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Sustainability from Policy to Practice: Assessing the Impact of European Research and Innovation Frameworks on Circular Bioeconomy

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Abstract: Europe leads in shaping circular bioeconomy (CBE) policies for sustainability, relying on dynamic research and innovation (R&I) projects to propel the transition. Increased European R&I investment, fueled by commitment and a societal demand for measurable project returns, lacks a comprehensive evaluation. This study provides an in-depth analysis of the alignment of European-funded R&I projects with CBE policy priorities and assesses their societal impact. Rooted in an interpretive paradigm, it employs content analysis through semi-structured questionnaires to survey project leaders. The study evaluates benefits using the triple bottom line concept and interprets results guided by the theory of change. Our results suggest that European-funded R&I projects actively cultivate a supportive ecosystem for CBE adoption, as evidenced by emerging themes such as knowledge sharing, capacity building, and collaborative learning, aligning closely with investment priorities and funding schemes. The societal impact focuses on the short and medium term, emphasizing the social dimension by committing to empowering individuals, fostering collaboration, and enriching knowledge. Long-term benefits primarily contribute to the economic dimension, highlighting the potential for positive impacts like promoting business growth, innovation, improving market efficiency, and fostering sustainability. This study seeks to enhance the impact of R&I projects and promote a paradigm shift towards sustainability by providing context-specific recommendations.

Keywords: circular bioeconomy; R&I projects; policy priorities; sustainability; triple bottom line; societal impact

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1. Introduction

The concept of a circular bioeconomy (CBE) has gained significant attention as societies strive for sustainable and environmentally friendly economic models. A CBE emphasizes the use of renewable biological resources and the efficient utilization of waste and by-products, thereby reducing reliance on fossil fuels and minimizing environmental impacts [1]. Industrial symbiosis (IS) is a key component of the CBE that involves the establishment of collaborative networks among industries, enabling the exchange of resources, energy, and expertise to optimize resource utilization and minimize waste generation [2].

In Europe, collaborative research and innovation (R&I) projects have emerged as crucial drivers to promote a CBE driven by IS. These projects bring together multidisciplinary teams, including researchers, industry representatives, policymakers, and other stakeholders, to develop innovative solutions, technologies, and practices [3]. Through collaboration, R&I projects address complex challenges and can promote the adoption of sustainable and circular practices within industries [4].

Despite the acknowledged significance of R&I projects in advancing sustainability and circular practices, there exists a notable research gap concerning the comprehensive

assessment and evaluation of the specific benefits derived from such initiatives. The literature offers a wealth of benefit concepts [5]. In our interpretation, benefits can be defined as measurable changes originating from an R&I result and are perceived as advantageous by stakeholders. Various models have been proposed to assess benefits, however, we opted for a simplified one based on Lutz Bornmann's proposal, categorizing benefits into social, economic, and environmental aspects [6].

The concept of 'benefits' is frequently intertwined with the term 'impact'. In our study, 'impact' is specifically defined as the significance of the results achieved by R&I projects concerning their project objectives [7,8]. Alongside impact, 'outputs' and 'outcomes' constitute the three categories of results commonly associated with projects and/or research [7,9].

Within the realm of R&I projects, the definitions of these terms can vary depending on different perspectives. Nevertheless, widely accepted definitions, often in alignment with the Organization for Economic Co-operation and Development (OECD), classify these terms as follows: outputs are the tangible products and services created by a project; outcomes are the expected or realized short- and medium-term effects; and impacts are the long-term effects, both positive and negative, resulting from the project, whether intended or not. Sometimes, the term 'results' may be used interchangeably to refer to all three items [7,9].

Unlike existing research that focuses on the general importance of R&I projects for sustainability or the potential of IS within a CBE [10–12], this study delves deeper. It acknowledges a critical knowledge gap: how effective are R&I projects in actually promoting IS-based CBE practices? This research addresses this novelty by employing a stakeholder-centric approach. By focusing on insights from project leaders and partners, it goes beyond the broader perspectives often taken in previous studies. Furthermore, the analysis does not just consider the overall impact of R&I projects, but also dissects the specific social, economic, and environmental benefits arising from their outputs, outcomes, and long-term impacts. Therefore, this research addresses the following questions: (RQ1) Do R&I projects effectively promote IS-supported CBE practices among consortium participants? (RQ2) What are the social, economic, and environmental benefits of the major outputs, outcomes, and impacts of these R&I projects? Finally, the geographical focus on cross-border funded projects in Europe allows for a nuanced understanding of the challenges and opportunities specific to this region. Through this novel approach, the research aims to illuminate the true value of R&I projects as drivers for a thriving CBE in Europe, ultimately providing actionable recommendations to strengthen their effectiveness and propel Europe towards a more sustainable future.

The remainder of the paper is structured as follows: Section 2 presents the literature review; Section 3 outlines the methods; Section 4 reports and discusses the results of the surveys; finally, Section 5 ends the paper with some concluding remarks, alongside limitations and future work.

2. Literature Review

2.1. Circular Bioeconomy: Achieving Sustainability through Industrial Symbiosis Synergies

CBE and IS are two concepts that share the potential to implement collective actions for achieving more sustainable resources management. The CBE is an innovative concept that integrates the principles of the bioeconomy and the circular economy. While in a bioeconomy the emphasis is on using renewable resources, the circular economy focuses on conserving resources [13]. At the intersection of both, the CBE specifically refers to the process of reusing waste streams derived from renewable bio-resources, such as biowaste or biomass, within a closed-loop system, for the development of innovative bio-based products and services [14]. This approach not only maximizes resource efficiency and promotes the use of renewable resources, enabling the extraction of maximum value from biological resources throughout their life cycle, but also minimizes waste disposal [15]. Therefore, the CBE effectively tackles the intertwined challenges of resource scarcity, environmental degradation, and climate change while promoting economic growth [15,16].

IS, on the other hand, emphasizes collaboration and mutually beneficial interaction between different industrial sectors, where the waste or by-products of one industry become valuable resources for another industry [2]. Within the CBE framework, IS can be particularly valuable for industries that rely on biological resources or generate biowaste. For example, agricultural residues or food processing by-products can be utilized as feedstocks for bioenergy production or converted into high-value bio-based products through IS [17,18]. Likewise, waste generated in the forestry sector can be repurposed within various industries, particularly in the wood sector, through the exchange of materials like wood chips, bark, sawdust, and shavings [19].

The combination of CBE and IS concepts has the potential to significantly enhance sustainability. Bijon (2022) emphasizes the pivotal role of dedicated implementation strategies and facilitating mechanisms, such as information sharing and collaboration, in nurturing these initiatives. Despite their potential, the widespread adoption of these concepts encounters several challenges [20]. Menato (2017) identifies barriers to IS adoption, emphasizing the delicate balance companies must strike between private and public benefits [21]. Additionally, Kosmol (2020) points out various obstacles to IS implementation, spanning economic, technological, and regulatory factors [22]. Gatto (2021) draws attention to the 'valley of death' in developing CBE business models, posing a hurdle to their market acceptance [23]. Ferreira (2021) delves into the technical and social challenges in transforming industrial and municipal side streams into bio-based products [9]. These challenges underscore the imperative for R&I efforts to develop and validate sustainable business models, address technical and social limitations, and overcome implementation barriers.

The CBE is gaining traction across Europe, with bioeconomy clusters focusing on maximizing resource utilization and minimizing waste. Research by Stegman et al. (2020) highlights a trend towards residue valorization, integrated biorefineries, and high-value applications within these clusters. However, challenges remain, particularly in areas like end-of-life product management, circular product design, and recycling [24]. While progress has been made, research by Kardung and Drabik (2021) indicates an overall advancement in circular bioeconomies across EU member states between 2006 and 2016. Notably, private sector research and development appears to be surpassing its public sector counterpart, suggesting a potential shift in funding priorities [25]. Additionally, Morone et al. (2022) identify significant variations in bioeconomy development across Europe. Ireland stands out as a leader, excelling in areas like manufacturing and bioenergy. However, the socio-economic indicator for the bioeconomy (SEIB) also reveals disparities, with countries like Slovakia and Malta lagging behind [26].

While some regions require further development, others demonstrate robust performance, with the European Nordic region standing out as a notable example, leading global rankings in establishing a sustainable and innovative economy. Nordic cooperation, involving Denmark, Finland, Iceland, Norway, Sweden, Faroe Islands, Greenland, and Åland Islands, is recognized as one of the most extensive forms of regional collaboration worldwide. Their collaborative efforts have resulted in a catalog of 25 exemplary cases, ranging from self-sufficient and sustainable cereal and dairy farms to smart forests, showcasing Nordic solutions for global challenges. Emphasizing four pillars—replace, upgrade, circulate, and collaborate—these initiatives contribute significantly to the CBE [27].

Overall, the Nordic success model emphasizes key aspects of stakeholder engagement, including collaboration, partnership building, and alignment around a shared vision [27]. These elements are crucial for creating a successful and sustainable collaborative effort. Beyond collaboration, identifying and prioritizing stakeholders is essential. Santos and Fernades (2024) propose a methodology to assess stakeholder importance within a project from a sustainability perspective. Key benefits were identified by the experts related to the categories "society and costumers" and "consumption". Based on such considerations, stakeholder management plans should prioritize research team members, leaders at the consortium organizations, project management team members, and environmental NGOs [3]. By implementing these principles, CBE projects can leverage collaborative strengths and

ensure that stakeholder engagement maximizes the project's positive impact on society and the environment.

2.2. European Policy Landscape for Circular Bioeconomy

The European Union (EU) is actively leading a transformative shift towards a novel societal and economic paradigm, centered around the responsible and circular utilization of resources. At the core of this transformative effort is the European Green Deal, a fundamental policy that articulates the EU's commitment to achieving climate neutrality by 2050 while safeguarding the well-being of people, the planet, and prosperity [28,29]. Two pivotal strategies, the EU Bioeconomy Strategy and its Action Plan (first launched in 2012 and updated in 2018), along with the Circular Economy Action Plan (initially introduced in 2015 and updated in 2020), form the cornerstone of these endeavors. They play a vital role in promoting climate neutrality and ensuring environmental, economic, and social sustainability [25,29]. Moreover, these strategies are integral components driving the development of the CBE, with a particular emphasis on the bio-based sectors [30]. The commitment to CBE development is further manifested in the EU's focus on cultivating partnerships, facilitating upscaling endeavors, and maximizing knowledge utilization, as highlighted by Lange et al. (2021) [31].

In parallel, IS is also increasingly acknowledged as a strategic tool for economic development and resource efficiency, garnering support from European policy documents [32]. For instance, the establishment of the Bio-based Industries Joint Undertaking (BBI JU) in 2014, a key outcome of the 2012 EU Bioeconomy Strategy, aimed to attract private investments, foster R&I, and coordinate activities in European bio-based industries. With an initial EUR 975 million EU allocation, matched by EUR 2.73 billion from the private sector represented by the Bio-based Industries Consortium (BIC), including over 250 entities (80% SMEs), the BBI JU positively impacted the environment, society, and the economy. Building on this success, the European Circular Bio-based Partnership (EC CBE) was launched in 2021, aligning with the 2018 Bioeconomic Strategy. With a EUR 1 billion EU contribution and an equal private sector contribution from the BIC, the EC CBE focuses on strengthening and expanding EU bio-based sectors, supporting the innovation cycle, and aligning with EU climate goals for sustainability and circularity. The partnership's key focus is to bring bio-based innovation to specific regions, aiming to revitalize them. As such, the European Commission collaborates with Member States to rapidly deploy local bioeconomies across Europe. Initiatives like the European Bioeconomy Policy Forum facilitate knowledge exchange, and the Bioeconomy Policy Support Facility supports collaboration, identifying key policy messages for national bioeconomy strategy development [29].

Moreover, various EU instruments have supported several pilot actions to promote the development of coastal, rural, and urban bioeconomies, effectively showcasing their potential impact on the ground. The main funding for R&I comes through the Framework Programmes (FPs) and the European Structural and Investment Funds (ESIFs). Initiated in 1984, FPs have undergone substantial growth in both scale and scope. Initially supporting basic research, their budgets increased, reaching over EUR 55 billion with FP7 in 2007, which focused more on technological research. Horizon 2020 represented a significant milestone, boasting an EUR 80 billion budget for 2014–2020, supporting R&I in collaborative projects, individual researchers, and SMEs, with a specific emphasis on the bioeconomy under Societal Challenge 2. The latest iteration, Horizon Europe, the ninth FP, spanning 2021–2027, is the most ambitious yet, featuring a nearly EUR 100 billion budget. Its pillar 'Global Challenges and European Industrial Competitiveness' includes a cluster dedicated to the bioeconomy, highlighting its crucial role in addressing global challenges and enhancing industrial competitiveness [33].

Within the ESIFs, the European Regional Development Fund (ERDF) stands out as the primary source, accounting for 95% of the R&I funding allocation. Interreg programs and projects are recipients of ERDF funding, with a substantial budget of EUR 359 million allocated for the current active Interreg period from 2021 to 2027. The Interreg framework

consists of programs strategically designed to promote cooperation and collaboration among European regions, focusing on cross-border or transnational cooperation to facilitate partnerships between neighboring regions or countries. The main goal is to support economic and social development across the EU by investing in projects that drive innovation, sustainable development, job creation, and overall improvements in living conditions [34].

Another noteworthy initiative stemming from the EU policy landscape for CBE is the European Circular Bioeconomy Fund. This groundbreaking venture fund is exclusively dedicated to the bioeconomy and circular bioeconomy in Europe, offering funding from Horizon 2020 and the European Investment Bank. Additionally, in 2021, the establishment of the Circular Cities and Regions Initiative further reinforced support for circular bio-based economy projects at the local and regional levels through demonstrations and technical assistance [29].

Examining EU policy documents, especially reports authored by the European Commission, particularly those addressing EU bioeconomy and circular economy policies, emphasizes the vital role of CBE governance. This governance is essential to maximize synergies among sectoral policies, establish an equitable playing field, and formulate a coherent framework for sustainability [28,29]. However, there are challenges in implementing these policies, and further research is needed to fully understand their implications for business and industry stakeholders [35].

2.3. Benefits of Collaborative R&I Projects on Circular Bioeconomy

Following World War II, scientific research gained momentum as governments, research institutions, and industry recognized the advantages of collaborative efforts in driving technological advancement [36]. Collaborative R&I projects have since expanded and proven effective in bringing diverse stakeholders together to address complex challenges, drive innovation, and accelerate the discovery and development of new technologies, products, or services [37,38].

The European Framework Programmes (FPs) and Interreg can play a crucial role in aligning these projects with the European policy landscape for CBE by offering essential funding and support for R&I endeavors [34]. As investments in R&I projects increase, the emphasis on ensuring tangible benefits for the invested public resources becomes paramount [39]. Success is now measured by societal impact, moving beyond a sole emphasis on scientific outputs like publications to encompass broader considerations of social, environmental, and economic returns [40]. This holistic evaluation extends across the 'triple bottom line' (TBL) framework, a sustainability concept that encapsulates the social, environmental, and economic value of an investment [41]. As such, the TBL is commonly employed to evaluate performance across the three pillars of sustainability, commonly referred to as the "3Ps" (People, Planet, Profit). This approach is exemplified in the work of Burksiene (2018), where the TBL served as a methodological foundation for studying sustainability and sustainability marketing in the competition for the title of European Capital of Culture [42].

Notable examples illustrating this shift from scientific to societal impact in research governance include the Research Excellence Framework (REF) in the United Kingdom, the Excellence in Research for Australia (ERA) framework, the Netherlands's Standard Evaluation Protocol (SEP), and Italy's Research Quality Evaluation [43,44]. Additionally, the EU's scientific research policy prioritizes societal needs, promoting R&I investment for the benefit of its citizens [9,43].

Collaborative R&I projects have a significant impact on CBE practices, particularly in the development of circular-oriented innovations [45]. These projects play a crucial role in the validation of sustainable circular bio-based business models, with a focus on market uptake of greener solutions and the empowerment of start-ups and SMEs [23]. They also drive the innovation of business models for a circular and sustainable bioeconomy, with a strong emphasis on macro-environmental conditions, internal objectives, and value co-creation [46]. Furthermore, research in this area has identified bioenergy boosters through

circular economy practices in agriculture, with a focus on electricity generation and biofuel production from biogas [47].

Establishing robust evaluation mechanisms to confirm the actual change or benefits resulting from R&I projects on sustainability poses a significant challenge. In response to this challenge, the theory of change (ToC) emerges as a versatile tool that intricately outlines the logical sequence of activities within an initiative (e.g., projects, programs, and organizations) leading to the intended (ex ante scenario) or the realized (ex post scenario) transformations. In other words, the ToC aids in understanding how and why a desired change is expected to occur, providing a systematic and visual representation of the relationships among inputs, activities, outputs, outcomes, and impacts [48]. Evolving over time, it has become widely applied in diverse project and program evaluations, earning recognition as a valuable tool in sustainability research [49]. Using the ToC as a guiding framework, the analysis of the study's results on the impact of EU-funded R&I projects on sustainability through CBE practices gains a structured approach, allowing for a comprehensive understanding of the pathways and mechanisms through which these projects contribute to the desired results and transformations.

3. Material and Methods

A visual representation of the methodology employed in this study is depicted in Figure 1. To evaluate the results of EU-funded collaborative R&I projects in the area of CBE promoted by IS, a qualitative research approach was employed rooted in an interpretivist research paradigm. The interpretivist research paradigm is particularly suitable when the research problem revolves around understanding subjective interpretations and exploring diverse perspectives within social and cultural contexts [50]. Within this paradigm, the ontology of subject–object interaction aligned with a constructivist epistemology was embraced. While the subject–object ontology recognizes that both the researcher and the participants have their own subjective perspectives and experiences and that reality is socially constructed, constructivist epistemology emphasizes the active construction of knowledge rather than its passive discovery [51].

The research design was, therefore, explorative, based on the case study method, with projects serving as the primary unit of analysis [52]. The non-probability technique of purposive sampling was used to select the case study participants (i.e., projects). This sampling technique allows for the deliberate selection of participants who can provide valuable information or unique perspectives related to the research problem [53]. Accordingly, the selected projects for analysis had to meet specific criteria, including being EU-funded in the field of CBE and/or IS. No time constraints were imposed. They were identified from the CORDIS and Keep.eu databases using as keywords 'circular bioeconomy' and 'industrial symbiosis', between 29 April and 3 May 2021 (CORDIS website), and on 8 May 2023 (Keep.eu website).

Data were collected through an Ethics Committee-approved semi-structured questionnaire at the Bragança Polytechnic University, utilizing a three-dimensional approach to evaluate project outputs, outcomes, and impacts. Following the approval, an email was dispatched to project leaders from the previously selected project sample. In cases where the contact information was unattainable or no response was received from the project's leader, other project partners were contacted. To streamline the response process, we made the decision to embed the questionnaire directly within the email body. By adopting this approach, participants were able to conveniently respond to the questionnaire by simply replying to the email. This simplified method eliminated the need for participants to open attachments or navigate external platforms, increasing the likelihood of their prompt response. Most project leaders promptly responded within a week of receiving the questionnaire. For those who did not reply within 15 days of the initial email, a reminder was sent. The total response rate reached approximately 32% one month after the initial questionnaire distribution, prompting the closure of response collection at that juncture. In parallel, a secondary information source was utilized to access documents and other

forms of evidence (e.g., reviewing scientific publications, project deliverables, datasets, software, and news related to the projects) to enhance understanding of the projects' context. By employing this approach, we aimed to compensate for the lack of immersion in the researched situation inherent to the questionnaire technique.

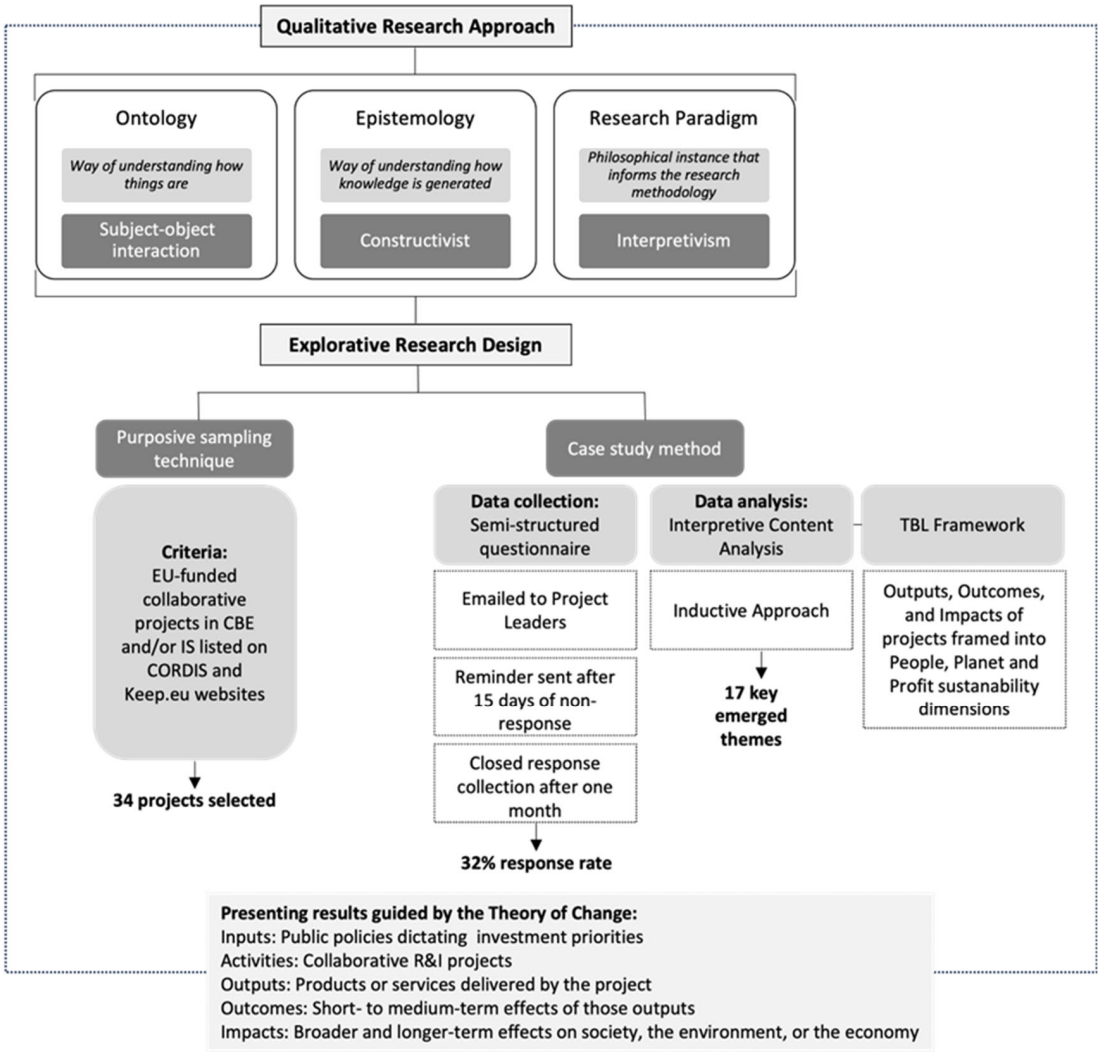

Figure 1. General methodological procedure adopted in the present study.

Interpretive content analysis was employed as the primary tool for data analysis [54]. The use of interpretive content analysis followed an inductive approach, allowing codes, themes, and interpretations to emerge organically from data [55]. The questionnaire responses analysis involved a systematic process of coding and categorizing, to identify recurring patterns, themes, and concepts within the data. Initially, a thorough reading of the questionnaire responses was conducted to familiarize with the data and gain a holistic understanding of the context. Next, an open coding process was employed, where significant ideas, phrases, or statements related to outputs, outcomes, and impacts were identified. This step resulted in 25 initial codes. Through an iterative process, the initial codes were then grouped and refined into higher-level categories, which represent broader themes within the dataset. This process involved constant comparison, discussion, and revisiting of the data to ensure accuracy and consistency. The emerging themes were reviewed and refined multiple times to enhance the validity and reliability of the analysis. The result was the identification of 17 key themes that formed the basis of our final sample.

Simultaneously, the TBL framework was employed to assess the performance of research on European R&I projects related to CBE across economic, social, and environmental

parameters. Using content analysis as a tool, each feedback, categorized as an output, outcome, or impact, was subsequently assigned to one or more of the three sustainability dimensions, namely, People, Planet, and Profit. This was accomplished by scrutinizing the responses provided by each coordinator in the questionnaire. Based on the nature of each response, whether it was more oriented towards social, economic, or environmental aspects, it was categorized accordingly—specifically, classified as primarily contributing to the People, Profit, or Planet dimension.

Ultimately, the findings were framed within the ToC to facilitate our understanding of how inputs and activities converge to produce outputs, outcomes, and impacts within the realm of programs or projects [48,49]. In this manner, this strategic approach acted as a guiding beacon for our analysis and interpretations, enabling us to shed light on the interconnectedness among these constituent elements (inputs, activities, outputs, outcomes, and impacts). Consequently, we tailored the ToC to harmonize with the interpretive and inductive approach of this study, harnessing its flexible structure to capture the emergent patterns in our data, rather than initiating the investigation with rigid hypotheses. By embracing this method, we significantly augmented and extended our examination of the all-encompassing benefits stemming from the R&I projects analyzed.

From the 34 projects contacted, 11 responses to the semi-structured questionnaire were received from projects completed at least one year before the information request. Table 1 offers a comprehensive overview of the specific project details under analysis. It is crucial to note that the subsequent sections do not merely present objective facts but rather convey the authors' interpretations based on valuable insights provided by the participants who willingly took part in the study and responded to the semi-structured questionnaire.

Table 1. Project details analysis.

Project Acronym	Implementation Period	Core Objective	Funder Programme	Funding Scheme	IP
INNOREX	01/12/2012–31/05/2016	To develop a novel reactor concept using alternative energies for the continuous, highly precise, metal-free polymerization of Polylactic Acid.	FP7-NMP	CP-FP	n.a.
SYNPOL	01/10/2012–30/09/2016	To revolutionize biopolymer production, integrating modern processing, syngas fermentation, and biowaste pyrolysis to address waste management challenges and position the EU as a global leader in sustainable biopolymer production.	FP7-KBBE	CP-TP	n.a.
SPLASH	01/09/2012–28/02/2017	To establish a sustainable bio-based industry using microalgae, with a focus on developing industrial biotechnology for producing polyesters and polyolefins, for applications in food packaging and fibers.	FP7-KBBE	CP-TP	n.a.
BIOREFINE-2G	01/10/2013–30/09/2017	To economically convert pentose-rich side-streams from 2nd generation biorefineries into dicarboxylic acids to produce bio-based polymers, emphasizing sustainability and profitability across the value chain.	FP7-KBBE	CP-TP	n.a.

Table 1. *Cont.*

Project Acronym	Implementation Period	Core Objective	Funder Programme	Funding Scheme	IP
STAR-ProBio	01/05/2017–30/04/2020	To drive the sustainability transition to a bio-based economy by developing a fit-for-purpose sustainability scheme, including standards and certifications, through integrated life-cycle assessments and case studies for bio-based products.	H2020-EU.3.2.4.3.	RIA	n.a.
DIET	01/05/2018–30/04/2020	To improve anaerobic digestion efficiency by introducing conductive materials, enhancing direct interspecies and electron transfer.	H2020-EU.1.3.2.	MSCA-IF-EF-ST	n.a.
CIRCTER	10/10/2017–27/09/2019	To focus on unveiling territorial dimensions of transitioning towards a CE, revealing local and regional material patterns and their alignment with CE.	2014–2020 ESPON 2020	n.a.	(11 ETC)
TRIS	01/04/2016–31/03/2021	To facilitate systemic IS integration across five European regions by enhancing SME competitiveness through IS practices.	2014–2020 Interreg Europe	n.a.	(06g)
COASTAL Biogas	01/07/2018–30/06/2021	To address coastal eutrophication and advancing CBE through innovative anaerobic digestion solutions using cast seaweed.	2014–2020 INTERREG VA South Baltic	n.a.	(06f)
ARDIA-Net	01/10/2019–30/06/2022	To foster value chains and leverage CBE and health economy trends by establishing an Alpine Research Development Area.	2014–2020 INTERREG VB Alpine Space	n.a.	(11 ETC)
BIS	01/01/2019–30/06/2021	To promote IS and eco-innovation through strategic inter-industry collaborations in the Baltic region.	2014–2020 INTERREG VB Baltic Sea	n.a.	(01b)

Legend: IP—investment priority; n.a.—not applicable; FP7-NMP—"Cooperation": Nanosciences, Nanotechnologies, Materials and new Production Technologies; FP7-KBBE—"Cooperation": Food, Agriculture and Biotechnology; H2020-EU.3.2.4.3.—Supporting market development for bio-based products and processes; H2020-EU.1.3.2.—Nurturing excellence by means of cross-border and cross-sector mobility; CP-FP—Collaborative Projects: Small or medium-scale focused research projects; CP-TP—Collaborative Project targeted to a special group (such as SMEs); RIA—research and innovation actions; MSCA-IF-EF-ST—Marie Skłodowska-Curie actions Standard European Fellowships; (01b) promoting business investment in R&I, developing links and synergies between enterprises, research and development centers and the higher education sector; (06f)—promoting innovative technologies to improve environmental protection and resource efficiency in the waste sector, water sector, and with regard to soil, or to reduce air pollution; (06g)—supporting industrial transition towards a resource-efficient economy, promoting green growth, eco-innovation, and environmental performance management in the public and private sectors; (11 ETC)—European territorial cooperation (ETC) specific for transnational cooperation: enhancing institutional capacity of public authorities and stakeholders and efficient public administration by developing and coordinating macro-regional and sea-basin strategies.

4. Results and Discussion

4.1. Inputs: Public Policies Dictating Investment Priorities

Our study initiates with foundational inputs from public policies dictating investment priorities, setting the strategic direction for actively encouraging innovation and research. Our analysis reveals a diverse funding portfolio from European FPs (FP7 and H2020) and the Interreg Programme (ESPON 2020, Interreg Europe, INTERREG VA South Baltic, INTERREG VB Alpine Space, INTERREG VB Baltic Sea).

Interreg projects strategically aligned with specific investment priorities, which in our sample includes collaborative R&I (1b), green technologies for environmental protection (6f), the transition to a resource-efficient economy (06g), and transnational cooperation focusing on institutional capacity building (11 ETC). While FPs lack designated investment priorities, through funding schemes we can deduce the areas prioritized for investigation and investment. Within our sample, under FP7 and H2020, financial support mechanisms (CP-FP, CP-TP, RIA, MSCA-IF-EF-ST) emphasize collaborative research, innovation actions, and individual fellowships.

By embodying principles of circularity, resource efficiency, and collaborative synergy, the specific investment priorities and funding schemes in our sample harmonize with broader EU initiatives such as the Europe 2020 Strategy, European Green Deal, and Digital Agenda [56]. Acting as catalysts for transformative change, the projects in our sample seamlessly integrate with the European vision of a sustainable, innovative, and unified future [57].

Furthermore, it is noteworthy that these funding schemes and investment priorities exert a significant influence on project results. For instance, projects funded under the MSCA-IF-EF-ST scheme, vital for knowledge transfer and skill development, are expected to have enduring impacts on research capacity and human capital. CP-(FP or TP)-funded projects, conversely, may wield a greater influence in fostering partnerships among diverse project partners. Similarly, outcomes of projects funded under the investment priority (06g) may involve the successful implementation of more sustainable industrial practices, resulting in significant reductions in carbon emissions and improvements in resource use efficiency. Moreover, projects funded under the investment priority 11 ETC may facilitate collaboration among public entities in specific areas such as environmental management, economic development, and territorial planning.

Public policies dictating investment priorities, thus, serve as transformative inputs for R&I projects, as evident in our study, steering them towards sustainable solutions and aligning them with the overarching objectives of the EU.

4.2. Activities: Collaborative R&I Projects

We have determined that R&I projects are the operational embodiment (i.e., activities) of the policies and priorities outlined above. They represent the practical translation of public policy guidelines into tangible actions, geared towards realizing the stated objectives.

Our investigation involved a thorough analysis of 11 distinct R&I projects. Table 1 provides a comprehensive overview of their primary objectives and key characteristics. Notably, the majority of these projects are collaborative in nature, aligning with the EU's R&I FPs' emphasis on establishing transnational research networks [58]. As Pisacane and Tagliacozzo (2023) suggest, collaborative networks foster synergistic collaborations among diverse stakeholders, including research institutions, businesses, and public authorities from various nations. This multifaceted engagement enhances research productivity and contributes to the successful implementation of innovative solutions by bringing together a rich diversity of perspectives and experiences [59].

On the other hand, the focus on R&I activities emphasizes the development and implementation of innovative or significantly enhanced solutions (e.g., products or services) to address real-world challenges, which contrasts with the traditional focus of R&D on knowledge expansion and basic research. This implies the pursuit of short-term solutions (i.e., closer to the market) that yield a lasting impact [60].

The EU's strategy of utilizing sponsored projects as a primary mechanism to achieve transformative goals in CBE and IS has demonstrated remarkable efficiency and measurability in generating tangible outcomes aligned with policy priorities. The structured framework of these projects enables the clear articulation of specific objectives and the focused implementation of strategies to achieve those goals within defined timelines. This approach is supported by research conducted by Matt et al. (2009), who compared two collaboration patterns—the typical model of EU-sponsored R&D projects and an idealized,

entirely spontaneous collaboration. Their findings revealed that government-sponsored collaborations tend to follow predefined rules, providing a stabilizing influence. As a result, these collaborations generally exhibit greater short-term stability, with fewer premature terminations, but less long-term durability, particularly in successful cases [61]. Additionally, Matt et al. (2009) observed that spontaneous collaborations can generate more critical knowledge, closer to core competencies, and often necessitate the creation of their own operational guidelines. These collaborations can also stimulate interactive learning processes, leading to the development of valuable assets specific to the collective [61]. However, Zamir et al. (2014) highlighted the high failure rate associated with such alliances and emphasized the importance of rigorous analysis, design, management, and evaluation when pursuing such strategic partnerships [62].

4.3. Outputs, Outcomes, and Impacts: Emerging Themes

4.3.1. Analysis of Emergent Themes

The themes that emerged from the content analysis are listed in Table 2. Upon initial examination, it becomes evident that certain themes in R&I CBE projects are more intricately interconnected than others, leading to cause-and-effect relationships that significantly influence project results.

Table 2. Main themes that emerged from interpretive content analysis.

Code	Acronymn	Designation	Definition
1	CB	Capacity Building	Encompasses activities and initiatives aimed at enhancing the capabilities of individuals or organizations in the area of CBE and IS. It can include training programs, workshops, mentoring, and access to tools or technologies. e.g., *"Training and peer-to-peer exchanges were held to build capacity among industrial symbiosis practitioners"*
2	Chl	Challenges	Showcases obstacles and limitations in the project. It can cover economic, technical, and viability constraints. e.g., *"Since [the project] is still at a low level of technological readiness with economic viability constraints"*
3	CL	Collaborative Learning	Refers to the process of individuals or groups coming together (e.g., academia and practitioners) to actively engage in shared learning experiences, allowing them to learn from each other's perspectives. The goal is to enhance collective understanding and improve the overall knowledge base of a group or organization. e.g., *"Living Labs provided innovative arenas for both start-ups, SMEs and large companies to analyze, test and discuss their resource flows and the development of new products"*
4	CE	Community Empowerment	Refers to the collective effort to empower local communities by fostering active participation, education, and support in local activities related to sustainable practices. e.g., *"Establishment of local stakeholder groups to share project outputs and develop local activity"*
5	DO	Dissemination and Outreach	Refers to actively spreading knowledge and information to a wider audience (such as the public, other organizations, policymakers, or specific target groups) beyond the immediate organization or community. It aims to promote awareness, education and engagement. e.g., *"Roadshow events were arranged (. . .) to disseminate all the learnings, articles, policy reports, guidelines and tools created"*

Table 2. *Cont.*

Code	Acronymn	Designation	Definition
6	IDM	Informed Decision Making	Focuses on providing guidance, assistance, and access to information to enable individuals or organizations to make informed decisions to drive sustainable practices. e.g., *"Decision support tool and training kit"*
7	KS	Knowledge Sharing	Refers to the process of distributing knowledge among individuals or groups within an organization or community. It involves making knowledge accessible through various channels, such as conversations, meetings, presentations, workshops, documentation, and digital platforms. e.g., *"Build a shared base of Good Practices for subsequent learning"*
8	KT	Knowledge Transfer	Refers to a specific process aimed at transferring knowledge from one party to another. The emphasis is on the practical applicability of the knowledge that is acquired and transferred, aiming to facilitate the replication or utilization of this knowledge among the project partners, or in other projects or organizations. e.g., *"Cross-border technology guidance and transfer in cast seaweed co-digestion"*
9	MP	Market Potential	Refers to the recognition of commercial value associated with a product or service. It also reflects the intention to enhance product/service attributes, performance, or market competitiveness, focusing on identifying and implementing methods that are both efficient and economically viable. e.g., *"In addition to [biogas company] that is ready to implement the results of the project, other biogas operators were informed, among others (. . .)"*
10	Ntw	Networking	Highlights the social dimension of sustainability, recognizing the importance of building relationships and fostering collaboration to promote effective sustainable initiatives. e.g., *"Screening of resources and matchmaking attracted companies eager to find sustainable green business models"*
11	NI	New Initiatives	Includes cases where the project has led to the development of new initiatives, projects, or endeavours in the field of R&I. It specifically emphasizes the creation of new efforts driven by the activities of the original project. e.g., *"The development of other European projects"*
12	PoD	Policy Development	Represents all activities related to policies formulation, implementation, and evaluation within the context of CBE and IS. e.g., *"The improvement of the regional policies addressing: Production and management of industrial waste; Efficient production processes; Access to innovative technologies and production techniques; Launch of new business strands and penetration of new markets"*
13	PrD	Product Development	Represents the process of creating, improving, or optimizing a product, service, or new technological solutions and processes that contribute to the circularity and efficiency of bio-based systems and IS initiatives. e.g., *"5 improved methods related to collection, pre-treatment and anaerobic digestion of seaweed"*

Table 2. *Cont.*

Code	Acronymn	Designation	Definition
14	SR	Sector Resilience	Focuses on increasing the resilience of sectors involved in the CBE and IS to various challenges and disruptions. e.g., *"The improved concept including improved methods for collection, pre-treatment and anaerobic digestion of cast seaweed was discussed continuously with [biogas company] and is expected to be implemented in the Municipality".*
15	SL	Skilled Labour	Represents the creation of job opportunities for highly qualified individuals within the industry, resulting from the transition of researchers from academia to the industrial sector. e.g., *"Creation of opportunities (direct or indirect) for scientific employment in industry"*
16	SE	Stakeholder Engagement	Refers to the active involvement and collaboration of diverse stakeholders, including local community, policymakers, and decision-makers to promote the CBE and IS. e.g., *"Council meetings acted as a platform for dialogue and policy learning"*
17	SBP	Sustainable Business Practices	Focuses on developing and promoting business models that align with sustainability principles. It includes, green business models, waste valorization, resource optimization, and environmental protection. e.g., *"(. . .) a best-practice example of how a community is already benefiting from using seaweed as a substrate to produce biogas and organic fertilizer, and at the same time benefits from a large number of additional socio-economic benefits"*

CL and CB are particularly intertwined, as evidenced by evidence of the study examples like 'peer-to-peer exchanges' and 'Living Labs', which exemplify their synergistic relationship. CL facilitates knowledge sharing and expertise exchange, while CB enhances practitioner skills and knowledge in CBE/IS. For instance, 'Living Labs' provide a collaborative platform for companies to analyze, test, and discuss resource flows, effectively fostering both CL and CB [63]. Similarly, the themes of IDM and PoD also share a strong connection. IDM based on project results can influence policy decisions, leading to more effective sustainability measures. For instance, if the project identifies sustainable solutions for industrial waste treatment, this information can be utilized to develop more robust regulations and incentivize greener practices across the industry. SE, in turn, serves as a foundational element that reinforces CB, IDM, CL, DO, and Ntw by empowering stakeholders, engaging stakeholders in decision making, fostering knowledge sharing, promoting project results dissemination, and strengthening partner connections, respectively.

Upon thorough examination of the emerging themes, we conducted a comparative analysis with the public investment priorities and funding schemes that supported the analyzed projects. We discovered that several of these themes resonated closely with the specific priorities outlined in the funding criteria (Table 3). The investment priorities emphasized the importance of promoting business investment in R&I, developing innovative technologies for resource efficiency, and supporting the transition to a resource-efficient economy. These priorities align closely with the identified themes of PrD, SBP, and SR, derived from thematic analysis. Likewise, funding schemes such as FP7-NMP, FP7-KBBE, or H2020-EU.1.3.2 demonstrate a dedicated effort to tackle sustainability challenges through research cooperation. These challenges can be illustrated by the themes of CL, CE, or Ntw.

Table 3. Alignment of emerging themes with investment priorities and funding schemes.

Investment Priority/Funding Scheme	Emerging Themes
(01b) Promoting business investment in R&I	Capacity building, community empowerment, networking, skilled labor
(06f) Promoting innovative technologies	Knowledge sharing, knowledge transfer, product development
(06g) Supporting industrial transition	Informed decision making, sector resilience, stakeholder engagement
(11 ETC) Enhancing institutional capacity	Capacity building, collaborative learning, dissemination and outreach, policy development
FP7-NMP—"Cooperation": Nanosciences, Nanotechnologies, Materials and new Production Technologies	Capacity building, collaborative learning, knowledge transfer, networking, product development, market potential
FP7-KBBE—"Cooperation": Food, Agriculture and Biotechnology	Collaborative learning, networking
H2020-EU.3.2.4.3.—Supporting market development for bio-based products and processes	Capacity building, collaborative learning, market potential, networking
H2020-EU.1.3.2.—Nurturing excellence by means of cross-border and cross-sector mobility	Community empowerment, sissemination and outreach, sustainable business practices
CP-FP—Collaborative Projects: Small or medium-scale focused research projects	Capacity building, collaborative learning, knowledge sharing, networking, product development
CP-TP—Collaborative Project targeted to a special group (such as SMEs)	Collaborative learning, knowledge sharing, networking, skilled labor
RIA—Research and Innovation Actions	Capacity building, collaborative learning, knowledge sharing, networking, product development
MSCA-IF-EF-ST—Marie Sokolowski-Curie actions Standard European Fellowships	Dissemination and outreach, skilled labor

A notable example that illustrates how different funding criteria can influence a project's orientation and impact is the DO theme. For example, in our study, in projects funded under the FPs scientific publications were emphasized as the primary short-term output. Conversely, in projects funded under the Interreg Programme, publications carry less weight in this theme. Instead, events like seminars, conferences, and roadshow events hold greater significance for DO. This shift can be attributed to the distinct priorities established by funding organizations, which shape the focus and character of the projects. Within the Interreg Program, projects typically prioritize innovation, technological advancements, and sustainability, placing less emphasis on scientific publications, as evident in MSCA Individual Fellowships under the H2020 framework.

Consistent with this reasoning, it is plausible that investment prioritization may have played a role in the limited emphasis on SL as an emerging theme in Interreg projects, contrasting with FP7 projects, which not only prioritized short-term scientific publications but also highlighted job opportunities as medium-term impacts. Similarly, a study by Ferreira et al. (2021) demonstrated the importance of employment opportunities in the societal impacts of the collaborative project ESGRID (Enhancing Smart Grids for Sustainability) [9].

Apart from the themes that align with investment priorities, other themes also receive support from the existing literature related to R&I sustainability projects in general, illustrating how these themes have been applied in practice. Paula and Abreu (2019) scrutinized the significance of institutional-level CB in driving the evolution of an IS network.

Their analysis underscores the imperative of channeling investments into enhancing the institutional environment, a prerequisite for fostering efficient management of natural resources and waste. This, in turn, facilitates the realization of eco-industrial parks [64]. Conallin et al. (2022), on the other hand, established a significant link between CB and IDM. Their research demonstrates how addressing CB through research enhances the local capacity to produce credible evidence, thereby informing sustainability decision-making processes [65]. Another connection was established by Fassio and Minotti (2019), this time between PoD and the circular economy, which are two emerging yet significant research themes, especially concerning the cities of the future. Specifically, their study centers around utilizing circular economy indicators and strategies to shape urban food policies, aiming to establish a novel business and political model for sustainability [66]. Li and Lange (2022) highlight the crucial role of involving communities in planning, design, and decision-making processes, emphasizing that this approach can lead to better outcomes. Their research, thus, recognizes the significance of CE in accelerating the transition to net-zero carbon emissions and achieving sustainability goals [67]. Lastly, the emergence of the SR theme in our research finds support in the work of Bloesch et al. (2015), who emphasize the importance of the concept of resilience in setting sustainability goals [68].

4.3.2. Analysis of the Frequency of Outputs, Outcomes, and Impacts across TBL Dimensions

During our analysis, a categorization process involved identifying the primary benefits expressed in each response (i.e., outputs, outcomes, and impacts cited by participants) and classifying them based on their influence on the People, Planet, or Profit dimension.

Two striking features emerged from this analysis: the overall high frequency of outputs and outcomes, particularly in the People dimension, and the high frequency of impacts in the Profit dimension (Figure 2). These findings suggest a strong commitment within the projects studied in our sample to generate tangible benefits for individuals in the short and medium term, while simultaneously cultivating enduring advantages for businesses in the long run.

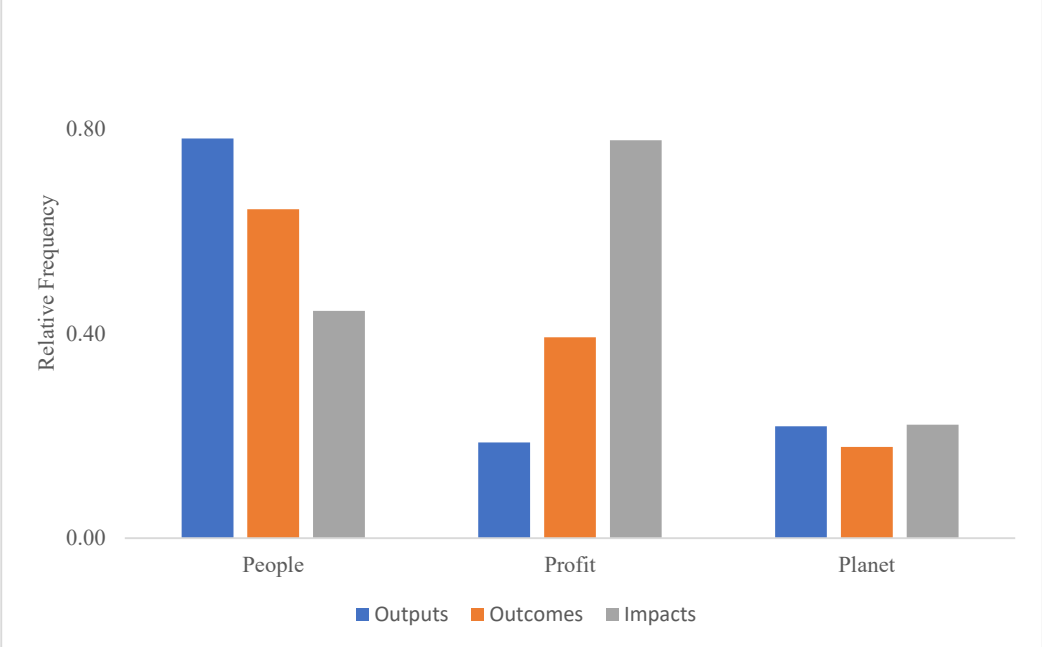

Figure 2. Benefits of collaborative R&I projects in circular bioeconomy and industrial symbiosis: distribution of outputs, outcomes, and impacts.

In comparison, the Barbosa et al. (2023) study on university–industry collaboration (UIC) projects revealed a somewhat different pattern. Their research indicated a higher

frequency of outcomes and impacts, while outputs were relatively less prevalent. However, UIC projects also have broader positive effects on society and the economy beyond direct outputs, highlighting their ability to transcend mere results and deliver wider-ranging benefits [37].

Regarding the emphasis placed on these outputs and outcomes within the "People" dimension, signifies a robust commitment to achieving tangible benefits for communities, workers, and direct stakeholders in the context of CBE and SI. This reflects the growing recognition within the EU of the need for innovation to address societal challenges and contribute to the well-being of citizens. For instance, the EU's R&I Framework Programmes, such as H2020 and its successor Horizon Europe, have been designed not only to advance scientific knowledge but also to foster innovation and deliver societal benefits [69]. As a result, R&I projects are expected to concentrate on societal impact, benefiting individuals, organizations, and nations [37].

In terms of impacts, a significant surge was observed in the Profit dimension, surpassing the growth in other dimensions. This could be construed as a potential trade-off between immediate benefits for individuals and enduring gains for companies. Nonetheless, of the three categories of results, impact is the most challenging to evaluate. This is primarily due to the inherent difficulty in accurately assessing long-term effects, which often require extended periods of observation. Whether influenced by this time constraint or not, in our study impact assessments tend to reflect potential impacts rather than actual realizations. While outputs and outcomes are more tangible and easily measurable concepts, impact is inherently more complex to quantify. This is evident in statements such as "*Concrete impacts of the project are difficult to indicate. The goal is that policymakers take up the results of the project and use them in developing Circular Economy strategies, plans, and projects. I don't know to what extent this has been done*" [CIRCTER project].

In the upcoming sections, we will delve into each of the TBL dimensions to analyze in more detail the emerging themes within the outputs, outcomes, and impacts that carry the most significance.

4.3.3. Outputs, Outcomes, and Impacts Affecting the People Dimension of the TBL

Figure 3 presents the relative frequency of several themes in the People dimension of the TBL framework across the outputs, outcomes, and impacts categories.

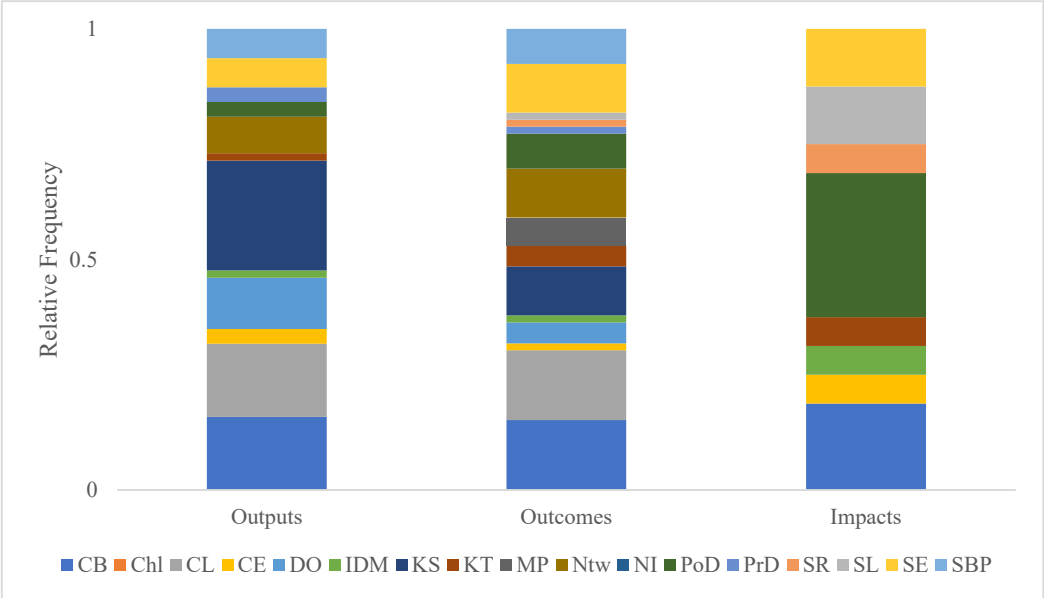

Figure 3. Social benefits: distribution of emerging themes in collaborative R&I project results within the circular bioeconomy and industrial symbiosis.

It is apparent that within the outputs category affecting the People dimension, the KS theme emerges as the most significant contributor, closely followed by CL and CB. In terms of outcomes, while KS decreases in prominence, CL and CB continue to play a significant role in this category. As for impacts, PoD emerges as the most frequently mentioned topic by far.

The theme of KS emerging as the most prevalent in outputs underscores the projects' strong dedication to sharing and disseminating information across various partners and stakeholders within the consortium. For instance, one participant highlighted "*Interregional thematic workshops to explore good practice*" [TRIS project] as an example. These workshops serve as platforms for participants hailing from different regions to exchange knowledge, experiences, and best practices pertinent to CBE/IS. A multitude of similar feedback underlines the prominence of KS in the answers. Indeed, prior researchers have already emphasized the significance of KS among team members and/or external partners to achieve successful collaborations [70].

On the other hand, the prominence of the CL and CB themes in the outcomes signifies the projects' aspiration for sustained learning beyond the initial exchange of knowledge. A participant stated that "*Successful training programs were developed and implemented based on close cooperation between the BIS partners from academia, and all training sessions were customized to each region in dialogue with the local BIS partners*" [BIS project]. The inclusion of the term "*successful*" in this context attests to the programs' effective accomplishment of their intended objectives, with customization tailored to accommodate the distinctive needs and contexts of each region. Moreover, the mention of "*close cooperation between project partners*" underscores a collaborative approach in the formulation and execution of impactful training initiatives, thus underlining a robust emphasis on CL. This cooperative strategy suggests a concerted effort to cultivate an environment where expertise and insights are collectively shared and applied. It is noteworthy that Back and Kohtamäki's study (2016) accentuates the vital role of motivation and mutual trust in catalyzing this dynamic process of joint learning in the realm of R&D collaborations [71].

The customization of training sessions for individual regions reflects an endeavor to equip participants with the requisite knowledge and expertise to apply their learnings, underscoring a focus on CB effectively. This facet assumes significance in empowering individuals and organizations within the realm of IS and is a pivotal ingredient for ensuring long-term impact, thereby fostering societal advancement.

This idea finds support in the research of Merino and Carmenado (2012), who assert that within rural development projects CB might carry more significance than the conventional technology transfer system. This is due to its notable impact on the sustainability of projects, thereby contributing to both economic growth and social development [72].

Last but not least, the prevalence of PoD as the most frequent theme in impacts with benefits in the People dimension underscores a robust connection between R&I projects and the realm of policymaking. For instance, a notable statement from a participant highlights this connection: "*ARDIA-Net was a concrete and impact-oriented contribution to turn S3 (and now S4+) principles into practice*" [ARDIA-NET project]. ARDIA-NET's emphasis on translating Smart Specialization Strategy (S3) principles into tangible practice further underscores its involvement in PoD. By endeavoring to implement these principles, the project manifests its dedication to propelling effective and targeted R&I policies within the Alpine region. This signifies ARDIA-NET's active engagement in influencing the formulation and execution of policies that promote impactful advancements, benefiting both the involved communities and organizations, as well as fostering broader societal progress.

4.3.4. Outputs, Outcomes, and Impacts Affecting the Profit Dimension of the TBL

Figure 4 presents the relative frequency of several themes in the Profit dimension of the TBL framework across the outputs, outcomes, and impacts categories.

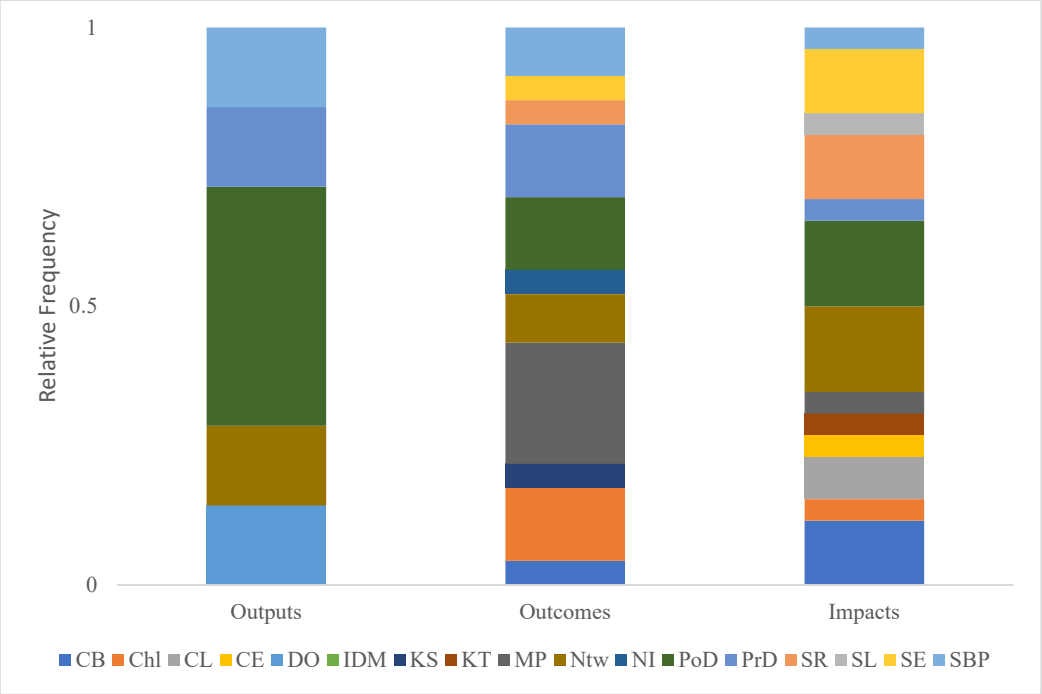

Figure 4. Economic benefits: distribution of emerging themes in collaborative R&I project results within the circular bioeconomy and industrial symbiosis.

In the outputs category, PoD emerges as the most prevalent theme. As we move into the outcomes category, MP take the lead. Within the impacts category, the themes exhibit a more balanced distribution, with PoD and Ntw receiving a slight emphasis.

These results suggest that PoD plays a significant role in enhancing profitability by shaping initial strategies and actions. This can involve developing blueprints, launching pilot calls, and creating pre-normative documents, as illustrated by the ARDIA-NET and STAR-ProBio projects.

A blueprint typically represents a detailed plan or guide for the development and implementation of policies, strategies, or initiatives [73]. In this context, the "blueprint" mentioned is related to the establishment of a policy framework or strategy for promoting and supporting CBE, particularly in terms of funding schemes, resource allocation, and coordination of innovation activities. Along the same lines, a "pilot call" is an initiative launched by funding agencies or organizations to support innovative projects or research ideas through funding or support. In this case, ARDIA-NET aims to identify and invest in projects with the potential to generate economic growth and profitability in areas related to CBE and IS (see project website at "https://www.alpine-space.eu/project/ardia-net/ (accessed on 31 January 2024)". Moreover, the development of a pre-normative document within the STAR-ProBio project marks a notable advancement in the business's pursuit of profitability. This achievement is primarily attributable to the document's ability to enhance market access, reduce regulatory uncertainty, and bolster consumer trust, all of which ultimately foster investor attraction and innovation promotion.

Compellingly, MP is the most prevalent theme in the outcomes category, indicating a strong focus on increasing market share and commercialization potential. This suggests that PoD indeed bears significant implications for market penetration or augmenting the commercialization potential of the products and/or services crafted throughout the projects of our sample. In addition, this finding aligns remarkably well with the essence of H2020 Programme, which has a strong focus on supporting research that is closer to the market [74].

Within the impact category, the presence of PoD and Ntw reinforces the notion that the policies formulated and the networks established during collaborative projects yield

lasting implications for financial growth and sustainability [75]. For instance, the "*ARDIA-Network, a kind of legacy of this project, could identify and promote future RDI cooperation, support a new call, administrate matchmaking platforms, as well as facilitate contacts within and with other regions*". While the impact remains anticipatory rather than realized, there is a strong likelihood that the ARDIA-Network can generate economic opportunities for businesses and organizations in the participating regions. By facilitating contacts and collaboration, it can facilitate partnerships and joint endeavors, potentially leading to business expansion, innovation, and broader market reach.

4.3.5. Outputs, Outcomes, and Impacts Affecting the Planet Dimension of the TBL

Figure 5 presents the relative frequency of several themes in the Planet dimension of the TBL framework across the outputs, outcomes, and impacts categories.

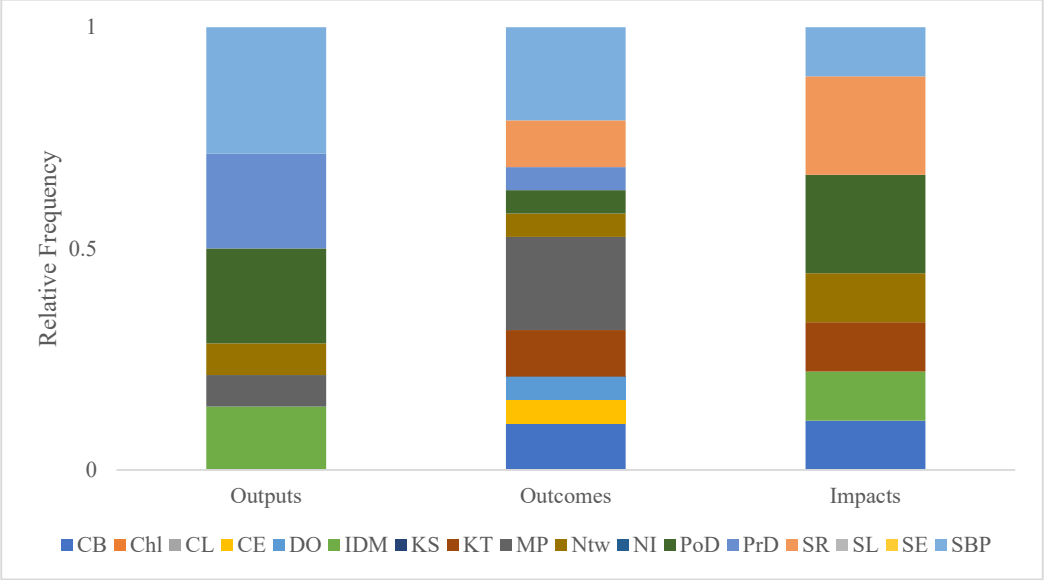

Figure 5. Environmental benefits: distribution of emerging themes in collaborative R&I project results within the circular bioeconomy and industrial symbiosis.

It can be observed that the themes SBP, PrD, and PoD stand out as the most prominent in the outputs category. In the outcomes category, SBP and MP have the greatest weight. As for the impact category, PoD and SR clearly distinguish themselves from the other themes. One interesting observation is the decreasing trend in the SBP theme as we progress from outputs to impacts.

The emphasis on SBP, PrD, and PoD within the outputs category suggests that these projects are aiming to create systemic changes that promote sustainable practices and environmentally friendly products. These outputs are likely to yield positive implications for the planet, as they contribute to reducing resource consumption, minimizing waste generation, and promoting eco-friendly production methods. This notion is exemplified by feedback such as "*One improved and one new concept/solution for nutrients removal*" [COASTAL project]. The incorporation of enhanced and innovative concepts/solutions for nutrient removal holds the promise of boosting water quality, mitigating nutrient pollution, and advancing environmental sustainability.

The observed pattern in the outcomes strongly indicates that the adoption of SBP is indeed leading to tangible environmental advantages. A participant from the COASTAL project shared a significant insight. They emphasized, "*In addition to biogas company that is ready to implement the results of the project, other biogas operators were informed (. . .) about environmental benefits, aspects to be considered and a best-practice example of how a community (. . .) is already benefiting from using seaweed as a substrate to produce biogas and organic fertilizer, and*

(. . .) benefits from a large number of additional socio-economic benefits" [COASTAL project]. These eco-friendly practices not only have positive environmental impacts but also create market opportunities for eco-friendly products like biogas and organic fertilizer, as evidenced by the MP aspect, which encourages a shift towards more sustainable consumption behaviors.

All of these outputs and outcomes, carrying the potential for environmental benefits, resonate harmoniously with the findings presented in Alam's et al. (2019) study [76]. For instance, Alam's research conclusively highlights that R&D investment contributes to the enhancement of environmental performance among firms engaged in collaborative projects. This improvement is particularly evident in metrics such as energy intensities and carbon emissions [76].

Regarding the long-term benefits, the SR theme underlines the projects' ability to bolster the resilience of specific sectors or industries when facing environmental challenges. Activities within the COASTAL project, involving biogas plants, municipalities, and other stakeholders, exemplify a focus on enhancing the resilience of the biogas sector: "*The improved concept including improved methods for collection, pre-treatment and anaerobic digestion of cast seaweed was discussed continuously with [biogas company] and is expected to be implemented in the Municipality*". By integrating the enhanced concept and disseminating knowledge, the project contributes to building a more robust and sustainable biogas industry in the region. Intriguingly, the work of Korhonen et al. (2021) delves into the notion of cross-border regional innovation systems (CBRIS) to probe the consequences of global and regional changes on cross-border regions. A noteworthy conclusion from their study is the often-overlooked significance of addressing the resilience and sustainability of CBRIS, emphasizing an area that warrants greater attention [77].

Moreover, the PoD theme, once again prominently featured within the impacts category, sheds light on how projects also wield influence over the implementation of environmentally conscious policies and regulations. The City of Birmingham, the TRIS project leader, articulated, "*In the long term, BCC (Birmingham City Council) will aim to develop its Circular Economy by working regionally with the West Midlands Combined Authority (WMCA)*". This reflects a PoD focus, as BCC seeks to collaborate with a regional authority to shape policies and initiatives related to IS practices. It exemplifies BCC's commitment to fostering an enabling environment for IS practices in the long run. These policies can have far-reaching effects on the planet by fostering sustainability practices at a broader level, positively impacting ecosystems, natural resources, and overall environmental health.

In contrast, the decreasing trend in the SBP theme might indicate that while the projects initially focus on implementing sustainable practices in the short term, their long-term impacts on the planet's health may take more time to fully materialize and become evident in the broader context of sustainability, which raises the importance of continuous monitoring and evaluation to better understand the enduring effects of these projects on sustainable practices.

5. Conclusions

This study comprehensively assessed the impact of EU-funded R&I projects on sustainability by promoting the deployment of CBE practices, according to the perspective of the surveyed project leaders.

Firstly, an analysis of emerging themes from the content of questionnaires suggests that publicly funded R&I projects actively foster a conducive ecosystem for the adoption of CBE (RQ1). Themes such as knowledge sharing, capacity building, and collaborative learning empower stakeholders, facilitating their active engagement in the transition. Furthermore, these themes align directly with the investment priorities and funding schemes supporting R&I projects, reinforcing their efficacy in promoting CBE practices.

Secondly, the study also revealed a distinct distribution of benefits across the three dimensions of sustainability: social, economic, and environmental (RQ2). In the short and medium term, the focal point of benefits primarily resides within the social dimension. Short-term project outputs exemplify a robust commitment to empowering individuals,

fostering collaboration, and enriching knowledge. These endeavors have the potential to yield medium-term outcomes, including increased knowledge and skills, enhanced collaboration and networks, effective policies and solutions, empowered individuals and communities, and successful cross-sectoral collaboration. Long-term benefits predominantly contribute to the economic dimension. Despite persistent challenges, the assessed R&I projects underscore substantial potential for positive economic impacts by promoting business growth and innovation, enhancing market efficiency, and fostering sustainability. While environmental benefits may take time to materialize due to their systemic nature, themes such as sector resilience suggest a positive trajectory towards future environmental improvements arising from these R&I projects.

In light of the study's conclusions, policymakers can derive key policy implications. Firstly, they should endorse collaborative ecosystems by supporting publicly funded R&I projects that actively facilitate a conducive environment for CBE practices. This involves prioritizing knowledge sharing, capacity building, and collaborative learning, aligning investment priorities and funding schemes with these objectives. Secondly, policymakers should recognize and balance the distribution of benefits across social, economic, and environmental dimensions resulting from R&I projects. While short- and medium-term benefits are predominantly social, the long-term contributions significantly impact the economic dimension. Effective policymaking should aim for a balanced approach, acknowledging both immediate social impacts and the enduring economic benefits of R&I projects promoting CBE. Thirdly, policymakers can contribute to enhanced sustainability results by emphasizing sector resilience as a crucial theme in R&I projects. Despite the acknowledgment of the time required for environmental benefits to manifest, a focus on sector resilience suggests a positive trajectory toward future environmental improvements. Supporting projects that strengthen the resilience of sectors involved in CBE practices aligns with long-term sustainability goals.

One potential limitation of this study is its reliance on self-reported data from project leaders, introducing the possibility of response bias or a tendency to portray projects positively. Furthermore, the study did not employ quantitative methods to gauge stakeholder involvement, potentially limiting the depth of understanding regarding the level of stakeholder engagement fostered by the R&I projects. Additionally, the study may not fully capture the diverse range of experiences or perceptions among all stakeholders involved. Another limitation is temporal bias and the challenge of providing a comprehensive long-term impact assessment. While the study emphasizes short- and medium-term results in the social dimension, predicting or evaluating long-term economic and environmental impacts poses challenges.

Future research could integrate multi-stakeholder interviews, encompassing perspectives from other involved stakeholders, such as participants, collaborators, and end-users. This approach aims to triangulate data from diverse sources, providing a more robust validation of reported impacts through various project contributors. Additionally, conducting longitudinal studies to monitor social, economic, and environmental impacts over an extended period would enhance understanding. Integrating scenario analysis or modeling techniques could explore various potential trajectories of long-term impacts, adding depth and foresight to the assessment.

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