring it as a selection criterion in green public procurements for stocking their food canteens, as well as office stores, warehouses, and refrigerators. Insights into how taxation, and in general policies and regulations may serve both as drivers and barriers for industrial symbiosis transition can be gained from the Kalundborg case study detailed in the **SymbioBeer Policy Guide**. **Educational support** Policy making stakeholders and regulatory bodies can facilitate industrial symbiosis transition by educating industry managers and practitioners, local authorities, and regional development representatives on the need to re-evaluate and change their mindset. There is need for community engagements tailored towards sensitization on the end-of-the-cliff effects of currently dominant linear economy model on the one hand; and reinforcement on the need for application of resource efficiency principles (internally within, as well as among companies and sectors) within the context of transition to more a circular economy on the other hand. Drawing more attention to success stories, case studies, EU best practices (see by way of example https://circuleire.ie/circular-economy-knowledge-library/) can contribute to improving knowledge about local involvement in industrial symbiosis activities, hence paving the way for successful partnerships. **Licensing, standards and regulatory procedures/compliance schemes** Licensing, standards and regulatory procedure/compliance schemes are important requirements for facilitation of industrial symbiosis within food and beverage sectors. Ensuring integrity, legality, traceability and alignment with regulations on the quality of raw material inputs and final products (for human and animal food production chains, and retailers) are important to guarantee the safety and protection of human and animal health (See Section 4.2). Due to the time investment required meeting licensing, standard and regulatory procedure obligations for use of production residues as secondary raw materials accelerating the uptake of industrial symbiosis may require dialogue between policy making stakeholders and regulatory bodies (e.g. EPA), food standards bodies and company representatives in relation to: (1) recognition of licensing, standards and regulatory procedures/compliance schemes as one of the tools needed for industrial symbiosis adoption in Ireland; (2) recognition and alignment of licensing, standards and regulatory procedures/compliance schemes as one of the steps in the process to meet traceability requirements and protocol,

(3) recognition of licensing, standards and regulatory procedures/compliance schemes as one of the sources for collection of data and work together for facilitating close proximity collaborations (by collecting company locations, reporting quantity and quality of potential residuals/material substitutes available).

Development of public data reporting tools and information sharing/dissemination channels
In Ireland, residues from the food and beverage sector tend to end up in lower value applications (e.g. animal feed, anaerobic digestion, composting and landfill disposal) due to lack of visibility of the flow of supply of and demand for residues available. This hinders the possibility of industrial symbiosis adoption as the security of supply of production residues to meet material substitution demands are not guaranteed.

Facilitating the visibility of data on production residues and tracking their relative availability in regions through public channels (as it is already done with waste statistics) is an avenue policy making stakeholders, authorities, regulatory bodies and company representatives can explore to facilitate implementation and scaling up of industrial symbiosis transactions.

Publicly available (online) data reporting tools (for data collection and analysis) and information sharing channels (for dissemination of information among potential industrial symbiosis partners) can make the supply of and demand for production residues more visible. See the **SymbioBeer Policy Guide** for further details on an example of how this has been addressed in France through the ACT'IF online tool which enables secondary raw material markets developed by the French Chamber of Commerce and Industry (CCI) of Haute-Garonne.

5. Conclusion

The SymbioBeer project sought to demonstrate that there are cross-sectoral opportunities to mainstream the use of production residues as material substitutes in the bakery and brewing sector (diverting by-products from animal feed into higher value applications) while delivering environment, social and economic benefits.

The new product development pilot(s) highlighted that whilst the utilization of brewer yeast for bread production was not feasible, it is technically feasible to use bread production residues (cooked dough) as a mainstream material substitute in beer - evidenced by St Mel's Brewery 750ml Belgian Style Golden Ale "SymbioBeer Project#1" (utilising surplus bread) was successfully launched in December 2020 and well perceived by the market. Equally, brewer spent grains (BSG) can be used as a flour or nutritional ingredient for bread.

Our techno-economic analysis suggested that if St Mel's Brewery and Panelto Food were to scale up from the pilot and annual 3% reduction in greenhouse gas emissions, with the potential to divert c.1000 tons of food production residues annually to higher value applications. However, in terms of the economic feasibility a key finding was that mainstreaming material substitution in the food sector requires economies of scale – pilot scale the maths does not work. However, both St Mel's and Panelto Foods believe that improved efficiencies associated with transforming larger volumes of production residues can make the industrial synergy commercially viable. This is due to the gains from operational efficiencies and the economies of scale in mass production. Moreover, even a small material substitution of imported ingredients was deemed to be strategically important due to the increased importation costs of ingredients due to Brexit.

In addition to the new product development activities, we also explored industrial symbiosis opportunities in the wider Longford area developing a register of opportunities for higher value applications. We also explored key barriers and success factors to the wider implementation of industrial symbiosis between brewery and bakery sectors (via stakeholder engagement) to support the implementation and scaling up of industrial symbioses more broadly. Key learnings from this activity were firstly, there is a need to demystify the inter-related food and environmental regulations required for industry to safely utilise production residues as a material substitute and secondly, incentivising industrial symbiosis requires regional production residues stream data combined with registers of opportunities of higher value applications associated with these material flows.

We leave the last word to our SymbioBeer industry partners:

> "Sustainability is a core value for St. Mel's Brewing Company, one of the key learnings for us from this project was a new understanding of the meaning and potential of the circular economy and industrial symbiosis. It is our belief that the circular economy is critical for the future of all companies and that all companies have opportunities for valorisation of waste"
> *Liam Hanlon, Co-Founder, St Mel's Brewing Company*

“The SymbioBeer partnership between Panelto Foods, St. Mel’s Brewing Company, facilitated by Irish Manufacturing Research (IMR), has been a huge learning experience in exploring possibilities in the Sustainable Circular Economy for both companies. St. Mel’s are to be applauded for successfully launching a mainstream beer using surplus bread as an ingredient substitution. This achievement took product, process, and route-to-market expertise as well as capitalising on social media platforms to raise awareness. Big challenges can be overcome with expertise, commitment, and the will to succeed - St Mel's have all these ingredients”

Brian Guerin, General Manager, Panelto Foods

Appendix 1: Dissemination Summary

Below is an overview of key dissemination activities undertaken by the SymbioBeer Project Team and Industrial Partners.

Date	Dissemination Activity	Who	Further Information / Impact
23/03/2021	Symbiobeer Webinar	Panel with representation from the EPA, IMR, Panelto Foods & St Mel's Brewery	48 attendees from across the brewery/bakery sector, academia and solution providers.
11/03/2021	SymbioBeer Stakeholder Workshop	Virtual Workshop delivered by IMR	Included representatives from Heineken, Diageo, Avoca Seafoods, Goodness Grain Bakery, Lough Ree Distillery, Biasol, Aryzta, Frylite, Adnams Brewery, Puratos, St.Mel's Brewery, Panelto Foods) and local government and regional economic development agencies (from Longford, Donegal, Derry and Strabane)
25/02/2021	Virtual Tasting of SymbioBeer Project#1 with Craic Beer Community	St Mel's Brewery	https://www.youtube.com/watch?v=z9xJXRh0spI&t=513s
14/12/2020	Social Media Campaign associated with Limited Edition "SymbioBeer Project1"	St Mel's Brewery	https://imr.ie/2020/12/14/symbiobeer-project1-launched-for-christmas-2020/
10/12/2020	Article in the Regional Press	Longford Leader	https://www.longfordleader.ie/news/home/594814/a-christmas-miracle-longford-company-st-mels-brewery-transforms-bread-into-delicious-beer.html
27/11/2020	Presentation on Symbiobeer	CIRCULÉIRE Ministerial Launch	SymbioBeer was called out by Julie Sinnamon, CEO of Enterprise Ireland in her (virtual) keynote at the Ministerial Launch of CIRCULÉIRE – The National Platform for Circular Manufacturingv
15/10/2020	Article in National Press	The Irish Times	https://www.irishtimes.com/business/technology/innovative-longford-project-brews-beer-from-waste-bread-1.4379748
25/11/2020	Exploratory Meeting with International Research Centres	IMR virtual meetings	IMR explored the potential for new collaborations, and exchanges of findings with three Italian representatives: Chamber of Commerce of Bergamo, AFIL (Association of Intelligent Factories of Lombardia region) and Intellimech (mechatronic research center).
23/11/2020	Good Practice Guide	LEO Donegal / Interreq SinCE-AFC	Interreg project SinCE-AFC – submission describing SymbioBeer which will be evaluated and it may be published in 2021 under Irish good practices.
28/10/2020	Poster	EPA Research programme workshop	
22/10/2020	Presentation on SymbioBeer	EPA Bioeconomy Week Webinar	https://irishbioeconomy.ucd.ie/event/green-enterprise-innovation-for-a-circular-economy/

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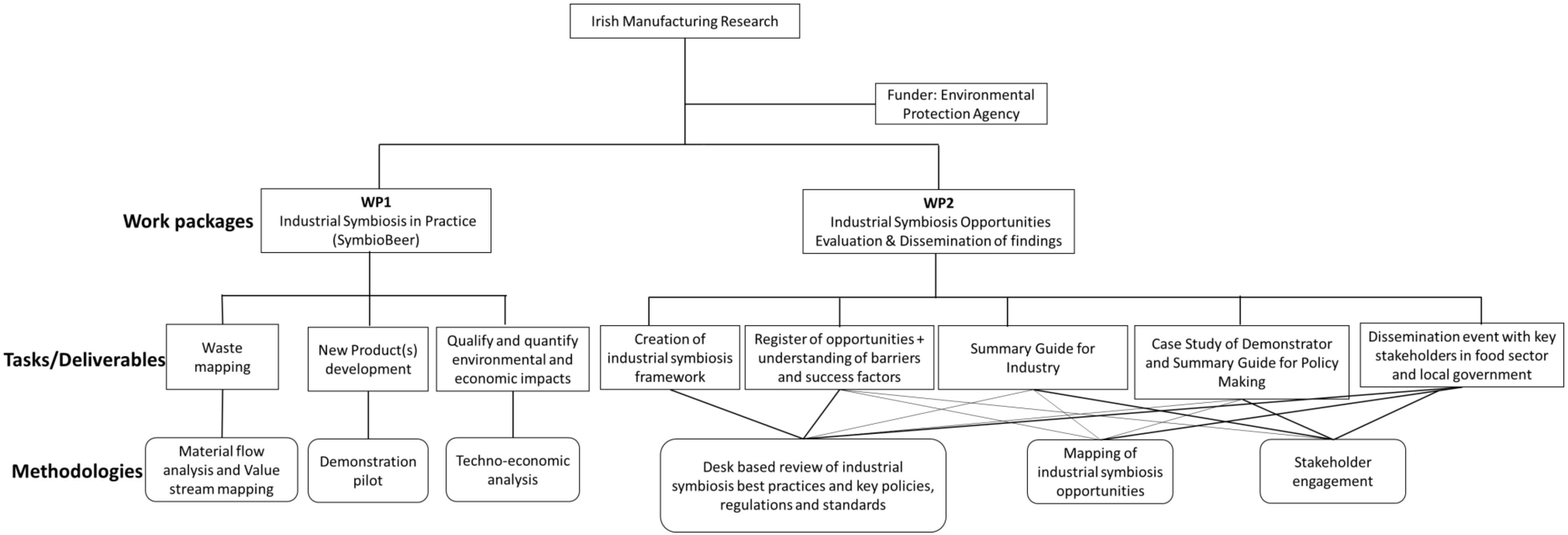

Figure 1: Pert Chart of SymbioBeer Project (including work packages, tasks/deliverables and methodologies)