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Measuring the Economic Impact of the Irish Bioeconomy: A Nowcasting Approach

Zeynep Gizem Can [1,2,*], Cathal O'Donoghue [1] and Antonina Stankova [3]

[1] School of Geography, Archaeology & Irish Studies, University of Galway, H91 TK33 Galway, Ireland; cathal.odonoghue@universityofgalway.ie
[2] Administrative and Social Sciences, Department of International Trade and Finance, Faculty of Economics, Adana Alparslan Türkeş Science and Technology University, 01250 Adana, Türkiye
[3] Department of Economics, Kemmy Business School, University of Limerick, V94 T9PX Limerick, Ireland; antonina.stankova@ul.ie
* Correspondence: zeynepgizem.can@universityofgalway.ie

Abstract

Bioeconomy policy requires timely, economy-wide evidence; however, two persistent measurement constraints remain: official input–output (IO) tables are published with time lags, novel start-up and novel prospective or hybrid bio-based activities are rarely identified as separate sectors in national accounts. This study develops an applied framework that combines IO nowcasting with an accounting-consistent sector-embedding procedure under limited data availability. Using Ireland's national IO system and an existing bioeconomy IO framework as the accounting backbone, we update the 2015 table to 2022 through calibration to macroeconomic control totals, providing a timely structural baseline. We then introduce a transparent method for constructing new bioeconomy sectors based on dominant input shares, import intensity, and output allocation, while preserving national accounting identities. The approach is demonstrated for aquaculture systems, anaerobic digestion scenarios, and plant-based protein value chains. Demand-driven Leontief multipliers reveal heterogeneity in domestic propagation effects across activities and development stages. The framework offers a resource-efficient and replicable tool for evaluating bioeconomy strategies under real-world data constraints. The paper finds that the bioeconomy is structurally heterogeneous rather than a single uniform sector. Aquaculture is strongly transport- and service-linked, anaerobic digestion is more manufacturing-oriented, and plant-based protein production combines agricultural and industrial inputs while showing relatively high import dependence.

Keywords: bioeconomy; input–output analysis; Leontief multiplier; nowcasting

Academic Editor: Davide Settembre-Blundo

Received: 3 March 2026
Revised: 7 April 2026
Accepted: 15 April 2026
Published: 18 April 2026

1. Introduction

The bioeconomy has become central to EU climate-neutrality and circular-economy strategies, as it seeks to reduce dependence on fossil resources by substituting renewable biological materials for fossil-based inputs [1,2]. The European Commission defines the bioeconomy as "all sectors and systems that rely on biological resources, their functions and principles" [3]. This definition highlights that the bioeconomy is not a single sector but a system-wide transformation that reshapes material and energy flows, restructures value chains, and alters production patterns across the economy [4–8].

Despite its policy prominence, measuring the economic size and structure of the bioeconomy remains challenging. Bio-based production is dispersed across industries, embedded within supply chains, and frequently combined with fossil-based activities within the same sectors. Because industrial classifications are organised by production process rather than biological input content, standard statistical systems capture only part of the bioeconomy and tend to obscure emerging or hybrid activities [9,10]. Assessing whether bioeconomy strategies genuinely reduce fossil dependence—rather than shifting environmental or economic pressures—therefore requires accounting systems capable of tracing inter-industry linkages and value-chain effects.

Input–output (IO) analysis provides such a system-wide accounting framework. By representing the structural interdependence of production activities, IO tables link intermediate inputs, value added, and final demand within a coherent accounting structure [11,12]. This enables the quantification of both direct and indirect effects, making IO particularly suitable for analysing bio-based technologies whose impacts propagate through upstream biomass supply, processing, logistics, and downstream substitution channels. IO methods thus allow consistent evaluation of spillovers, import leakages, and value-added distribution across bioeconomy value chains [13,14].

However, applying IO frameworks to the bioeconomy presents two persistent constraints. First, official IO tables are published with time lags and may not reflect current production structures [11,12]. Second, novel or hybrid bio-based activities are rarely identified as separate sectors within national accounts. Although detailed disaggregation or satellite accounts can improve visibility, these approaches are typically data- and resource-intensive [15,16]. On a related note, but with less rigorous demands than national accounts reporting, input–output models are frequently used to undertake technoeconomic assessments of novel products and subsectors within the bioeconomy [17]. As a result, a gap persists between methodological best practice and practical policy needs: comprehensive structural accounting is required, yet statistical infrastructures adapt slowly. Novel or hybrid bio-based activities are rarely identified as separate sectors within standard national accounts classifications. As a result, there can be a mismatch between the timeliness and sectoral detail needed for policy analysis and what is directly available from official IO statistics. This limitation has been noted in the literature, where the monitoring of the bioeconomy is described as "hampered by a lack of statistics on emergent and partially bio-based sectors" [6].

Existing IO applications illustrate both the potential and the limitations of current approaches. Cross-country IO studies quantify upstream and downstream bioeconomy linkages [18], while scenario-based analyses allocate bio-based shares under alternative assumptions [19]. Other contributions extend IO tables to incorporate specific emerging technologies, such as green hydrogen [20] or advanced biofuels within environmentally extended models [21]. Although informative, these approaches typically rely on benchmark IO tables combined with bespoke disaggregation or strong allocation assumptions, limiting their adaptability for timely, economy-wide assessment under constrained data conditions.

This study addresses this methodological gap by developing a practical and accounting-consistent framework for integrating bioeconomy sectors into an updated national IO system. The framework is implemented for Ireland, using the IO system published by the Central Statistics Office and an existing bioeconomic input–output (BIO) model covering traditional bioeconomy sectors. To overcome temporal mismatch, the 2015 Irish IO table is nowcast by calibrating it to external macroeconomic control totals, extending the production structure to 2022. The paper's contribution lies in combining a nowcasting procedure for updating the benchmark bioeconomy IO table with a practical sector-embedding procedure for incorporating new or statistically invisible bioeconomy activities under limited data conditions. The reduced-dimensional specification is used as a pragmatic data-collection and calibration device, supported by the observed concentration of dominant domestic input linkages. Third, we demonstrate the framework across heterogeneous traditional (aquaculture), operational (anaerobic digestion), and prospective (plant-based protein) case sectors and compare their economy-wide propagation effects using demand-driven Leontief multipliers. Its main contribution lies in improving the timeliness, flexibility, and policy relevance of input–output-based sustainability modelling.

By combining IO nowcasting with structured sector construction, the study provides a transparent and adaptable methodology for analysing bioeconomy size, structure, and value-chain effects under real-world data constraints. The remainder of the paper presents the methodological framework, empirical results, and policy implications.

2. Methodology

Bioeconomy policies aim to transform entire value chains, requiring economy-wide evidence on spillovers, leakages, and value creation. Measurement is challenging because bio-based activities are dispersed across industries, embedded in supply chains, and often combined with fossil-based production within the same sectors. Standard industrial classifications therefore capture only part of the bioeconomy and obscure emerging or hybrid activities [6,9]. This complicates assessment of whether bioeconomy strategies reduce fossil dependence or shift pressures elsewhere.

To address these challenges, this study applies an input–output (IO) framework to analyse the structure and demand-driven propagation effects of the Irish bioeconomy. IO analysis provides an accounting-consistent system for tracing inter-industry relationships and quantifying how changes in final demand transmit through production networks [11,12,22]. It is particularly suited to bioeconomy analysis, where activities span primary production, processing, energy, and services and are not observed as a single sector in national accounts [23].

Disaggregation refers to the process of breaking aggregated sectors into more detailed subsectors in order to improve analytical precision, particularly when examining environmental impacts such as those related to the bioeconomy, emissions, or energy use. It becomes necessary when a sector is too heterogeneous—for example, when "manufacturing" includes both bio-based and fossil-based production processes that differ in their input structures and environmental intensities. Disaggregation is also important when environmental performance varies within sectors, when policy analysis requires product-level detail, or when multiplier effects differ across subsectors. In bio-input–output (bio-IO) models specifically, disaggregation is crucial because biomass-based production may have different import intensities compared to fossil-based sectors, the value-added structure may vary, and upstream linkages can influence the size of output and employment multipliers. By separating these components, researchers can better capture structural differences and produce more accurate economic and environmental impact assessments. It provides a practical and scalable method for integrating emerging green activities into national accounts, while strengthening the evidence base for industrial policy and sustainability transitions. The methodology integrates three components: (i) a standard IO framework used to compute output shares, input shares, and Tier I Leontief multipliers; (ii) an inter-temporal nowcasting procedure that updates the benchmark bioeconomy table to a recent year using macroeconomic control totals; and (iii) a sector-embedding algorithm that incorporates new bioeconomy activities not separately identified in official classifications using external information (official statistics, targeted data collection, or structured expert judgement), while preserving accounting identities. The analysis builds on the Irish bioeconomy IO framework developed in earlier work [24–26], which disaggregates the national IO table to explicitly represent bio-based activities. The present study extends this framework by updating the benchmark bioeconomy table over time and using it to compute output shares, input shares, and Tier I Leontief multipliers for aggregated bioeconomy groupings and selected case sectors. The section first introduces the IO framework and structural indicators, then describes sector aggregation and multiplier construction, before outlining the nowcasting procedure and the algorithm for sector incorporation.

2.1. Input–Output Modelling Framework

At the core of the IO framework is the national input–output table, a matrix of inter-sectoral flows that records intermediate transactions between producing sectors, final demand components, and primary inputs [27–29]. Each sector's gross output can be represented equivalently from the expenditure side and the input side. It includes the full accounting structure of the input–output table, including the treatment of intermediate flows, final demand components, taxes, imports, and value added.

In order to create sectoral components of GDP, we start with a theoretical description of an input–output table in Table 1. The accounting structure of the input–output table implies a set of identities linking sectoral output, intermediate transactions, and final demand. In terms of outputs the gross output of sector i can be defined ignoring change in stocks and in terms of household inter-industry trade $\sum_j X_{ij}$ across other sectors j, consumption C_i, capital K_i, government consumption G_i and exports E_i.

Table 1. Input–Output Table Structure $\sum_j X_{ji}$.

	Manu (M)	Non-Manu (N)	HH (H)	Gov (G)	Capital Formation (K)	Final Demand	Exports (€)	Outputs
Manu	X_{MM}	X_{MN}	H_M	G_M	K_M	$H_M + G_M + C_M$	E_M	$X_{MM} + X_{MN} + H_M + G_M + C_M + E_M$
Non-Manu	X_{NM}	X_{NN}	H_N	G_N	K_N	$H_N + G_N + C_N$	E_N	$X_{NN} + X_{NM} + H_N + G_N + C_N + E_N$
Inter-Cons *IC* (X)	$X_{MM} + X_{NM}$	$X_{MN} + X_{NN}$						
Taxes (T)	T_M	T_N	T_H	T_G			T_X	$T = T_M + T_N + T_C + T_G + T_X$
Imports (I)	I_M	I_N	I_H	I_G			I_X	$M = I_M + I_N + I_C + I_G + I_X$
Wages (W)	W_M	W_N						$W = W_M + W_N$
Profit (P)	P_M	P_N						$P = P_M + P_N$
Depreciation (D)	D_M	D_N						$D = D_M + D_N$
Value Added (GVA)	$GVA_M = W_M + P_M + D_M$	$GVA_N = W_N + P_N + D_N$						
Inputs *GO*	$X_{MM} + X_{NM} + T_M + I_M + W_M + P_M + D_M$	$X_{NN} + X_{MN} + T_N + I_N + W_N + P_N + D_N$			$K = K_M + K_N$		$X = E_M + E_N + T_X + I$	

Note: Footnotes refer to a simplified two-sector framework, related to M, Manufacturing, and N, Non-Manufacturing.

On the expenditure side gross output GO_i:

$$GO_i = \sum\nolimits_j X_{ij} + FD_i, \quad where\ FD_i = C_i + G_i + K_i + E_i \tag{1}$$

where X_{ij} denotes deliveries from sector i to sector j and FD_i denotes final demand for sector i's output. Framing in terms of inputs, the gross output of sector i can be defined in terms of intermediate consumption, $\sum_j X_{ji}$, imports I_i, taxes T_i, wages W_i, profits P_i, and depreciation D_i:

On the input side:

$$O_i = \sum\nolimits_j X_{ji} + VA_i + I_i, \quad where\ VA_i = T_i + W_i + P_i + D_i \tag{2}$$

where VA_i is value added and I_i denotes imports. These identities ensure consistency between production, income, and expenditure accounts and form the accounting backbone of IO analysis [12].

Summing, we then produce total gross output:

$$GO = \sum_i \left(\sum_j X_{ji} + I_i + T_i + W_i + P_i + D_i \right) = X + I + T + W + P + D \tag{3}$$

As gross output under both inputs and expenditures are equivalent, the left-hand side intermediate consumption or intermediate demand X, private consumption C, government consumption G, capital K, exports E, right hand-side X intermediate consumption, imports I, taxes T, wages W, profits P, depreciation D combine as

$$X + C + G + K + E = X + I + T + W + P + D \tag{4}$$

Swapping, we highlight the classic textbook equivalence between the three definitions of GDP, respectively expenditure, income and production (at factor cost):

$$C + G + K + (E - I) = W + P + T + D = GO - X - I - T = \sum_i \left(GO_i - \left(\sum_j X_{ji} + I_i + T_i \right) \right) \tag{5}$$

Value added is inferred as $VA_i = GO_i - \left(\sum_j X_{ji} + I_i + T_i \right)$. To allocate intermediate inputs across supplying sectors, we use the domestic technical shares from the 1956 table:

We compute sectoral value added as:

$$VA_i = GO_i - \left(\sum_j X_{ji} + I_i + T_i \right) \tag{6}$$

These identities correspond directly to the row (output) and column (input) structure reported in Table 1.

For inter-temporal analysis, consistent benchmark tables are essential so that changes in indicators reflect genuine structural evolution rather than differences in table construction [30]. In the present study, this consistency is ensured by starting from a detailed bioeconomy benchmark (BIO2015) [25] and updating it to a later year using a nowcasting approach described in the subsequent subsection. The methodological framework outlined here applies identically across benchmark years, allowing meaningful comparison of structural indicators and multipliers over time.

To characterise the economic structure of bioeconomy activities, the analysis reports output shares and input shares for sectors and aggregated sectoral groupings. Output shares describe how a sector's gross output is allocated across final demand components and intermediate uses. For each sector or group, output is decomposed into domestic intermediate sales, exports, and final demand categories, expressed as shares of total output. These indicators provide insight into market orientation and the degree of external demand exposure [31].

2.2. Technical Coefficients Are Defined as Intermediate Flow from Sector i to Sector j Denoted as z_{ij}

$$a_{ij} = \frac{z_{ij}}{x_j}, \tag{7}$$

and the demand-driven Leontief system is:

$$x = \left(I - A \right)^{-1} f. \tag{8}$$

Tier I output multipliers are computed as the column sums of the Leontief inverse and interpreted as structural propagation indicators. They quantify the total domestic output required (directly and indirectly) to satisfy a one-euro increase in final demand for a sector's output. Imports are treated as leakages and excluded from endogenous propagation. To characterise production structure, the analysis reports output shares, decomposing each sector's gross output across intermediate sales, exports, and domestic final demand components, and input shares, decomposing gross output into domestic intermediate inputs, imports, and value added. All shares are computed from balanced IO tables and summed to unity.

Understanding both multipliers and production structure is particularly important in the bioeconomy because bio-based activities are highly heterogeneous in their supply-chain integration and import dependence. A high output multiplier may indicate strong domestic inter-industry linkages, but it may also reflect input-intensive production with limited domestic value creation. Without examining input and output shares, it is not possible to distinguish whether a sector's expansion strengthens local biomass supply chains, increases reliance on imported intermediates, or primarily redistributes value within existing industries.

2.3. Aggregation of Bioeconomy Sectors

Traditional sectors are fully represented in official IO classifications; novel start-up sectors are operational but statistically embedded within existing categories; and novel prospective sectors refer to emerging technologies not yet commercially established, requiring structured parameterisation for integration into the IO framework. The BIO framework used in this study comprises 168 production sectors, reflecting a high level of disaggregation across agriculture, forestry, food processing, energy, manufacturing, and services. While this detail is essential for model construction, it is not suitable for presentation or interpretation in figures and comparative analysis.

To ensure analytical clarity and visual coherence, sectors are aggregated into five mutually exclusive classes (Appendix A):

- Primary bioeconomy—agriculture, forestry, fishing, and other primary biomass-producing activities;
- Secondary bioeconomy—food processing, wood products, bio-based manufacturing, and related processing industries;
- Industry (non-bio)—manufacturing activities not primarily based on biological inputs;
- Services—market and non-market services supporting production and consumption;
- Energy—energy production and supply activities, including bioenergy and non-bio energy carriers.

This aggregation follows the logic used in applied bioeconomy IO studies, including [32] where bioeconomy activities are grouped according to their position in the production system rather than treated as a single homogeneous sector. Each of the 168 sectors is uniquely assigned to one class based on its dominant production function and input structure. The aggregation is applied consistently across all benchmark years.

2.4. Class-Level Multipliers and Weighting

To quantify economy-wide propagation effects, the study computes Tier I Leontief multipliers on a domestic basis, treating imports as exogenous to the inter-industry system [33,34].

The Leontief demand-driven model captures how an exogenous change in final demand propagates through upstream production linkages. Let A denote the domestic technical coefficients matrix and f the vector of final demand. Total output is given by:

$$x = (I - A)^{-1} f. \tag{9}$$

The Tier I Leontief multiplier for sector j is defined as the column sum of the j-th column of the Leontief inverse $(I - A)^{-1}$. It measures the total direct and indirect output generated across the economy by a one-euro increase in final demand for sector j's output [12,31].

Because the analysis focuses on aggregated sectoral classes rather than individual sectors, class-level multipliers are computed as final-demand-weighted averages of sectoral multipliers. Specifically, the multiplier for class c is calculated as:

$$M_c = \sum_{i \in c} w_i M_i \tag{10}$$

where M_i is the sectoral multiplier and w_i is the share of sector i in total final demand of class c. This weighting ensures that class-level multipliers reflect both technological linkage strength and the relative economic importance of sectors within each class, consistent with applied IO practice [32].

This approach avoids dominance by small sectors with extreme coefficients and provides economically meaningful summary indicators for comparative analysis across bioeconomy classes and benchmark years.

2.5. Nowcasting Input–Output Tables

The objective of the nowcasting procedure is to update the benchmark BIO2015 input–output (IO) table to represent the structure of the Irish bioeconomy in 2022, while preserving consistency with national accounting identities. Because an official BIO2022 IO table is not available, the update is implemented under conditions of incomplete sector-to-sector flow information. Three broad strategies can be considered when updating IO tables to a more recent year. The first involves full structural updating using complete inter-industry transaction data for the target year. Although such data may exist within institutional statistical systems, complete flow matrices are not publicly accessible for research purposes, rendering this approach infeasible.

The second strategy relies exclusively on macroeconomic control totals, such as gross output, value added, intermediate consumption, and final demand aggregates, while maintaining the technical coefficients of the benchmark table unchanged. Although this approach ensures accounting consistency, it implicitly assumes fixed production technologies and therefore cannot capture sector-specific structural adjustments over time.

The third strategy, adopted in this study, combines fixed technical coefficients from BIO2015 with partial sector-level flow information and macroeconomic scaling constraints.

This hybrid approach represents a pragmatic compromise between data availability and structural realism. It preserves the accounting coherence of the original IO framework while allowing selective updating where new information exists, providing a resource-efficient and transparent method for nowcasting the BIO2022 table under real-world data constraints. The nowcasting procedure does not fully re-estimate the 2022 matrix of technical coefficients. Where detailed new flow information is not available, the relative input structure from BIO2015 is retained and scaled to updated 2022 control totals. Where more recent sector-specific information is available, this is incorporated into the relevant parts of the table before rebalancing.

2.6. Nowcasting Data Requirements

Teagasc Farm Survey data (2025) [35] informed the original construction of the benchmark BIO2015 table [25]. For the nowcasting of BIO2022, we rely on aggregate control totals for 2022. The nowcasting step is based on updated aggregate 2022 control totals matched to the BIO/IO sector classification. These totals are used to construct updated sectoral targets. Where detailed 2022 inter-industry transaction data are not observed, the BIO2015 transaction structure is retained as the benchmark allocation structure, and the table is then scaled and rebalanced to restore full accounting consistency.

The Central Statistics Office (CSO) [36] provides macro-level control totals for output by industry, intermediate consumption, and final demand categories (household, government, capital formation, etc.). While we do not use the CSO control totals for direct sector-level updates, the macroeconomic aggregates they provide allow us to scale the sectoral data appropriately. The CSO data also include imports and exports, which are critical for adjusting intermediate consumption in the updated BIO2022 table.

2.7. Nowcasting Process

The nowcasting procedure begins by combining the balanced BIO2015 benchmark with updated 2022 sectoral totals and control data. These updated data are first matched to the BIO/IO sector structure and then used to construct sector-specific 2022 targets for output and related components of the table.

Where detailed 2022 inter-industry transaction data are unavailable, the relative structure of intermediate input use from the BIO2015 benchmark is retained as the allocation structure. In this way, benchmark domestic technical relationships are preserved where more recent detailed flow information is not observed, while available sector-specific 2022 evidence is used to update the relevant totals.

Where sector-to-sector flows are not directly observed for 2022, the nowcasting approach preserves the relative structure of intermediate input use from the BIO2015 benchmark. Specifically, domestic technical coefficients from the 2015 base year are defined as:

$$a_{ji}^{2015} = \frac{X_{ji}^{2015}}{\sum_{j} X_{ji}^{2015}} \tag{11}$$

The resulting provisional matrix is then rebalanced so that, for each sector, gross output remains consistent from both the output distribution and input composition sides of the IO system. On the output side, sectoral output is allocated between intermediate deliveries and final demand:

$$GO_i = \sum\nolimits_j X_{ij} + FD_i \tag{12}$$

On the input side, gross output is composed of intermediate inputs, value added, and imports:

$$GO_i = \sum\nolimits_j X_{ji} + VA_i + I_i \tag{13}$$

The final BIO2022 table is obtained by reconciling the updated sectoral totals with these accounting identities. This ensures that intermediate flows, value added, imports, and final demand are jointly consistent within a balanced IO framework.

The consistency of the calibration is reported in Appendix B Table A1, which presents target control totals, calibrated BIO2022 totals, and the corresponding residuals.

2.8. Incorporating a New Sector

Once the IO table has been updated to the simulation year, new bioeconomy activities can be incorporated to evaluate their structural position and multiplier effects. For emerging or pilot-stage technologies, however, it is typically infeasible to obtain a complete 168-sector cost structure consistent with the granularity of the IO system. While developers and technical experts can often identify major cost components, detailed allocations across numerous minor input categories are rarely available.

To incorporate new bioeconomy activities and in particular to undertake technoeconomic assessments under limited data availability, we apply a reduced-dimensional data collection strategy focusing on the key determinants of the domestic Tier I multiplier: import share (leakage), labour and capital shares (value-added intensity), and the dominant domestic intermediate inputs (upstream linkages). A structured questionnaire (Appendix C) collects the shares of the top five domestic input categories, alongside aggregate shares for imports, labour, and capital, ensuring total inputs sum to unity. Output allocation is similarly specified by identifying the main domestic B2B destinations and the overall distribution across domestic B2B sales, exports, and B2C sales.

A structurally comparable reference sector is used to complete minor input and output categories and to calibrate profit and tax shares. The new sector is then inserted into the IO matrix and the system rebalanced to preserve accounting identities. This approach enables transparent and consistent integration of emerging bioeconomy activities while keeping data requirements proportionate to multiplier relevance.

The goal is to source the input shares and the output shares at 4 different stages. Inputs are broken up into (1) purchased goods and services (excluding imports, labour, capital) and (2) total purchases (including imports, labour, capital). In both cases we ignore profit and taxes. For purchased goods and services, we look for data on the share of inputs for the top 5 input products, naming each product and putting other expenditures into the rest. Providing approximate shares is sufficient for our exercise, with total inputs summing to 1. The next block details the share of domestic purchases, labour, capital and imported products. Again, these sum to 1. We classify inputs into 4 phases: R&D, development, growth, mature. It is likely that the labour share and the purchased share will go down as processes become more efficient. We ask our questionnaire respondents to use their best judgement.

We do the same for sales, detailing business-to-business (B2B) sales, again listing the top 5 domestic sectoral destinations (although there may be fewer) (excluding exports and business-to-consumer (B2C) sales). In the next block, we list the share of domestic B2B sales, exports and B2C sales. Lastly, we itemise the potential market size to get a sense of scale. However, as the multiplier is independent of this, it is less important.

In order to incorporate a new sector or product into the input–output model from the supplier questionnaire, we create a Visual Basic macro to automate it. The first thing we must do is to find the most similar existing sector within the model. We use this to get an approximate starting position for the components that are missing, including profit share, tax rate, the distribution of other purchased goods and services and the distribution of other sales sectors. Aggregating purchased goods and services into 12 NACE aggregate sectors plus top 5 inputs/outputs, we consult with R&D engineers to get a sense check of the full input–output structure as well as profit and tax shares and adjust as necessary based upon their feedback. The VBA algorithm adds a new column and a new row to the sector. In order to approximate the total output, we apply taxes and profit to the cost based on starting sales.

While this approach may be regarded as a pragmatic simplification, in our experience in undertaking technoassessments, the manual process can be quite slow and relatively ad hoc, making comparative exercises challenging and cumbersome. Having a more systematic approach which is automated allows for more efficient modelling and provides consistency

https://doi.org/10.3390/su18084035

of approach in comparing the technoeconomic impact of different novel products and sectors. It thus can be regarded as an organisational innovation.

2.9. Assumptions and Limitations

The analysis is subject to several assumptions and limitations that are standard in input–output (IO)-based structural analysis and are explicitly acknowledged here. First, the IO framework is accounting-based and represents production relationships through proportional flows within each benchmark table. BIO2015 is used as the most recent fully reconciled benchmark capturing a normal production structure of the Irish bioeconomy. Where detailed new information is unavailable, elements of the benchmark structure are retained. The resulting estimates should therefore be interpreted as an updated and accounting-consistent structural representation under data constraints, rather than as a fully observed 2022 production structure.

Aggregation is required to ensure interpretability. The BIO framework includes 168 sectors, which is too granular for comparative graphical analysis. Sectors are therefore grouped into five broad categories: primary bioeconomy, secondary bioeconomy, industry, services, and energy following classification principles consistent with bioeconomy IO studies [32,37].

Finally, multipliers are computed on a domestic basis and are weighted by sectoral final demand when aggregated at the category level. As with all IO multipliers, results should be interpreted as indicative of structural linkages rather than causal impact estimates. Despite these limitations, the framework provides a transparent and policy-relevant representation of bioeconomy structure and interdependencies, suitable for comparative analysis and strategic assessment.

3. Results I: Nowcast of Input–Output Table

This section compares the structural composition and economy-wide propagation effects of the Irish bioeconomy between the benchmark BIO2015 table and the nowcasted BIO2022 table. The analysis uses three complementary input–output indicators: input shares, output shares, and Tier I Leontief multipliers. Input shares describe production structure and the balance between domestic intermediates, imports, and value added; output shares show how production is distributed across intermediate uses, final demand, and exports; and Leontief multipliers quantify changes in inter-industry linkages and system-wide spillovers over time within a consistent framework.

3.1. Bioeconomy Class Composition

Figure 1 presents the class composition of output within the BIO input–output framework for 2015 and 2022, based on five aggregated classes: primary bioeconomy, secondary bioeconomy, industry, services, and energy. Primary bioeconomy activities account for a small proportion of total output, declining marginally from 1.29% in 2015 to 1.23% in 2022. Secondary bioeconomy activities show similarly limited variation, decreasing slightly from 2.55% to 2.52%. The small magnitude of these changes indicates stability in the relative contribution of directly bio-based production and processing activities within the aggregated system.

Energy represents the smallest class but shows the most noticeable proportional increase, rising from 1.81% in 2015 to 1.97% in 2022. Although modest in absolute terms, this increase distinguishes energy from the other bio-related categories, which remain largely stable. Industry constitutes a slight increase in share of outputs from 26.36% in 2015 to 26.84% in 2022. The modest rise suggests limited reallocation toward industrial activities over the period.

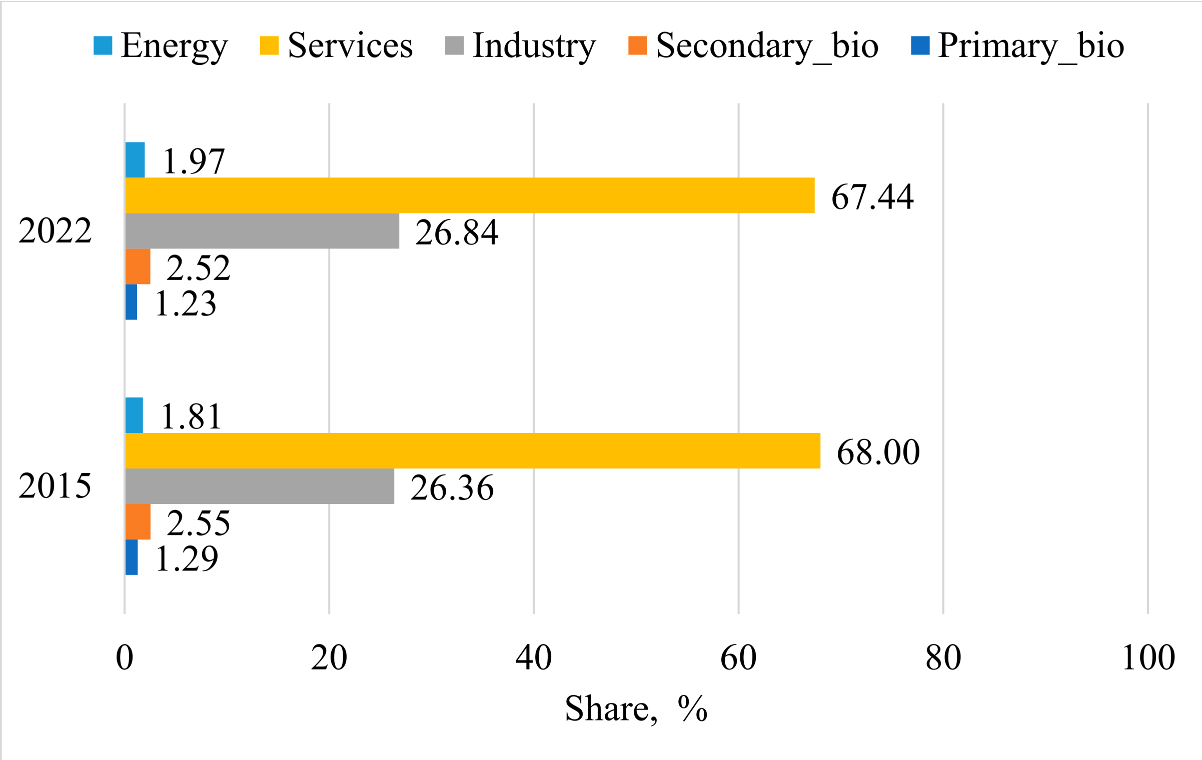

Figure 1. Bioeconomy class output shares 2015, 2022. Note: Supporting sectors refer to sectors classified as Industry, Services, and Energy, that is, sectors not assigned to the Primary_bio or Secondary_bio groups. In this classification, Primary_bio denotes biomass-producing activities, while Secondary_bio denotes biomass-processing activities. Industry, Services, and Energy are therefore shown separately as supporting sectors because they fall outside the two core bioeconomy production classes.

Within the aggregated BIO production system, services represent the largest supporting class, accounting for 68.00% in 2015 and 67.44% in 2022. The marginal decline of 0.56 percentage points indicates overall stability rather than structural change. The dominance of services reflects the structure of the aggregated BIO system within which bioeconomy activities are represented.

3.2. Input Structure of the Bioeconomy

This subsection analyses the input structure of the Irish bioeconomy by decomposing total output into domestic intermediate inputs, imports, and value added. The objective is to evaluate how production is generated and how the balance between domestic linkages, external sourcing, and value creation has changed between 2015 and 2022. Figure 2 presents the aggregate input composition for both benchmark years, illustrating shifts in sourcing patterns and value generation over time.

The intermediate input share increased from 0.10 in 2015 to 0.18 in 2022, representing a rise of 0.08. This indicates that a larger proportion of bioeconomy output is absorbed as intermediate consumption in 2022 relative to 2015. In accounting terms, this reflects a higher intensity of inter-industry input use within the production structure. The import share remains the dominant component of total output in both years, accounting for 0.57 in 2015 and 0.56 in 2022. Although the change is small (−0.01), the consistently high import share indicates reliance on imported inputs in the bioeconomy production system. The marginal reduction in 2022 does not materially alter this pattern.

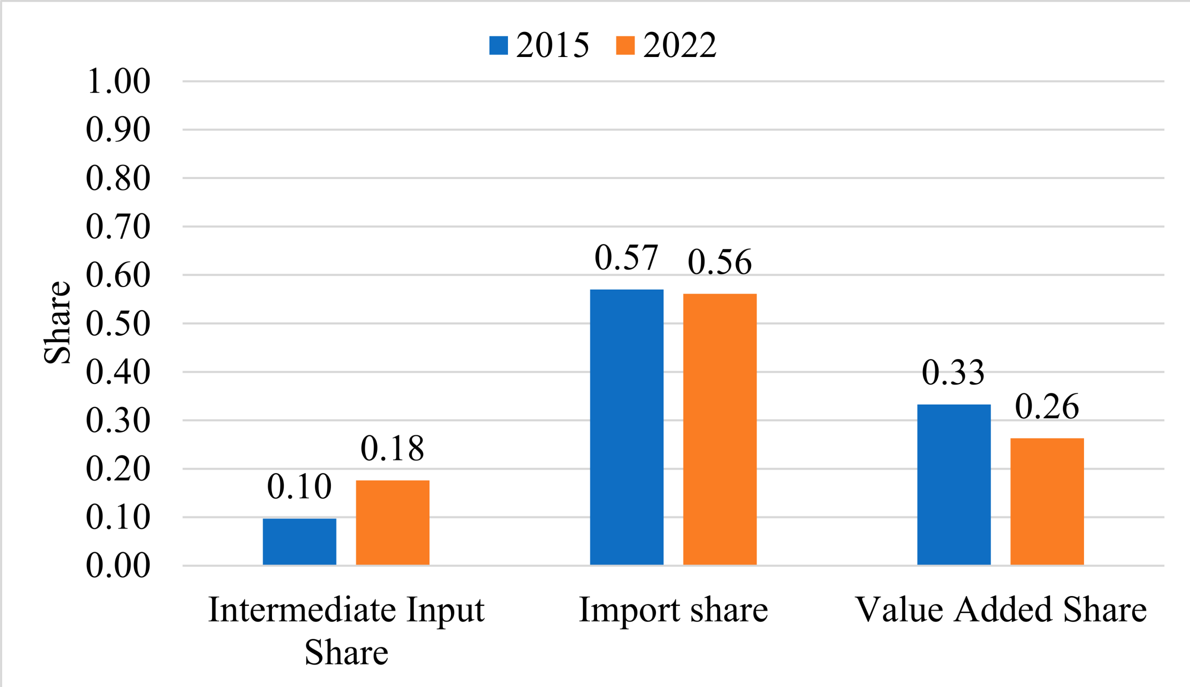

Figure 2. Input shares 2015, 2022.

The value-added share declines from 0.33 in 2015 to 0.26 in 2022, a decrease of 0.07. This indicates that a smaller proportion of gross output is retained as domestic primary income (labour compensation, capital returns, and depreciation) in 2022. The reduction in value added corresponds mechanically to the combined increase in intermediate consumption and the persistently high import share.

3.3. Input Structure by Bioeconomy Class: Input Shares

This subsection extends the aggregate input analysis by examining how production technologies vary across five aggregated classes: primary bioeconomy, secondary bioeconomy, industry, services, and energy, consistent with applied bioeconomy IO studies [32]. Primary and secondary bioeconomy represent bio-based production stages, while industry, services, and energy reflect the broader production environment interacting with bioeconomy activities. Figure 3 reports input shares for 2015 and 2022, decomposing output into intermediate inputs, imports, and value added, thereby highlighting differences in production intensity, import dependence, and domestic value generation.

Energy shows a marked compositional shift. Value added declines from 46% in 2015 to 35% in 2022, while intermediate inputs increase from 24% to 37%; imports fall slightly from 30% to 28%. Secondary bioeconomy follows a similar pattern: value added decreases from 45% to 37%, intermediate inputs rise from 30% to 39%, and imports remain broadly stable (25% to 24%). In both classes, a larger share of output is absorbed by intermediate requirements in 2022 relative to 2015.

Primary bioeconomy maintains a constant import share of 11%, but value added falls from 43% to 35% and intermediate inputs rise from 46% to 54%, indicating a higher input intensity within production. Industry records an increase in intermediate inputs from 8% to 12%, alongside persistently high import shares (55% to 57%), reflecting high import intensity within the industry class as represented in the BIO framework. Services exhibit a doubling of intermediate input share from 9% to 18%, while value added declines from 31% to 24% and imports remain high (61% to 58%). As this class includes broad service activities interacting with bioeconomy production, its input structure reflects the role of the services class within the aggregated BIO production system.

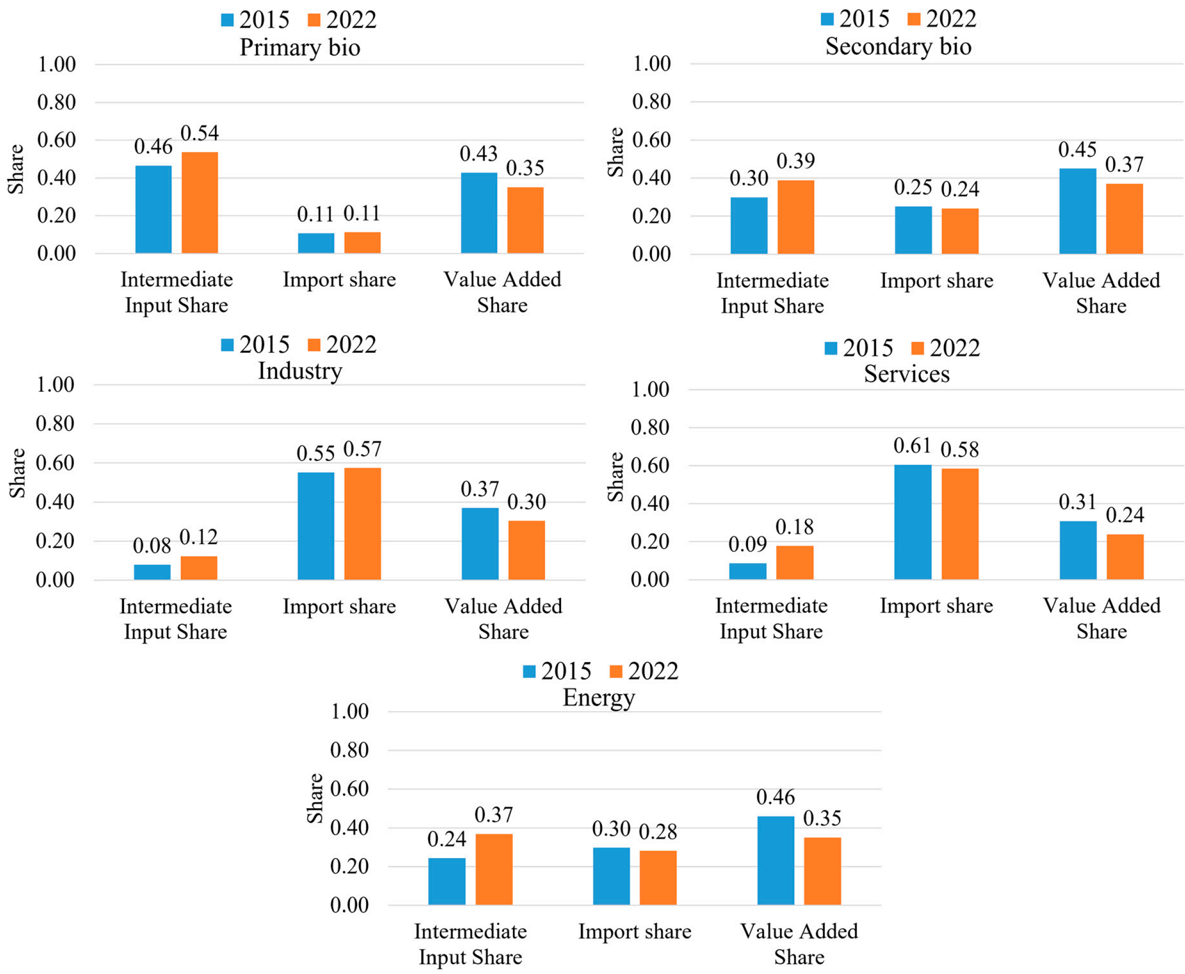

Figure 3. Evolution of Bioeconomy classes. Input shares 2015, 2022. Note: Industry, services, and energy represent supporting sectors within the aggregated BIO system and include both bio-based and non-bio activities interacting with bioeconomy production.

3.4. Output Structure of the Bioeconomy

This subsection analyses the output structure of the Irish bioeconomy by decomposing total output into intermediate demand, final domestic demand, and exports for 2015 and 2022. Output shares provide an accounting-consistent view of market orientation and demand composition, establishing a baseline for subsequent class-based analysis presented in Figure 4.

Between 2015 and 2022, the export share of total bioeconomy output increased from 0.63 to 0.69. This indicates that a larger proportion of bioeconomy production was directed toward external markets in 2022 compared with 2015. Over the same period, the share of output absorbed as intermediate consumption declined from 0.22 to 0.18, while the final domestic demand share decreased from 0.15 to 0.13.

These changes reflect an increase in the relative weight of exports within total bioeconomy output, accompanied by a reduction in the shares allocated to domestic intermediate and final uses. The magnitude of the shifts is moderate, indicating a gradual adjustment in output composition rather than a discontinuous change in production allocation.

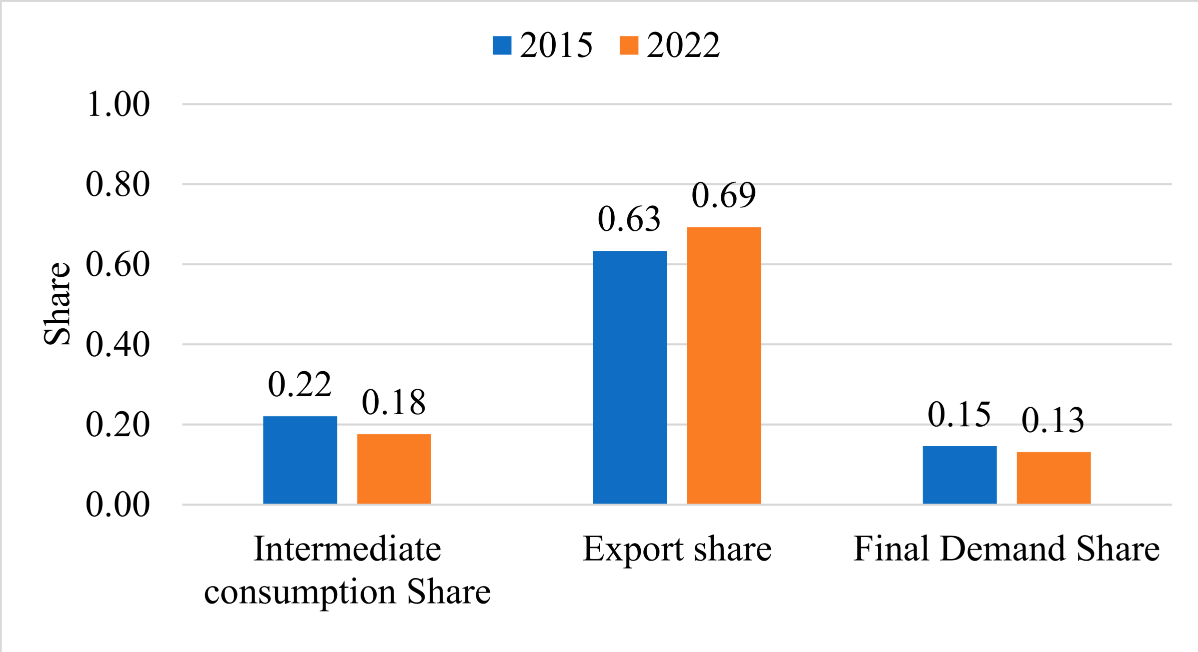

Figure 4. Output share 2015, 2022.

This shift has two immediate implications. First, a larger share of bioeconomy activity becomes tied to external demand conditions, reducing the relative importance of domestic final demand as a driver of expansion. Second, stronger export orientation does not by itself imply stronger domestic spillover effects. Within the input–output framework, domestic spillovers depend on the extent to which export production is supported by domestic intermediate suppliers rather than imported inputs. The implications for domestic propagation are examined further in the subsequent class-level and inter-industry analysis.

3.5. Output Structure by Bioeconomy Class: Output Shares

To examine how demand composition differs across stages of production within the bioeconomy framework, this subsection extends the aggregate analysis by presenting output shares aggregated into five classes. Sectors are grouped into primary bioeconomy, secondary bioeconomy, industry, services, and energy, following established practice in applied bioeconomy input–output studies [32]. Figure 5 reports output shares for each class in 2015 and 2022, decomposing production into intermediate demand, final domestic demand, and exports.

Secondary bioeconomy and industry display strongly export-oriented structures in both years. In secondary bioeconomy, exports account for 78% of output in 2015, rising to 82% in 2022. Intermediate use remains limited (15% to 14%), while final domestic demand declines from 7% to 4%. Industry follows a similar pattern: export shares increase from 85% to 87%, intermediate consumption falls from 10% to 8%, and final demand remains small at 5–6%. In both classes, exports clearly dominate output allocation and the overall structure remains stable across benchmark years.

Primary bioeconomy and energy are characterised by high intermediate use shares. In primary bioeconomy, intermediate consumption accounts for 88% of output in 2015 and 84% in 2022. Exports increase from 8% to 13%, while final demand remains marginal (4% to 3%). Energy shows a comparable configuration: intermediate use rises from 78% to 82%, exports increase from 3% to 5%, and final demand declines from 19% to 13%. Services present a more balanced structure. In 2015, output is divided between exports

(55%), intermediate use (24%), and final demand (21%). By 2022, exports increase to 65%, while intermediate use and final demand decline to 19% and 17%, respectively.

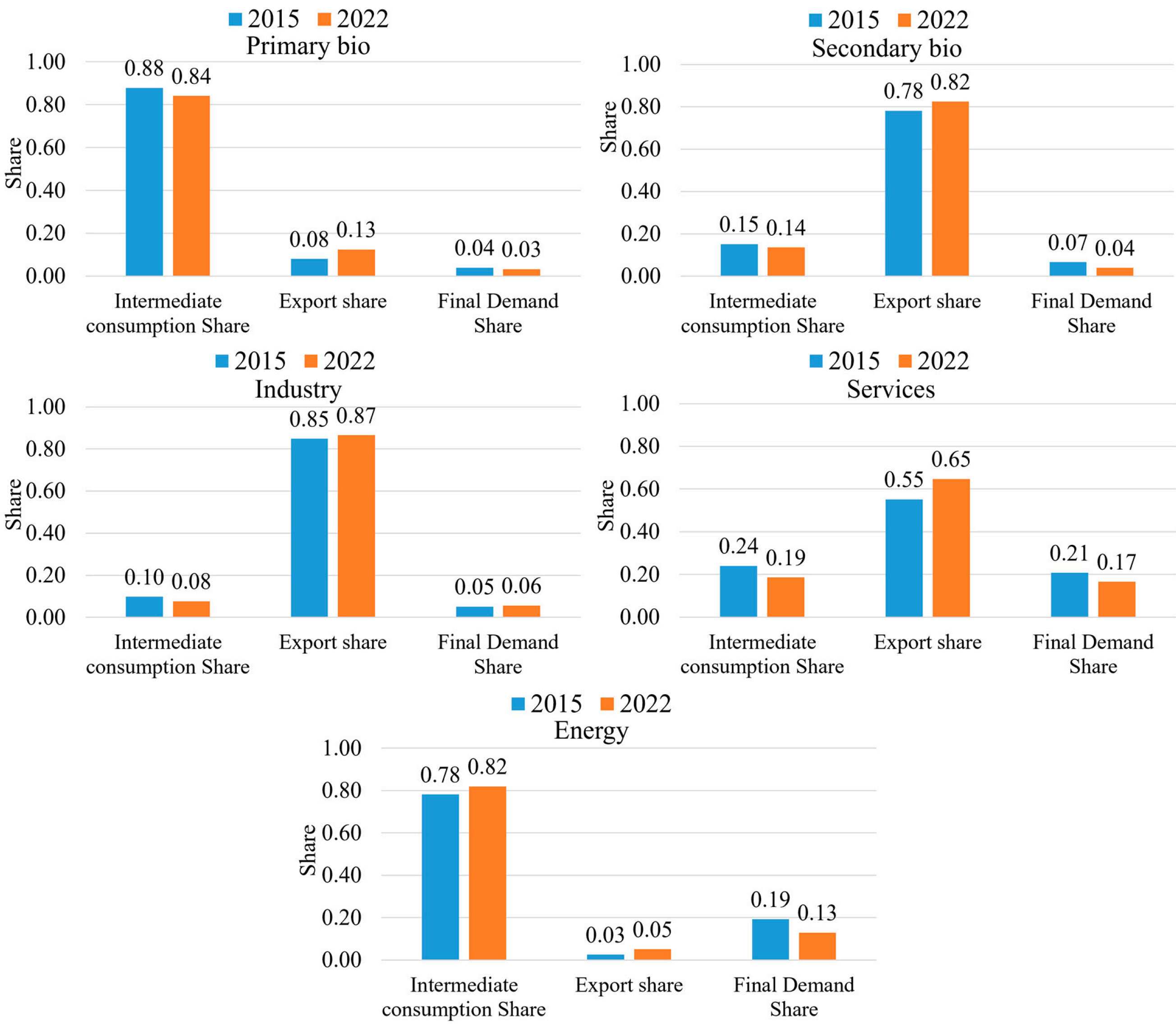

Figure 5. Structural Evolution of Bioeconomy classes. Output shares 2015, 2020, 2022. Note: Industry, services, and energy represent supporting sectors within the aggregated BIO system and include both bio-based and non-bio activities interacting with bioeconomy production.

The class-level evidence suggests that export orientation should be interpreted jointly with domestic input structure, since sectors with relatively similar export-oriented profiles may differ in their domestic multiplier effects depending on import leakage and the strength of domestic backward linkages.

This subsection focuses on the demand-side propagation within the BIO production network, analysing backward linkages and their role in shaping Ireland's production structure. Backward linkages describe how final demand in one sector stimulates production across its network of suppliers, reflecting the degree of domestic reliance on intermediate goods. Using Leontief multipliers [11,38], we assess each bioeconomy class's dependence on domestic intermediate inputs and explore how these relationships evolved between 2015 and 2022 in Figure 6.

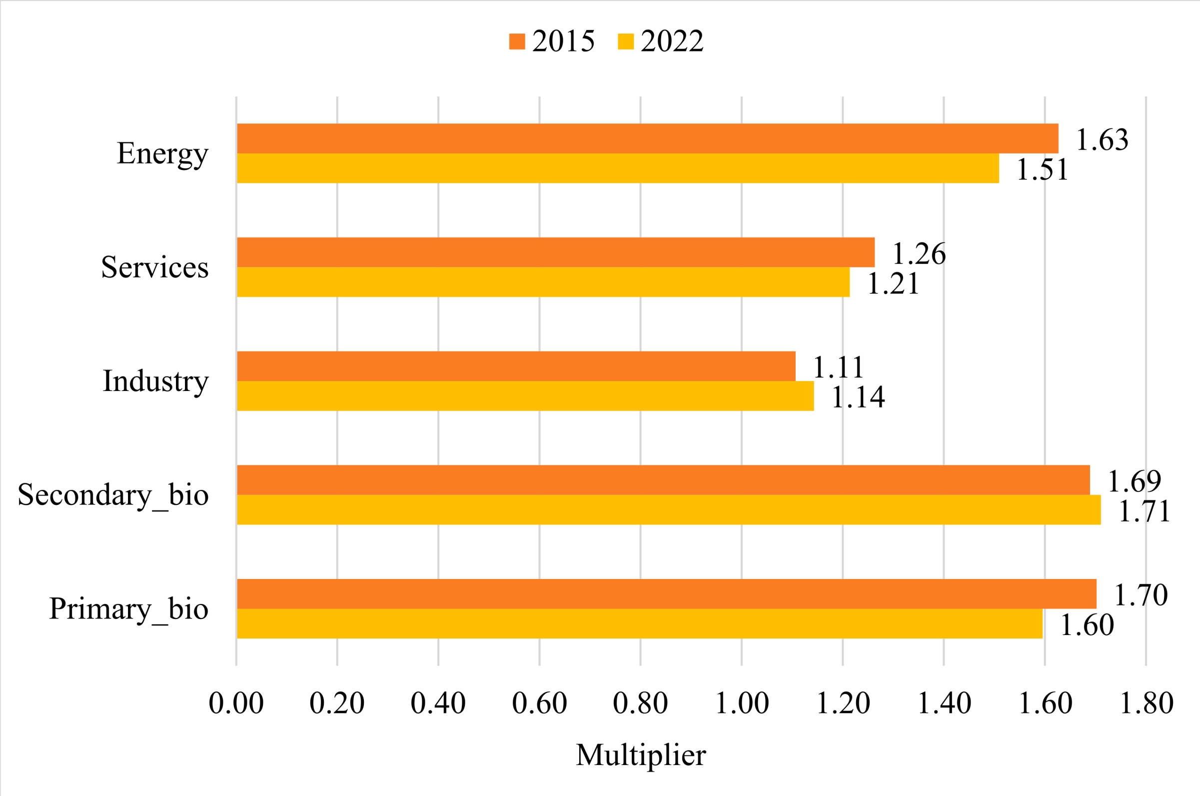

Figure 6. Leontief, Tier I Multiplier 2015, 2022. Note: Industry, services, and energy represent supporting sectors within the aggregated BIO system and include both bio-based and non-bio activities interacting with bioeconomy production.

3.6. Classes with Strong Backward Linkages

Figure 6 shows primary bioeconomy continues to exhibit the highest Tier I Leontief multipliers in both 2015 and 2022, although it shows a slight decline from 1.70 to 1.60. This decline coincides with an increase in intermediate input intensity from 0.46 to 0.54, while the import share remains constant at 0.11. The reduction in the multiplier appears to reflect a shift in the composition of inputs rather than an increase in import leakage.

Secondary bioeconomy maintains strong backward linkages, with a slight increase in its multiplier from 1.69 to 1.71. This change corresponds with an increase in intermediate input intensity from 0.30 to 0.39, while the import share remains largely unchanged (from 0.25 to 0.24). The stability of the import share, combined with the rise in intermediate input use, suggests a marginally stronger propagation of demand-driven activity domestically.

Energy also demonstrates strong backward linkages, but its multiplier declines from 1.63 in 2015 to 1.51 in 2022. This decline corresponds with a noticeable increase in intermediate input share from 0.24 to 0.37, while the import share slightly decreases from 0.30 to 0.28. Despite the increase in intermediate input intensity, the decline in the multiplier indicates that the overall demand-driven propagation has weakened.

3.7. Classes with Weaker Backward Linkages

Services shows moderate backward linkages, with its multiplier declining from 1.26 in 2015 to 1.21 in 2022. This decline is accompanied by an increase in intermediate input share from 0.09 to 0.18, while the import share remains high but decreases slightly (from 0.61 to 0.58). The combination of relatively low-to-moderate intermediate input intensity and persistent high import leakage likely contributes to the constrained domestic multiplier effects observed in services.

Industry records the lowest Tier I Leontief multipliers in both years, with a modest increase from 1.11 in 2015 to 1.14 in 2022. This small increase aligns with a rise in intermediate input share from 0.08 to 0.12, while import dependence remains high, increasing from 0.55 to 0.57. The high import share limits the extent to which increases in final demand translate into increased domestic upstream output, which helps explain the modest increase in industry's multiplier.

The preceding results establish the nowcasted BIO2022 table as the updated structural baseline for the Irish bioeconomy; the next section builds on this accounting-consistent framework to examine how the sector-embedding approach performs when applied to specific traditional, operational, and prospective bioeconomy activities.

4. Results II—Novel Sector Multipliers Modelled

In order to test our algorithm we pilot the analysis for sectors and products with different degrees of technology readiness level.

- Traditional bioeconomy sectors—mainly national accounts information. In this case we disaggregate our existing aquaculture sector into aquaculture sectors which have different economic footprints.
- Novel start-up sectors—these are novel bioeconomy sectors that are in operation, perhaps at a lower scale. In this study we shall explore the economic impact of bioenergy (anaerobic digestors and biomass-based bioenergy).
- Novel prospective sectors—these are novel bioeconomy sectors or products that are in the development stage and perhaps have not had sales yet.

4.1. Aquaculture

Aquaculture is a key sector in sustainable food systems, contributing to protein diversification and, in many production systems, offering relatively low-carbon protein compared with conventional terrestrial livestock, thereby alleviating pressures on capture fisheries [39–42]. In BIO2022, aquaculture is represented as a single sector encompassing marine and land-based systems, including salmon, oysters, mussels, and other finfish categories. In this benchmark representation, the production technology reflects an average input structure across aquaculture systems rather than distinguishing between specific production types [43,44]. This aggregated structure provides the observed technological base from which species-level disaggregation is subsequently implemented as an extension to the BIO2022 framework.

Consequently, the representation captures the prevailing economic footprint of the industry but does not differentiate between intensive finfish, shellfish, or recirculating aquaculture systems. Within the input–output framework, aquaculture exhibits a relatively high degree of intermediate input intensity. Intermediate consumption accounts for 48.48% of total output, while value added represents 35.86%, indicating upstream input dependence alongside a moderate contribution from primary factors. Imports comprise 15.66% of output, reflecting structural import leakage, particularly through specialised feed and input components not fully supplied domestically. As such, the sector demonstrates partial dependence on international supply chains, moderating the domestic retention of expenditure shocks.

Upstream demand is concentrated in prepared animal feeds, gasoil (diesel/derv), repair and installation services, and manufacturing activities. This composition highlights strong linkages to agricultural feed supply chains and industrial service providers, embedding aquaculture within both primary and secondary production networks. The concentration of inputs in feed and energy-related categories underscores the biological and energy requirements of production, while repair and manufacturing inputs reflect capital maintenance and operational intensity.

From a demand-driven perspective, the Tier-1 Leontief output multiplier is 1.64, implying that a €1 increase in final demand for aquaculture generates €1.64 in total economy-wide output. The multiplier is supported by relatively strong domestic upstream linkages, particularly through feed and service inputs. However, the magnitude of the effect is moderated by import dependence within key intermediate categories. Aquaculture represents a structurally embedded and moderately import-dependent bioeconomy sector, with measurable indirect effects across agricultural and industrial supply chains.

4.2. Anaerobic Digestion

Anaerobic digestion (AD) is increasingly recognised as a key bioeconomy sector in Ireland, integrating waste management with renewable energy and circular economy objectives. AD biologically breaks down organic substrates such as agricultural residues, food waste and manure to produce biogas, predominantly methane, and nutrient-rich digestate that can displace fossil fuels and synthetic fertilisers, thereby contributing to greenhouse gas mitigation and resource efficiency [35,45–48]. Technically, Ireland's National Biomethane Strategy aims to deliver up to 5.7 TWh of indigenous biomethane by 2030, requiring scaling of AD infrastructure to valorise organic feedstocks for energy and bioproducts [49]. Recent life cycle and scenario analyses indicate that large-scale AD can maximise climate benefits when coupled with targeted land use and policy frameworks, though deployment must be aligned with agricultural transitions and strategic incentives [50]. Moreover, integrated AD-based biorefineries offer pathways to diversify rural incomes and enhance circular bioeconomy outcomes, but economic viability remains contingent on technological innovation and supportive policies [51].

4.3. Bioenergy

Bioenergy, a start-up technology, faces similar challenges with sparse data and limited sectoral representation. Sectoral data are often derived from proxies or engineering estimates [52]. Like other renewable sectors [17,53,54], bioenergy is underrepresented in IO tables, requiring adaptation and approximation, making it an essential test case for the framework's capacity to integrate early-stage technologies. Anaerobic digestion is modelled as a constructed operational bioeconomy sector because it is not separately identified in standard accounts but can be parameterised using technoeconomic evidence. We use a 40 GWh plant supplied by a 50:50 grass silage and cattle manure mix. The sector's structure is upstream demand dominated by agriculture (feedstocks), finance/professional services (project and risk-related costs), and manufacturing (construction, equipment, O&M). On the output side, revenues are concentrated in energy-related sales (biomethane/electricity), with smaller flows to transport (distribution/logistics) and agriculture (digestate). This input concentration supports strong indirect effects through biomass and capital-service supply chains; results are reported as Leontief (demand-driven) multipliers.

4.4. Plant-Based Protein Products (Novel Developing Value Chain)

Plant-based protein products are not separately identified in national accounts, so we construct new sectors by parameterising production technology. We draw upon novel protein products from two research projects. The FUNGITECH project, led by University College Dublin, funded by Research Ireland, has developed an innovative high-protein, high-fibre fungal food ingredient intended for use by food manufacturers in further product formulation. The project is embedded within a broader research agenda focused on advancing circular bioeconomy solutions by valorising low-value agri-food by-products, notably spent brewers' grain, into nutritionally valuable food ingredients. The production process

https://doi.org/10.3390/su18084035

involves a series of input stages, including cleaning, rolling and milling of raw materials, controlled drying, fermentation in bioreactors with selected fungal strains, and subsequent drying, milling, and heat treatment to ensure product stability and food safety. The final output is a shelf-stable powdered ingredient, packaged using minimal material inputs. Additional inputs include energy, transport and storage logistics, labour, and regulatory safety testing. Overall, FUNGITECH demonstrates the technical and economic potential of fungal biotechnology to support sustainable protein production and waste reduction.

The Protein-I portfolio comprises four domestically oriented food products based on locally sourced cereals and pulses, each occupying distinct market segments and cost structures. Rolled oat porridge, produced from Irish-grown oats, is a minimally processed cereal product yielding one tonne of retail output from approximately 1.10 tonnes of raw grain; raw materials and processing each account for roughly 30% of unit costs, with packaging representing about 25%, reflecting its positioning as a premium domestically sourced offering. Oat drink, a plant-based beverage containing 10–11% oats supplemented with functional ingredients, involves capital- and energy-intensive processes, including enzymatic conversion, homogenisation, thermal treatment, and aseptic packaging, such that processing and packaging together exceed 65% of total costs, consistent with its placement in the expanding dairy-alternative market. The pea burger, manufactured through protein fractionation, formulation, structuring, and chilled or frozen distribution, exhibits the highest processing intensity, with manufacturing accounting for approximately 38% of costs alongside additional cold-chain logistics, and is positioned within the alternative protein segment as a competitively priced domestic product. Finally, dried wheat pasta, produced via conventional extrusion and drying technologies, displays a more balanced cost distribution across raw materials, processing, and packaging (each 20–30%), benefiting from technological maturity and economies of scale while competing across standard and premium cereal markets. Collectively, these products illustrate varying degrees of processing complexity, value addition, and market differentiation within domestically embedded agri-food supply chains. Different types of sectors and products have different data availability, depending upon data sources.

4.5. Level of Aggregation Possible

In our analysis we wish to model the value-chain economic impact of multipliers for bioeconomy subsectors. However, for analytical tractability and efficiency, we need to reduce the dimensionality of the data collection approach. Examining existing domestic flows within the BIO framework, Figure 7 provides an empirical justification for a reduced-dimensional sector-embedding approach. The figure reports, for each of the 168 sectors in the BIO framework, the cumulative share of domestic intermediate inputs accounted for by the top three, four, five, and six supplying sectors. Sectors are ranked along the horizontal axis according to their share in nationally purchased domestic business-to-business (B2B) inputs. After consultation with product scientists, we choose, in the questionnaires collected here, to focus on the top 4 sectors, as the gains in terms of moving to the top 5 sectors were low and thus a minor precision cost, relative to the challenge of identifying their cost share in the production process.

The results show that intermediate input structures are typically concentrated. For the majority of sectors, a small number of upstream suppliers account for most domestic intermediate inputs. While the most input-diverse sectors; primarily service activities; exhibit lower concentration (with the top three inputs accounting for roughly 30–45% of total intermediate inputs), sectors outside this lower tail display stronger concentration. In particular, for most sectors beyond the bottom quintile, the top five supplying sectors account for at least half of total intermediate inputs and often considerably more.

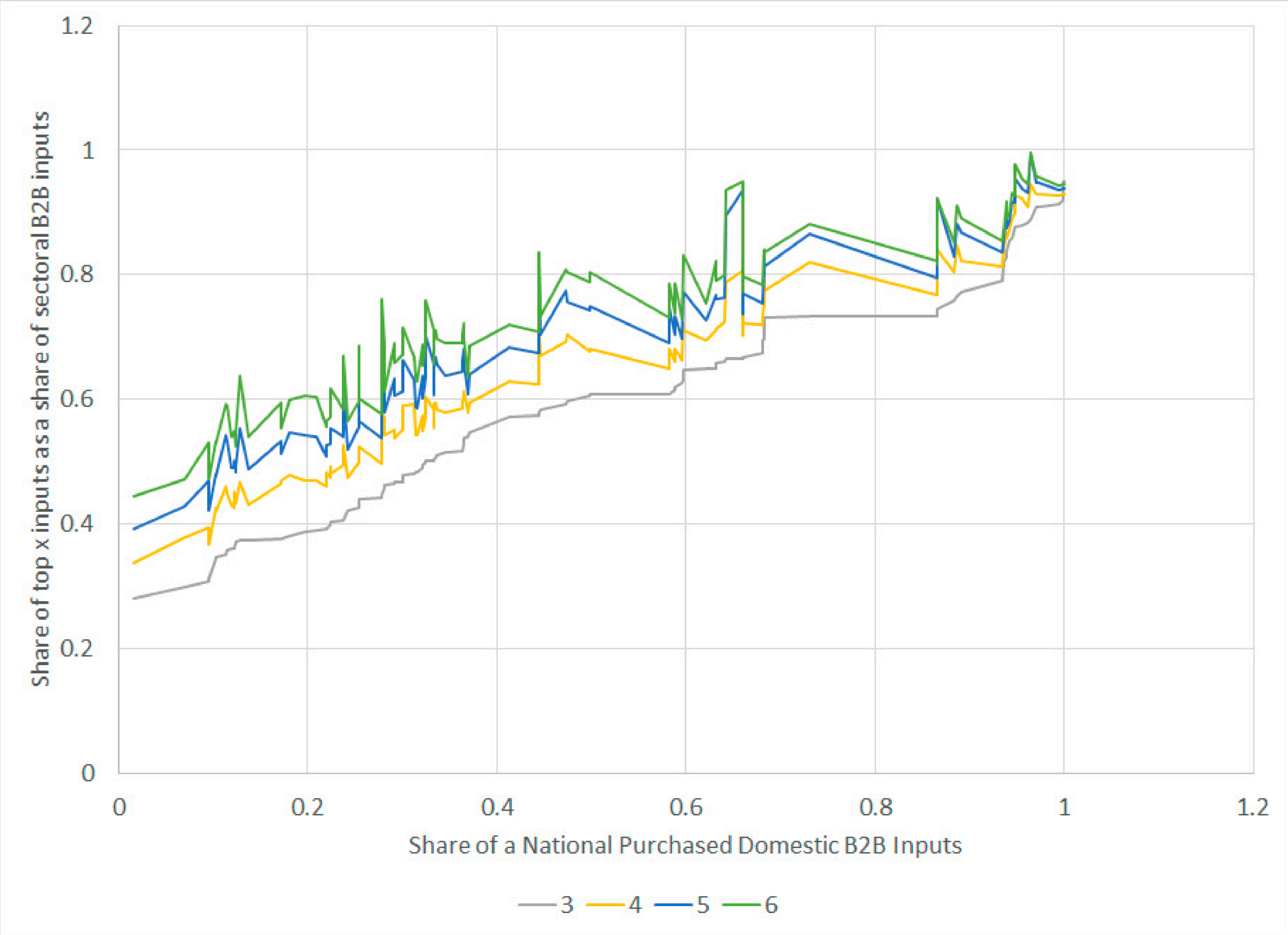

Figure 7. Share of Sectoral Domestic B2B Inputs for top (3, 4, 5, 6) Inputs, Ranked from Lowest to Highest expressed as the share of Nationally Purchased Domestic B2B inputs. Source: BIO.

The relatively small gap between the "top five" and "top six" curves further indicates diminishing incremental contribution from additional minor input categories. Since demand-driven multipliers in the Leontief framework are primarily driven by dominant technical coefficients, capturing the largest input relationships is sufficient to approximate a sector's structural propagation effects. On this basis, the sector-embedding procedure focuses on collecting information on the top five intermediate inputs, supplemented by import and value-added shares.

The multiplier of a particular sector will depend directly upon the share of domestically sourced intermediate inputs and the multiplier of these inputs and inversely on the import share and value-added share of the inputs. As an aid to understanding the drivers of bioeconomy sectoral multipliers, Table 2 reports sectoral Tier I output multipliers and the decomposition of gross output into domestic intermediate consumption, value added, and imports. The Tier I multiplier measures the direct and first-round domestic indirect effects of a one-unit increase in final demand, capturing the strength of domestic backward linkages. Heterogeneity emerges across sectors. Agriculture exhibits the largest multiplier (1.756), followed by Construction (1.378) and Transport (1.257), indicating relatively strong domestic production linkages. In contrast, Finance and Professional Services (1.068) and Wholesale and Retail Trade (1.095) display weaker first-round spillovers. These differences are consistent with the structure of intermediate inputs. Agriculture (0.464) and Construction (0.304) rely more heavily on domestic intermediates, whereas Finance and Professional Services (0.063) and Manufacturing (0.081) exhibit limited domestic input dependence.

Import intensity is particularly high in Manufacturing (0.511), Accommodation (0.627), Finance and Professional Services (0.651), and Public Administration (0.578), suggesting foreign input reliance. Overall, sectors with stronger domestic intermediate linkages generate larger first-round spillover effects, while import-intensive or value-added-dominant sectors display weaker domestic multipliers, with implications for the transmission of demand shocks across the economy.

Table 2. Tier I Multiplier and Share of Domestic Intermediate Consumption.

	Agri	**Manuf**	**Construct**	**Whole&Retail**	**Transp**	**Accomm**	**Commun**	**Finance&Prof**	**Admin**	**PubAdmin**	**Educ**	**Social**
Domestic IC Share	0.464	0.081	0.304	0.084	0.222	0.132	0.124	0.063	0.099	0.129	0.148	0.121
Value Added	0.424	0.408	0.445	0.380	0.516	0.240	0.813	0.286	0.399	0.292	0.469	0.328
Imports	0.112	0.511	0.251	0.536	0.262	0.627	0.063	0.651	0.501	0.578	0.383	0.551
Tier I Multiplier	1.756	1.102	1.378	1.095	1.257	1.152	1.138	1.068	1.110	1.148	1.175	1.138

Note: Sectors: Agriculture: Agri; Manufacturing: Manuf; Construction: Construct; Wholesale and Retail: Whole&Retail; Transport:Transp; Accommodation and Restaurants: Accomm; Communications: Commun; Finance and Professional Services: Finance&Prof; Private sector administration: Admin; Public Administration; PubAdmin; Education and Health: Educ; Social Services and other: Social.

Table 3 summarises the upstream principle input composition of bioeconomy sectors considered at different levels of technology readiness. Drawing upon the level of aggregation identified as possible in Figure 7, we report here (a) the domestic input share of the principal inputs and the composition of high-level inputs (excepting profit and tax). Across aquaculture activities, intermediate inputs are relatively dispersed, with a share captured by the residual "Other" category (47–76%), suggesting a broad domestic supply base. Among the identified input sectors, Sector 1 is particularly relevant for penned salmon and land-based finfish aquaculture, whereas Sector 2 plays a more prominent role in shellfish production. In contrast, plant-based products such as pea burgers, oat drink, and dried wheat pasta exhibit a more even distribution of inputs across the main supplying sectors. The high-level input structure further highlights important differences. Aquaculture production combines labour (20–37%), capital (8–13%), imported inputs (15–21%), and purchased goods and services (30–67%), with shellfish activities relatively more labour-intensive. By comparison, plant-based products are characterised by markedly higher import shares (approximately 61%), moderate labour intensity (around one-third of total inputs), and negligible capital shares. More broadly, these findings suggest that the sustainability of plant-based transitions should be evaluated not only in environmental terms but also in relation to supply-chain resilience, domestic value-chain development, and the capacity to build more circular and locally embedded bioeconomic systems [55].

Taken together, the evidence indicates that aquaculture activities maintain broader domestic production linkages, whereas plant-based processed foods rely more heavily on imported inputs, implying different exposure to international supply chains and domestic multiplier effects.

Table 4 illustrates marked differences in upstream input structures across the bioeconomy sectors (aquaculture, bioenergies, alternative protein food products). Aquaculture production is strongly transport-intensive, with transport services accounting for 42–71% of total intermediate inputs, reflecting the logistical demands of feed supply, live handling, and distribution. Manufacturing inputs constitute the second-largest component (16–31%), while agricultural inputs are particularly relevant for penned salmon and land-based finfish aquaculture. Other service categories contribute only marginally. By contrast, alternative protein technologies and plant-based foods are predominantly manufacturing-driven. Manufacturing accounts for 60–71% of inputs in alternative technologies and around 36% in plant-based products, while agricultural inputs represent 25–30% in the latter. Transport plays a comparatively smaller role.

Table 3. Top Input Sectors.

	Penned Salmon	Farmed Oyster	Suspended Mussel	Seabed Cultured Mussel	Land-Based Finfish Aquaculture	AD1GW	FUNGITECH (Start)	Porridge Oats	Pea Burger	Oat Drink	Dried Wheat Pasta
1	0.247	0.000	0.000	0.000	0.172	0.709	0.150	0.300	0.300	0.250	0.300
2	0.107	0.121	0.184	0.262	0.273	0.101	0.450	0.300	0.380	0.350	0.300
3	0.053	0.055	0.132	0.095	0.048	0.070	0.150	0.250	0.200	0.300	0.200
4	0.051	0.060	0.042	0.050	0.034	0.000	0.120	0.070	0.060	0.050	0.100
Other	0.542	0.764	0.642	0.592	0.473	0.120	0.130	0.080	0.060	0.050	0.100
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
High-Level Inputs											
Labour	0.107	0.358	0.368	0.318	0.206	0.160	0.550	0.330	0.330	0.330	0.330
Capital	0.079	0.131	0.133	0.087	0.107	0.206	0.074	0.000	0.000	0.000	0.000
Imported Goods and Services	0.147	0.206	0.203	0.151	0.171	0.014	0.000	0.609	0.609	0.609	0.609
Purchased Goods and Services	0.667	0.305	0.296	0.443	0.517	0.634	0.376	0.083	0.083	0.083	0.083
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000

Note: Table 3 explains Principal Input Composition of Bioeconomy Sectors: Evidence Across Technology Readiness Levels.

Table 4. Intermediate Input Share—NACE categories.

	Penned Salmon	Farmed Oyster	Suspended Mussel	Seabed Cultured Mussel	Land-Based Finfish Aquaculture	AD1GW	FUNGITECH (Start)	Porridge Oats	Pea Burger	Oat Drink	Dried Wheat Pasta
agri	0.247	0.000	0.000	0.000	0.172	0.167	0.085	0.300	0.300	0.250	0.300
manuf	0.158	0.180	0.226	0.313	0.307	0.709	0.600	0.356	0.356	0.356	0.356
construction	0.053	0.055	0.132	0.095	0.048	0.009	0.005	0.004	0.006	0.004	0.006
whole&ret	0.017	0.017	0.017	0.017	0.017	0.001	0.006	0.029	0.045	0.029	0.045
transp	0.491	0.713	0.591	0.541	0.422	0.017	0.270	0.250	0.200	0.300	0.200
accom	0.001	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.002	0.001	0.002
commun	0.006	0.006	0.006	0.006	0.006	0.016	0.010	0.010	0.015	0.010	0.015
finance&Prof	0.026	0.026	0.026	0.026	0.026	0.070	0.019	0.045	0.070	0.045	0.070
admin	0.002	0.002	0.002	0.002	0.002	0.005	0.003	0.003	0.005	0.003	0.005
pubadmin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
educ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
social	0.001	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.002	0.001	0.002

These findings carry direct implications for Irish bioeconomy strategy. Ireland's Bioeconomy Action Plan 2023–2025 emphasises bringing sustainable scientific practices, technologies, and bio-based innovation into use, while the broader policy framework highlights decarbonisation, circularity, competitiveness, and rural/regional development. More recent government framing also links the bioeconomy to resilience and strategic autonomy [56]. Many proposed sectors aim to utilise indigenous biomass to create domestic value added. However, economic incentives do not automatically align with resource nationalism. Evidence shows that imported biomass or biomaterials can be cheaper than domestic alternatives [57], a pattern observable in practice through biomass imports for electricity generation and Ireland's reliance on imported high-protein feed while specialising in comparatively lower-cost grass-based systems. Thus, comparative advantage and cost competitiveness may favour import-intensive configurations, even within a bioeconomy framework.

Combining the information from Tables 2–4, we calculate the Tier I multipliers. Figure 8 compares Tier I Leontief multipliers across selected bioeconomy activities, revealing variation in domestic propagation effects. The highest multipliers are observed for FUNGITECH in its start-up and development phases, exceeding 2.0, indicating strong upstream linkages and limited import leakage at early stages of scale-up. Multipliers decline modestly in the mature phase, suggesting structural stabilisation and potentially higher efficiency or import content over time. Anaerobic digestion scenarios (AD1–AD40GW) display moderate multipliers clustered around 1.6–1.7, reflecting stable but less intensive domestic inter-industry linkages. Aquaculture activities exhibit more heterogeneous outcomes: land-based finfish and penned salmon show multipliers around 1.5, while mussel and oyster production are lower, closer to 1.2–1.4, indicating comparatively weaker upstream domestic integration. Protein-I occupies an intermediate position. Overall, the results highlight that emerging and technology-intensive bio-based activities can generate stronger domestic production spillovers than more traditional primary production systems, underscoring the importance of structural composition in assessing bioeconomy development strategies.

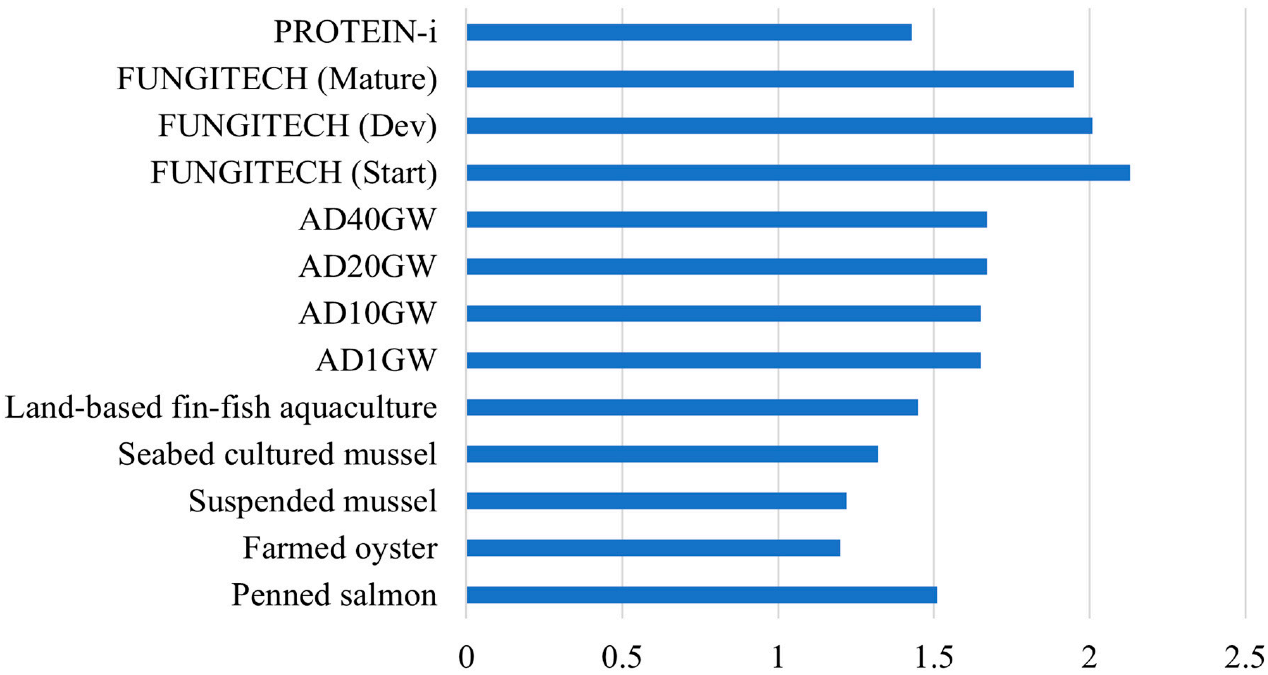

Figure 8. Tier I Leontief Multipliers. Note: bars related to the Tier I multiplier.

While it is commonplace to report economic multipliers of value chain economic impact assessment, it is interesting to ask how a multiplier analysis tallies with actual industrial strategies. Figure 9 is included to provide historical context for the nowcasting analysis. The long-run decline in multipliers points to a weakening of domestic production linkages over time, likely associated with greater global value-chain integration. This is directly relevant to the emerging bioeconomy, since one important question is whether bio-based sectors can generate stronger domestic linkages and resilience during the 2015–2022 period than those observed in the broader economy. Figure 9, drawing upon the analysis of [26], shows a clear long-term decline in sectoral output multipliers across the Irish economy from the mid-1950s to 2020 during a period of economic change and development. Multipliers were highest in the 1960s, peaking above 6 in sectors such as food and AFF, reflecting strong domestic inter-industry linkages. From the 1970s onward, multipliers fell sharply across nearly all sectors, reaching troughs in the early 1980s. Although there was a partial recovery during the late 1980s and early 1990s, the overall trend remained downward. By the 2000s and especially after 2010, multipliers converged at lower levels, generally between 2 and 3, indicating weaker domestic production spillovers. This pattern suggests increasing import penetration, structural transformation toward higher value-added and internationally integrated sectors, and a gradual reduction in domestic intermediate intensity across the economy. These trends highlight that Ireland's economic growth strategy has focused on exploiting comparative advantage, moving away from import substitution towards participation in vertically integrated global value chains, moving up the value-added distribution. While bioeconomy sectors provide useful lower carbon opportunities for biomaterials, long-run economic delivery will depend upon following these trajectories and integrating in international value chains. This may have the impact of the bioprocessing sectors occasionally using imported raw materials rather than domestic raw materials where imported materials are cheaper, a trend visible in bioenergy-based electricity production [57].

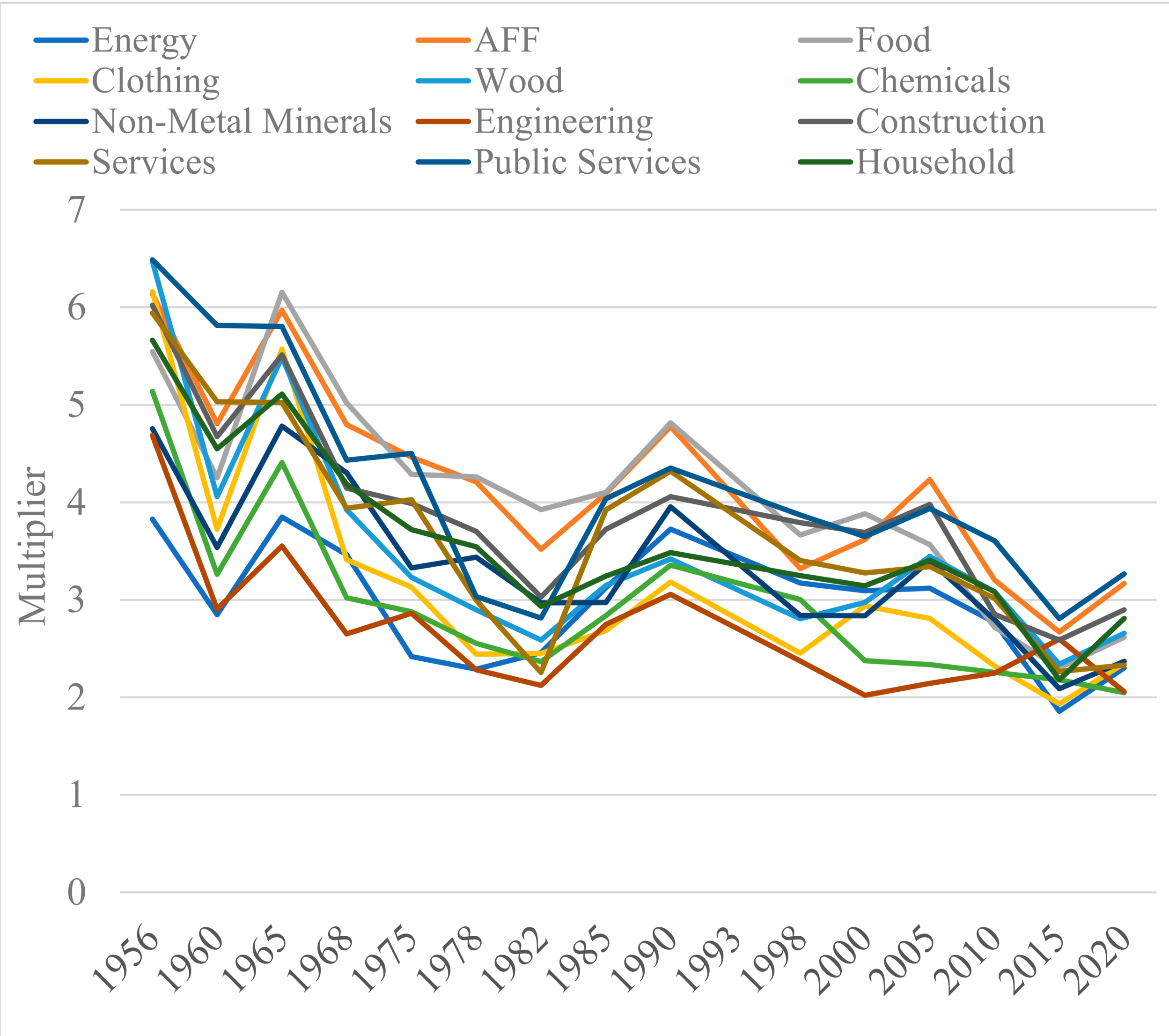

Figure 9. Trend in Multipliers. Source: [48].

5. Conclusions

This paper develops and applies a methodological framework to provide timely and economy-wide measurement of Ireland's bioeconomy under conditions of data constraints. By integrating nowcasting with an accounting-consistent sector-embedding procedure under a limited data availability approach, the study addresses two persistent limitations in bioeconomy analysis: the publication lag of official input–output tables and the absence of newly emerging bio-based activities in standard industrial classifications.

The nowcasting procedure updates the benchmark bioeconomy IO table to 2022 using macroeconomic control totals and partial sectoral information while preserving accounting consistency. This enables structural indicators and multipliers to reflect recent developments rather than relying on outdated benchmark years. The sector-embedding method further allows new or hybrid bioeconomy activities to be incorporated using limited but high-value information on dominant input shares, import intensity, and output allocation. Empirical evidence on input concentration supports the reduced-dimensional specification, demonstrating that a small number of upstream linkages typically drive demand-driven propagation effects. Taken together, the framework bridges timely macroeconomic modelling with sector-specific bioeconomy analysis.

The results highlight heterogeneity across bioeconomy activities in terms of intermediate intensity, import leakage, and domestic multiplier effects. Aquaculture is strongly transport-intensive and service-linked, anaerobic digestion is manufacturing-oriented, and plant-based protein production combines agricultural and industrial inputs with relatively high import shares. Reporting domestic input shares by NACE provides transparency on domestic value retention and foreign supply-chain dependence, reinforcing the view that the bioeconomy represents a structurally diverse system rather than a single sector [6,8]. These findings underscore that the bioeconomy is not structurally homogeneous and that policy assessments must account for differences in value-chain integration and domestic sourcing patterns.

Aggregate multipliers further reinforce this structural interpretation. While certain bio-based activities generate measurable first-round spillovers, multiplier strength is closely tied to domestic intermediate intensity. Import-heavy production models exhibit weaker domestic propagation. Importantly, the trend evidence indicates that, as the Irish economy expanded and became more internationally integrated, aggregate multipliers declined rather than increased. This reflects structural transformation toward higher value-added, vertically integrated sectors operating within global supply chains, where substitution effects and domestic inter-industry intensity are lower.

Understanding sector-specific input structures and multiplier dynamics therefore matters for policy design. Promoting bio-based activities without considering domestic linkage strength may overstate local value creation. Conversely, prioritising sectors with stronger domestic integration can enhance regional spillovers but may face cost constraints in open markets. A credible bioeconomy strategy must therefore balance environmental objectives, competitiveness, and domestic value retention within the realities of international trade and evolving comparative advantage. The results suggest three priorities for policymakers: supporting bioeconomy sectors with stronger domestic sourcing potential; investing in domestic upstream capabilities for import-dependent activities such as plant-based products; and evaluating bioeconomy expansion not only by environmental criteria but also by its contribution to resilience, local value creation, and supply-chain security.

Several limitations should be acknowledged. First, although the BIO2022 table incorporates updated sectoral totals and observed 2022 information where available, the allocation of inter-industry flows that are not directly observed continues to rely on the relative input structure of the BIO2015 benchmark. This is particularly relevant for traditional sectors, where technological change between 2015 and 2022 may have altered input composition and domestic-versus-import sourcing patterns. If these changes reduced domestic intermediate input requirements or increased import dependence, the benchmark-based structure may overstate domestic Tier I Leontief multipliers. Conversely, if domestic inter-industry linkages strengthened over time, the reported multipliers may be understated. The multiplier estimates for traditional sectors should therefore be interpreted as structurally informed approximations based on currently observable 2022 totals, rather than as exact representations of the full 2022 transaction structure. Future research could assess the sensitivity of these results as more recent data becomes available and as technical coefficients can be updated more dynamically over time. Future research could extend the framework to multi-regional IO models, incorporate environmental satellite accounts, or explore dynamic updating of technical coefficients as technologies mature.

Author Contributions: Conceptualization, Z.G.C., C.O. and A.S.; Methodology, Z.G.C., C.O. and A.S.; Investigation, Z.G.C. and C.O.; Data curation, Z.G.C., C.O. and A.S.; Writing—original draft, Z.G.C., C.O. and A.S.; Writing—review & editing, Z.G.C., C.O. and A.S.; Visualization, Z.G.C., C.O. and A.S.; Project administration, Z.G.C. All authors have read and agreed to the published version of the manuscript.

Funding: This paper has been funded by the Department of Agriculture, Food and the Marine (BioValue, Protein-I), the Environmental Protection Agency (LandingZones), Research Ireland (FUNGITECH) and the Sustainable Energy Authority of Ireland (BioAssess, Bioeconomy Renewable Energy). We appreciate input data from Shivali Sahota, Claire Duffy, Aoife O'Gorman, Cathal Geoghegan, Fiona Doohan, Lorraine Brennan and Ghassan Al Masbhi.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. BIO Sectoral Aggregation into 5 Classes (Sector Name)

Sectors	Base_Class
Contractor	Industry
Nursery	Primary_bio
ConForestry0	Primary_bio
ConForestry5	Primary_bio
ConForestry10	Primary_bio
ConForestry15	Primary_bio
ConForestry20	Primary_bio
ConForestry25	Primary_bio
ConForestry30	Primary_bio
ConForestry35	Primary_bio
ConForestry40	Primary_bio
ConForestry45	Primary_bio
ConForestry50	Primary_bio

BLForestry0	Primary_bio
BLForestry5	Primary_bio
BLForestry10	Primary_bio
BLForestry15	Primary_bio
BLForestry20	Primary_bio
BLForestry25	Primary_bio
BLForestry30	Primary_bio
BLForestry35	Primary_bio
BLForestry40	Primary_bio
BLForestry45	Primary_bio
BLForestry50	Primary_bio
BLForestry55	Primary_bio
ForestryClearfell	Primary_bio
Forestry Thinning	Primary_bio
ForestrylossClearfell	Primary_bio
Forestryloss Thinning	Primary_bio
Commercial Fishing	Primary_bio
Aquaculture	Primary_bio
Concentrate Own	Secondary_bio
Concentrate Opening	Secondary_bio
Pasture	Primary_bio
Winter Forage Own	Primary_bio
Silage own	Primary_bio
Hay Own	Primary_bio
Winter Forage Op	Primary_bio
Silage Op	Primary_bio
Hay Op	Primary_bio
Winter Forage Pur	Primary_bio
OtherCashCrop	Primary_bio
PotatoFruitVeg	Primary_bio
Setaside	Primary_bio
SugarBeet	Primary_bio
Dairy Cows	Primary_bio
Dairy Calves	Primary_bio
Dairy Heifers	Primary_bio
Roots	Primary_bio
Milk Quota Lease	Services

HOME_GROWN_SEED_VALUE_EU	Services
MACHINERY_HIRE_EU	Services
Other Cows	Primary_bio
Other Calves	Primary_bio
Beef Cow Replacements	Primary_bio
Bulls	Primary_bio
Cattle male: under 1 year	Primary_bio
Cattle female: under 1 year	Primary_bio
Cattle male: 1–2 years	Primary_bio
Cattle female: 1–2 years	Primary_bio
Cattle male: 2 years and over	Primary_bio
Cattle female: 2 years and over	Primary_bio
Sheep	Primary_bio
Horses	Primary_bio
Pigs	Primary_bio
Poultry	Primary_bio
Deer and Goats	Primary_bio
Mining, quarrying and extraction	Industry
Beef and veal	Secondary_bio
Pig meat	Secondary_bio
Sheep meat	Secondary_bio
Poultry meat	Secondary_bio
Fish, crustaceans and molluscs	Secondary_bio
Fruit and vegetables	Primary_bio
Vegetable, animal oils and fats	Secondary_bio
Dairy products	Secondary_bio
Grain mill products, starches and starch products	Secondary_bio
Bakery and farinaceous products	Secondary_bio
Other food products	Secondary_bio
Prepared animal feeds	Secondary_bio
Beverages	Secondary_bio
Textiles (13)	Industry
Wearing apparel (14)	Industry
Leather and related products (15)	Industry
Wood and wood products, except furniture (16)	Secondary_bio
Paper and paper products (17)	Secondary_bio
Printing and reproduction of recorded media (18)	Industry
Manufacturing n.e.s. (19,21,26,28,31,32)	Industry

https://doi.org/10.3390/su18084035

Chemicals and chemical products (20)	Industry
Rubber and plastic products (22)	Industry
Other non-metallic mineral products (23)	Industry
Basic metals (24)	Industry
Fabricated metal products, except machinery and equipment (25)	Industry
Electrical equipment (27)	Industry
Transport equipment (29,30)	Industry
Repair and installation of machinery and equipment (33)	Industry
Electricity, gas, steam and air conditioning supply (35)	Energy
Water collection, treatment and supply (36)	Services
Sewerage, waste management and remediation activities (37 to 39)	Services
Construction (41 to 43)	Industry
Motor trades (45)	Services
Wholesale trade (46)	Services
Retail trade (47)	Services
Land transport (49)	Services
Water transport (50)	Services
Air transport (51)	Services
Warehousing and support activities for transportation (52)	Services
Postal and courier activities (53)	Services
Accommodation services (55)	Services
Food and beverage services (56)	Services
Publishing, audiovisual and broadcasting services (58 to 60)	Services
Telecommunications (61)	Services
Computer programming, consultancy and Information service activities (62,63)	Services
Financial service activities, except insurance and pension funding (64)	Services
Insurance, reinsurance and pension funding, except compulsory social security (65)	Services
Activities auxiliary to financial services and insurance activities (66)	Services
Real estate activities (68)	Services
Legal and accounting activities (69)	Services

Head office and management consultancy activities (70)	Services
Architectural and engineering activities technical testing and analysis (71)	Services
Scientific research and development (72)	Services
Advertising, other professional, scientific, technical and veterinary activities (73 to 75)	Services
Renting and leasing activities (77)	Services
Employment activities (78)	Services
Travel agency, tour operator and other reservation service and related activities (79)	Services
Administrative and support service activities (80 to 82)	Services
Public administration and defence, compulsory social security (84)	Services
Education (85)	Services
Human health and social work activities (86 to 88)	Services
Arts, entertainment and recreation (90 to 92)	Services
Sports activities and amusement and recreation activities (93)	Services
Activities of membership organisations (94)	Services
Repair of computers and personal and household goods (95)	Services
Other personal service activities (96)	Services
Activities of households as employers of domestic personnel (97)	Services
Bituminous coal	Energy
Anthracite and manufactured ovoids	Energy
Coke	Energy
Lignite	Energy
Milled peat	Energy
Sod peat	Energy
Briquettes	Energy
Crude oil	Energy
Natural gas	Energy
Refinery gas	Energy
Gasoline	Energy
Kerosene	Energy
Jet kerosene	Energy
Fuel oil	Energy

LPG	Energy
Gasoil/diesel/DERV	Energy
Petroleum coke	Energy
Naphta	Energy
Bitumen	Energy
White spirit	Energy
Lubricants	Energy
Hydro	Energy
Wind	Energy
Biomass	Energy
Landfill gas	Energy
Biogas	Energy
Liquid Biofuel	Energy
Solar	Energy
Geothermal	Energy
Electricity	Energy
Heat	Energy
Non renewable waste	Energy

Appendix B

Table A1. Calibration diagnostics for BIO2022.

Sector/Control Total	Target Total	Calibrated BIO2022 Total	Residual	% Residual
Contractor	199.558	199.593	0.036	0.0%
Nursery	15.113	15.115	0.001	0.0%
ConForestry0	(4.706)	(4.719)	(0.013)	0.3%
ConForestry5	3.847	3.813	(0.034)	(0.9%)
ConForestry10	28.508	28.495	(0.014)	(0.0%)
ConForestry15	89.543	89.530	(0.013)	(0.0%)
ConForestry20	154.823	154.808	(0.015)	(0.0%)
ConForestry25	105.513	105.503	(0.010)	(0.0%)
ConForestry30	55.287	55.282	(0.005)	(0.0%)
ConForestry35	181.159	181.153	(0.006)	(0.0%)
ConForestry40	149.943	149.940	(0.004)	(0.0%)
ConForestry45	66.494	66.493	(0.002)	(0.0%)
ConForestry50	49.098	49.098	(0.000)	(0.0%)
BLForestry0	(8.033)	(8.047)	(0.014)	0.2%
BLForestry5	0.849	0.847	(0.001)	(0.2%)

Table A1. *Cont.*

Sector/Control Total	Target Total	Calibrated BIO2022 Total	Residual	% Residual
BLForestry10	3.312	3.310	(0.001)	(0.0%)
BLForestry15	4.917	4.916	(0.001)	(0.0%)
BLForestry20	5.225	5.224	(0.001)	(0.0%)
BLForestry25	2.693	2.692	(0.000)	(0.0%)
BLForestry30	1.162	1.162	(0.000)	(0.0%)
BLForestry35	1.243	1.243	(0.000)	(0.0%)
BLForestry40	1.641	1.641	(0.000)	(0.0%)
BLForestry45	1.056	1.056	(0.000)	(0.0%)
BLForestry50	0.697	0.697	(0.000)	(0.0%)
BLForestry55	0	0	0	
ForestryClearfell	710.982	706.873	(4.108)	(0.6%)
Forestry Thinning	56.807	56.397	(0.410)	(0.7%)
ForestrylossClearfell loss	16.151	16.138	(0.013)	(0.1%)
Forestryloss Thinning loss	0.089	0.089	0.000	0.0%
Commercial Fishing	470.017	470.152	0.135	0.0%
Aquaculture	271.795	271.873	0.077	0.0%
ConcentrateOwn	147.203	147.271	0.068	0.0%
ConcentrateOpening	293.604	293.655	0.050	0.0%
Pasture	1044.846	1045.200	0.354	0.0%
WinterForageOwn	15.551	15.557	0.006	0.0%
Silageown	282.415	282.527	0.112	0.0%
HayOwn	6.221	6.223	0.003	0.0%
WinterForageOp	26.033	26.033	0.000	0.0%
SilageOp	664.921	664.921	0.000	0.0%
HayOp	27.729	27.729	0.000	0.0%
Winter Forage Pur	145.927	145.927	0.000	0.0%
OtherCashCrop	186.299	186.356	0.057	0.0%
PotatoFruitVeg	1390.020	1390.680	0.660	0.0%
Setaside	0	0	0	
SugarBeet	0	0	0	
Dairy Cows	4911.189	4913.217	2.028	0.0%
Dairy Calves	1009.927	1010.576	0.650	0.1%
Dairy Heifers	743.216	743.968	0.752	0.1%
Roots	0.504	0.504	0.000	0.0%
Milk Quota Lease	0	0	0	
HOME_GROWN_SEED_VALUE_EU	0	0	0	
MACHINERY_HIRE_EU	0	0	0	
Other Cows	684.529	687.094	2.564	0.4%
Other Calves	559.312	559.856	0.544	0.1%

Table A1. *Cont.*

Sector/Control Total	Target Total	Calibrated BIO2022 Total	Residual	% Residual
Beef Cow Replacements	406.440	406.666	0.226	0.1%
Bulls	2.416	2.422	0.006	0.3%
Cattle male: under 1 year	865.122	865.809	0.687	0.1%
Cattle female: under 1 year	866.932	867.659	0.727	0.1%
Cattle male: 1–2 years	1435.110	1437.031	1.921	0.1%
Cattle female: 1–2 years	1251.125	1254.794	3.669	0.3%
Cattle male: 2 years and over	1061.392	1062.914	1.522	0.1%
Cattle female: 2 years and over	674.923	675.623	0.700	0.1%
Sheep	618.499	618.869	0.369	0.1%
Horses	128.283	128.380	0.097	0.1%
Pigs	935.280	935.612	0.332	0.0%
Poultry	207.266	207.352	0.087	0.0%
Deer and Goats	72.209	72.209	0.000	0.0%
Mining, quarrying and extraction	958.798	959.035	0.237	0.0%
Beef and veal	3536.164	3539.651	3.488	0.1%
Pig meat	2016.077	2016.894	0.817	0.0%
Sheep meat	1044.698	1045.142	0.444	0.0%
Poultry meat	720.417	720.682	0.265	0.0%
Fish, crustaceans and molluscs	881.923	882.194	0.271	0.0%
Fruit and vegetables	134.156	134.176	0.019	0.0%
Vegetable, animal oils and fats	90.911	90.936	0.026	0.0%
Dairy products	6775.171	6779.485	4.314	0.1%
Grain mill products, starches and starch products	1126.733	1127.126	0.393	0.0%
Bakery and farinaceous products	5119.124	5121.285	2.161	0.0%
Other food products	13,193.197	13,194.185	0.988	0.0%
Prepared animal feeds	3282.378	3283.863	1.485	0.0%
Beverages	5186.716	5188.687	1.971	0.0%
Textiles (13)	478.801	478.988	0.187	0.0%
Wearing apparel (14)	124.336	124.367	0.031	0.0%
Leather and related products (15)	58.555	58.574	0.018	0.0%
Wood and wood products, except furniture (16)	2704.617	2706.337	1.721	0.1%
Paper and paper products (17)	744.048	744.247	0.199	0.0%
Printing and reproduction of recorded media (18)	1894.472	1894.866	0.395	0.0%
Manufacturing n.e.s. (19,21,26,28,31,32)	308,159.249	308,280.439	121.191	0.0%
Chemicals and chemical products (20)	94,416.135	94,460.975	44.840	0.0%

Table A1. *Cont.*

Sector/Control Total	Target Total	Calibrated BIO2022 Total	Residual	% Residual
Rubber and plastic products (22)	14,433.373	14,439.108	5.734	0.0%
Other non-metallic mineral products (23)	3788.795	3790.517	1.722	0.0%
Basic metals (24)	2150.146	2150.853	0.707	0.0%
Fabricated metal products, except machinery and equipment (25)	5165.564	5167.243	1.680	0.0%
Electrical equipment (27)	18,299.247	18,307.294	8.048	0.0%
Transport equipment (29,30)	1239.970	1240.371	0.401	0.0%
Repair and installation of machinery and equipment (33)	2093.914	2094.579	0.666	0.0%
Electricity, gas, steam and air conditioning supply (35)	20,898.171	20,904.696	6.525	0.0%
Water collection, treatment and supply (36)	686.183	686.321	0.139	0.0%
Sewerage, waste management and remediation activities (37 to 39)	2932.904	2933.912	1.008	0.0%
Construction (41 to 43)	45,888.231	45,901.314	13.082	0.0%
Motor trades (45)	3515.587	3516.681	1.094	0.0%
Wholesale trade (46)	81,821.017	81,856.612	35.595	0.0%
Retail trade (47)	20,161.571	20,168.634	7.063	0.0%
Land transport (49)	8130.757	8133.185	2.427	0.0%
Water transport (50)	1197.644	1198.101	0.457	0.0%
Air transport (51)	8832.010	8834.739	2.729	0.0%
Warehousing and support activities for transportation (52)	2726.667	2727.603	0.937	0.0%
Postal and courier activities (53)	2148.518	2149.022	0.504	0.0%
Accommodation services (55)	4147.006	4148.208	1.201	0.0%
Food and beverage services (56)	17,300.394	17,309.553	9.159	0.1%
Publishing, audiovisual and broadcasting services (58 to 60)	47,309.694	47,313.929	4.235	0.0%
Telecommunications (61)	7270.393	7271.755	1.361	0.0%
Computer programming, consultancy and Information service activities (62,63)	622,874.246	623,184.010	309.763	0.0%
Financial service activities, except insurance and pension funding (64)	71,586.196	71,610.978	24.782	0.0%
Insurance, reinsurance and pension funding, except compulsory social security (65)	49,754.057	49,770.492	16.436	0.0%
Activities auxiliary to financial services and insurance activities (66)	14,744.100	14,748.398	4.298	0.0%
Real estate activities (68)	38,491.806	38,500.011	8.204	0.0%

Table A1. *Cont.*

Sector/Control Total	Target Total	Calibrated BIO2022 Total	Residual	% Residual
Legal and accounting activities (69)	12,228.060	12,229.626	1.566	0.0%
Head office and management consultancy activities (70)	12,149.695	12,154.525	4.830	0.0%
Architectural and engineering activities technical testing and analysis (71)	4836.508	4837.380	0.873	0.0%
Scientific research and development (72)	12,137.839	12,144.148	6.310	0.1%
Advertising, other professional, scientific, technical and veterinary activities (73 to 75)	16,819.295	16,822.908	3.612	0.0%
Renting and leasing activities (77)	37,751.731	37,762.102	10.371	0.0%
Employment activities (78)	4241.377	4242.344	0.967	0.0%
Travel agency, tour operator and other reservation service and related activities (79)	2035.615	2036.040	0.425	0.0%
Administrative and support service activities (80 to 82)	12,248.172	12,253.993	5.821	0.0%
Public administration and defence, compulsory social security (84)	33,281.666	33,296.105	14.439	0.0%
Education (85)	21,129.212	21,136.420	7.209	0.0%
Human health and social work activities (86 to 88)	48,925.960	48,946.204	20.244	0.0%
Arts, entertainment and recreation (90 to 92)	1533.690	1533.857	0.166	0.0%
Sports activities and amusement and recreation activities (93)	17,295.351	17,301.140	5.789	0.0%
Activities of membership organisations (94)	6623.392	6626.426	3.034	0.0%
Repair of computers and personal and household goods (95)	344.934	345.069	0.136	0.0%
Other personal service activities (96)	5333.753	5336.701	2.948	0.1%
Activities of households as employers of domestic personnel (97)	169.420	169.420	0.000	0.0%

Appendix C. Input Questionnaire

Field	Response
Sector Name	
Nature of Product/Service (brief description)	
Nature of Product/Service (brief description)	
Nature of Product/Service (brief description)	
Top 5 Inputs by Business Phase	

Field					Response
No.	Name of Input/Purchase	R&D	Development	Growth	Mature
1					
2					
3					
4					
5					
Other					
Total		1	1	1	1
Share of Total Pre-Tax and Pre-Profit Expenditure					
Expenditure Category		R&D	Development	Growth	Mature
Labour					
Capital					
Imported Goods and Services					
Purchased Goods and Services					
Total		1	1	1	1
Sales Category		R&D	Development	Growth	Mature
Consumer (Households or Government)					
Exports					
B2B					
Total		1	1	1	1
Market Size					
Phase		Market Size (€m)			
R&D					
Development					
Growth					
Mature					
Phase		Description			
R&D		Research and development stage			
Development		Early commercial development stage			
Growth		Expansion and scaling stage			
Mature		Established market stage			

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