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A Multi-Dimensional Framework for Assessing the Societal Benefits of Collaborative R&I Projects Over Time

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Abstract

This paper contributes to the ongoing discussion on assessing the actual societal benefits of collaborative research and innovation (R&I) projects, focusing specifically on Circular Bioeconomy (CBE) initiatives funded under European Interreg programs. Utilizing an abductive method aligned with a grounded theory approach, the study conducted a multiple case study of five cross-border CBE projects. Data from project leaders and secondary sources underwent inductive content analysis and were classified using the Triple Bottom Line (TBL) framework. Seven cross-cutting benefit categories emerged: capacity building, collaborative learning, community empowerment, networking, knowledge sharing, policy development, and sustainable business practices, identified as influencing results across TBL dimensions temporally. Findings reveal projects excel at generating short/medium-term outputs and outcomes strongly aligned with the social dimension, particularly through capacity building, collaborative learning, and knowledge sharing. Over time, long-term impacts demonstrate a more balanced distribution across all three TBL dimensions (social, environmental, and economic), indicating a trajectory towards broader benefits. Policy development and networking are emphasized as key drivers for achieving significant long-term, multi-dimensional impacts. This study introduces a novel, empirically grounded, multi-dimensional theoretical model. By inductively categorizing benefits and analyzing their temporal manifestation across TBL, it provides a practical framework for assessing comprehensive societal impact beyond conventional output metrics.

Keywords:

Collaborative Research and Innovation Projects;

Societal Impact;

Circular Bioeconomy;

Triple Bottom Line;

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1- Introduction

The current unsustainable 'take-make-dispose' economic model is straining the planet's resources. The Circular Bioeconomy (CBE) offers a promising alternative, promoting renewable biological resources and minimizing waste by keeping materials circulating within the economy for longer and minimizing environmental impacts [1]. Industrial symbiosis (IS), a crucial element of the CBE, involves creating cooperative networks among industries. These networks facilitate the sharing of resources, energy, and knowledge to enhance resource efficiency and reduce waste production [2]. To advance a CBE through IS, collaborative research and innovation (R&I) projects have become essential catalysts for transformation. These initiatives unite multidisciplinary teams comprising industry professionals, researchers, policymakers, and other stakeholders to create innovative technologies, practices, and solutions. Through collaboration, R&I projects are particularly suited to address complex challenges and can promote the adoption of sustainable and circular industrial practices [3]. However, while the importance of collaborative R&I projects in advancing sustainability is widely recognized [4], there is a need to assess and evaluate their actual benefits comprehensively. Understanding the effects and broader implications of these projects is essential to refine strategies, allocate resources effectively, and maximize their contribution to sustainable development.

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Collaborative projects, particularly those involving diverse organizational partnerships, are recognized for their significant potential to drive innovation [5]. Such initiatives have been demonstrated to positively impact innovative performance, especially concerning product and process innovation [6-8]. Several factors are critical to enhancing project performance. These include equitable benefit distribution, effective management of resource dependence, a supportive organizational climate, and robust collaborative innovation capability. Effective communication, leadership support, and knowledge sharing also play crucial roles in this dynamic [9]. Furthermore, the innovation experience of partnering firms, adept management of rules and regulations, and a commercial focus in R&I projects significantly influence outcomes [6]. The economic benefits of extensive collaboration are underscored by the positive direct effect of R&I subsidies and the breadth of organizational involvement on innovation output [10]. Public funding frameworks, such as the EU Framework Programs, are instrumental in creating diverse research networks that enhance the full potential of innovations [5]. Indeed, R&I policies are increasingly shifting focus from purely economic impacts to addressing grand socio-political challenges [11].

Collaborative projects contribute significantly in this arena by fostering environmental sustainability, creating jobs, and reducing energy costs. They can support the development and market uptake of new technologies, such as smart grids, which promote energy efficiency. Technologies developed in these settings can also yield long-term societal benefits, such as mitigating climate change [12]. The societal impact of research is further amplified through transdisciplinary and participatory projects that involve extra-academic partners, thereby extending collaboration beyond traditional scientific boundaries. This approach helps achieve societal goals, even if direct epistemic outcomes are not the primary objective [13]. Knowledge diffusion is another key aspect, with research networks fostering the dissemination of innovation-related knowledge by complementing existing diffusion networks and increasing engagement in knowledge exchange [14]. Collaboration, particularly with public research institutions, fosters this diffusion, though it can also raise innovation costs due to appropriability concerns and coordination difficulties [15]. The mechanism of knowledge diffusion is also influenced by network characteristics such as density and project roles [16].

However, collaborative R&I projects face notable barriers. These include a lack of confidence, financial constraints, trust issues, and challenges in commercializing results, especially for projects addressing specific market needs such as silver markets [17]. Geographic diversity, while fostering diverse networks, can introduce coordination challenges [5]. The cost of innovation might also increase due to leakages of strategic information [15]. Furthermore, structural barriers such as increased competition for resources, heightened steering of research, and the casualization of research workers can hinder success [18]. Stronger support from funding organizations is often crucial to help collaborative projects overcome their inherent challenges [17].

To navigate these complexities and enhance societal impact, frameworks such as the research impact quintuple helix model [11] and pathway models [19] can be utilized. These models emphasize policy alignment, societal engagement, and sustainable practices. However, empirical studies are needed to further develop, validate, and refine theoretical models [19]. Also, there is a continued need for research to understand the complex mechanisms through which collaboration leads to impact [9, 19-21]. Specifically, more systematic research is needed on the combined impact of tangible and intangible factors on project performance [9].

Europe is a global leader in shaping policies for the CBE transition (e.g., the Green Deal strategy), with collaborative R&I being crucial for its success. In particular, the Interreg Programme, co-funded by the European Regional Development Fund (ERDF), stands out as a key instrument to foster cross-border collaboration towards sustainable growth. While these collaborative R&I projects have demonstrably increased research output in the form of publications and patents [22], there is an important gap in the literature regarding empirical evidence of their actual societal impact in the CBE area [23].

To address these gaps, this study seeks to answer the following research question: "Are EU-funded collaborative R&I projects effectively delivering societal benefits in the CBE context?"

In seeking an evidence-based answer to this question, a stakeholder-centric, abductive approach aligned with grounded theory was used. Insights from project leaders were collected to capture a nuanced understanding of their successes. A multiple case study approach was used based on five cross-border CBE-focused collaborative R&I projects funded under the Interreg Programme. This funding instrument was chosen due to its local/regional intervention dimension in supporting cooperation across borders. This aligns with the local/regional focus on CBE, aiming to empower local communities, provide customized solutions, and decrease the reliance on transporting biomass.

This paper adds to the ongoing discourse on evaluating the real benefits of collaborative R&I projects by introducing a novel multi-dimensional theoretical model. This model, grounded on empirical data, goes beyond the common reliance on scientific and economic output metrics. By evaluating the results of these projects, this study seeks to provide useful insights into the effectiveness of collaborative R&I projects as a public driver for the CBE. These findings are valuable for both policymakers and practitioners. The former can use the findings to redesign science policies and funding instruments that optimize the use of public funds to drive an impactful CBE. The latter can use the study findings to develop collaborative R&I projects focused on realistic outputs, outcomes, and, notably, impacts.

Following this introduction, the background section provides context on the CBE, IS, and the role and benefits of collaborative R&I. The methods are then detailed, with a multiple case study approach aligned with grounded theory. The results section presents the key benefit categories identified from empirical data. The paper then discusses these findings in the context of the effective delivery of societal benefits and develops a theoretical model for these benefits. Finally, the conclusions summarize the study's contributions and implications for policymakers and practitioners accelerating the transition to a thriving CBE.

2- Background

2-1- Circular Bioeconomy and Industrial Symbiosis

CBE and IS both hold the promise of enabling collaborative efforts for more sustainable resource management. The CBE merges the ideas of the bioeconomy and the circular economy. The bioeconomy prioritizes the use of renewable resources, whereas the circular economy emphasizes resource conservation [1]. At their intersection, the CBE focuses on reusing waste flows from renewable bio-resources, such as biomass or biowaste, within a closed-loop system. This process supports the creation of innovative bio-based products and services [24]. Thus, the CBE effectively addresses the interconnected issues of environmental degradation, resource scarcity, and climate change while fostering economic growth [25].

IS prioritizes collaboration among diverse industries. This approach facilitates mutually beneficial exchanges, where waste or by-products from one sector become valuable resources for another [2]. The CBE framework particularly highlights the benefits of IS for industries reliant on biological resources or those generating biowaste. IS practices enable the transformation of agricultural residues or food processing by-products into valuable resources, such as feedstock for bioenergy production or high-value bio-based products [26].

Both CBE and IS drive a transformation away from linear and wasteful practices towards the adoption of circular systems characterized by core principles such as resource efficiency, waste reduction, and value chain optimization [27]. The CBE involves maximizing the value extracted from each unit of input by using resources in a cascading flow [28]. IS also embraces resource efficiency by fostering collaboration and resource sharing among different organizations [2]. In terms of waste reduction, the CBE aims to minimize waste generation throughout the entire lifecycle of products and materials. It advocates for a closed-loop system where materials and waste are continuously circulated and reused, eliminating the concept of waste [28]. IS complements this by transforming one organization’s waste or by-products into inputs for another, reducing the need for disposal [2]. Moreover, it considers the entire chain of activities involved in delivering a product or service, including sourcing, production, distribution, and end-of-life management. Thus, value chain optimization, driven by IS, aims to enhance efficiency and value creation by analyzing and improving each step of the chain [29].

The implementation of the CBE requires the development of specialized knowledge and technologies. The scientific community has been prolific in this regard, with the number of publications and patents significantly increasing in the last decade [24]. However, the actual benefits of CBE to society at large lack visibility and are mostly focused on economic aspects [24]. Therefore, the need exists for further evidence of the wider societal benefits of CBE initiatives.

2-2- Supporting CBE through Collaborative R&I

Collaborative research gained momentum in the post-World War II era when collaborative projects became increasingly common as governments, research institutions, and industry recognized the benefits of shared resources and expertise in driving technological advancement. Collaborative R&I projects have since expanded and proven to be effective tools for bringing together diverse stakeholders to achieve common goals [4]. These initiatives are often launched to tackle intricate problems, stimulate groundbreaking advancements, and expedite the creation and implementation of novel technologies, products, or services [30]. In the context of CBE, collaborative R&I projects can play a vital role in driving the development and implementation of IS practices. Particularly, collaborative R&I projects and IS share a close relationship, as they both involve cooperation and resource sharing among different entities [3].

The European Union (EU) prioritizes the CBE as a strategic tool to achieve a climate-neutral future as outlined in the Green Deal, supported by policies like the Bioeconomy Strategy and the Circular Economy Action Plan [31]. Additionally, the EU recognizes IS as crucial for resource efficiency and economic growth, exemplified by initiatives such as the Circular Bio-based Europe Joint Undertaking [32].

The bulk of funding allocated to EU-funded collaborative R&I endeavors flows through two principal channels: the Framework Programs (FPs), notably the ongoing Horizon Europe, and the EU's cohesion policy supported via the European Structural and Investment Funds (ESIF). Within ESIF, the ERDF stands out as the predominant source, accounting for 95% of the R&I funding allocation [3]. The primary aim of these core R&I funding schemes is two-fold. Firstly, they seek to enhance European excellence in science and technology by fostering cross-border collaboration among European organizations. Secondly, they aim to bolster the competitiveness of EU regions by championing intelligent, inclusive, and sustainable growth [33].

Interreg programs and projects are recipients of ERDF funding, boasting a substantial budget of EUR 359 million allocated for the current active Interreg period spanning from 2021 to 2027 [3]. The Interreg framework encompasses a collection of strategically designed programs that promote cooperation and collaboration between European regions. These programs target either cross-border or transnational cooperation, enabling partnerships between neighboring regions or countries. Investments are prioritized in projects that drive innovation, promote sustainable development, and ultimately improve the overall quality of life. Thus, the rationale behind the Interreg programs is aligned with the local/regional focus of CBE on the need to minimize the transportation of biomass, develop tailored solutions, and empower local communities.

The consequences of enhanced cross-border R&I cooperation have been studied by Korhonen et al. [34]. These authors explore the concept of cross-border regional innovation systems, examining the impact of global and regional changes on these areas. A significant finding from their study is the frequently neglected importance of enhancing the resilience and sustainability of these systems, highlighting a critical area that requires more focus [34]. Thus, the existence of actual benefits of cross-border R&I initiatives, exemplified by EU-funded projects, and their delivery of added value to society at large demands the collection of empirical evidence. These insights can inform the development of more effective and efficient public policies and funding instruments dedicated to the development of resilient and sustainable cross-border regions.

2-3- Benefits of Collaborative R&I Projects

‘Outputs’, ‘outcomes’, and ‘impacts’ represent the three categories of results commonly associated with the benefits of R&I projects [35]. The actual definitions of these terms can vary, but the most consensual versions are those aligned with the Organization for Economic Co-operation and Development concepts [12, 36]: a project generates tangible deliverables such as products and services (outputs); these lead to intended and unintended short- and mid-term effects (outcomes); finally, the project's long-term consequences, positive or negative, are its impacts. 'Results' sometimes encompasses all three. The growing emphasis on the social value generated by R&I investments has not only heightened the pressure to hold researchers accountable for delivering these benefits but also increased the political demand for demonstrating their impact [37]. Scientific outputs, such as publications and patents, or economic outcomes, such as the implementation of new production lines, are no longer considered sufficient results [4]. Successful projects are increasingly expected to effectively demonstrate their societal impact, i.e., their benefits on society at large [23, 36-38].

Collaborative R&I is seen as an effective approach to drive innovation and accelerate the discovery and development of new technologies, processes, products, or services [39], increasing the inimitability of the resulting technology [7]. Publicly funded collaborative R&I schemes are found to confer positive benefits in terms of innovation outputs [7]. Studies show that collaborative projects can lead to large numbers of patents and innovations [7, 10, 40]. Furthermore, these projects are effective in promoting knowledge diffusion [16, 41] and the cross-fertilization of knowledge and technologies [42], which can drive technological advancement [19] and provide solutions for innovation [43], including overcoming key technological challenges [44]. Organizational diversity (heterogeneity of partner types) has a positive effect on innovation potential, while geographic diversity may have a negative effect [41].

Collaborative R&I projects contribute significantly to long-term economic growth [7]. They can generate more business and new products, leading to profit from implemented results, and improve existing products [39]. Positive impacts on the economic performance of participating firms, such as profitability or employment change, have been explored in impact assessment studies [5, 41]. Benefits for participating enterprises include micro-economic benefits [7]. Collaboration accelerates the commercialization of scientific and technological achievements [44] and can lead to market impact [45, 46]. Furthermore, research networks can lead to the creation of new firms that emerge during the collaborative efforts and spur regional or national wealth and competitiveness [41]. Collaborative projects, when coordinated by private or public organizations, may also increase the likelihood of securing more funding [45]. They can also generate crowding-in effects on the total availability of R&I funding and on the level of companies' R&I investments [7].

Collaborative R&I facilitates knowledge creation and transfer [19, 44] and is an effective way of resource integration and knowledge interaction [10]. Benefits include access to tacit and codified knowledge and to costly and complex equipment [46], creating knowledge capital [39], and being effective for both the creation and diffusion of knowledge and technologies [41]. Collaboration provides an interface for knowledge sharing, transfer, and absorption [10, 47]. It can lead to gaining new knowledge and skills [21] and enhances an organization's absorptive capacity [7], which is the ability to integrate both internal and external knowledge [7, 44]. Interdisciplinary learning and collaboration are also fostered [19, 44, 48]. Accessing a broader network of knowledge sources and competences [41] and fostering scholarly dialogue through various dissemination methods [19] are additional knowledge-related benefits. The multidisciplinary nature of projects contributes significantly to the cross-fertilization of knowledge [42]. The network's relational characteristics (tie strength) and structural characteristics (network range and density) are important determinants of knowledge transfer and diffusion [16, 49]. Strategic positioning in R&I collaboration networks favors knowledge access [50].

One frequently addressed benefit of collaborative R&I projects in the literature is the increasing citation impact of scientific knowledge [46]. Publications resulting from research collaboration are likely to have a higher impact (citations) than publications without collaboration [8, 46]. International collaboration has been found to boost the quantity of articles published and, to a smaller degree, the ranking of journals published in Al-Abbas & Saab [51]. Collaborative efforts support scientific excellence by attracting top scientists and institutions [7] and foster cross-disciplinary interaction [19]. Doctoral students participating in collaborative university-industry projects have been found to achieve higher performance in terms of the number of publications and citations [20]. Collaborative research is also critical for advancing scientific knowledge, with basic research influencing policy decisions [19].

Benefits occur when research generates impact beyond the academic knowledge base, including social and environmental impacts [7, 52]. Research benefits assessment now encompasses a broader evaluation that scrutinizes how research influences policy development, drives innovation, and enhances societal welfare [19]. EU policy prioritizes societal needs, promoting R&I investment for the benefit of its citizens. Collaborative innovation practices have been found to deliver positive outcomes in public service reform [48]. Collaborative R&I aims to extend its scope beyond academic achievements by aligning activities with broader societal needs and environmental considerations [19]. This includes addressing real-world challenges and delivering social benefits [5].

Factors influencing collaborative innovation project performance include benefit distribution, collaborative innovation capability, resource dependence, organizational climate, effective communication, leadership support, knowledge sharing, and the incentive mechanism [9]. Trust and commitment also play important roles. Familiarity among partners and a positive attitude towards exploiting results contribute positively [7, 53]. A holistic technology transfer approach and practices such as seconding scientists to SMEs can be major factors in generating positive results [43]. R&I subsidy is found to have a positive effect on innovation output and collaboration breadth [10]. Supporting national policies and institutional frameworks act as catalysts for partnerships, enhancing research relevance and societal benefits [19]. Policy alignment with societal needs and investment priorities is also relevant [19].

The theoretical landscape surrounding the benefits of collaborative R&I projects is evolving, extending beyond traditional academic measures to encompass broader societal, economic, and environmental significance [19]. Current approaches emphasize that understanding benefits requires considering the complex dynamics and mechanisms within collaborative settings, such as knowledge transfer and diffusion facilitated by network characteristics such as density and partner roles [10, 15, 16, 49]. Frameworks such as the quintuple helix model are emerging to provide a holistic perspective, integrating diverse elements such as research, publication, researchers, institutions, and countries to analyze how strategic collaborations across different sectors foster synergies and contribute to wider outcomes [19, 54]. Additionally, theories drawing on resource-based and organizational learning views highlight how internal capabilities, such as absorptive capacity and prior experience, are crucial for participants to derive innovation impacts from collaborative efforts [7, 10, 55]. This collective body of work underscores the multifaceted nature of collaborative benefits and the need for comprehensive theoretical models to capture its complexity.

Various approaches and frameworks have been used or proposed for assessing the impact of collaborative R&I, including the Payback Framework, Research Impact Framework, societal impact assessment methods such as SIAMPI, the UK Research Excellence Framework (REF), electronic databases (e.g., Researchfish®), and Balanced Scorecards for measuring the impact of university-industry collaboration [20, 52]. In another example, the Innovation Radar Survey was specifically designed to measure the innovative output of EU-funded collaborative projects [53]. Common methods to measure research impact include peer review, return of investment, financial data analysis, number of patents and publications, and satisfaction surveys [39]. However, focusing solely on tangible outputs such as product and process innovation may underestimate significant intangible outputs such as the development of new capabilities and knowledge acquisition [6]. Other assessment approaches include that of Hiruy & Wallo [38], who illustrated the use of Social Impact Assessment to measure the benefits of research projects on fisheries across Southeast Asia and the Pacific Island countries. By using a survey, interviews, and case studies, these authors illustrate that this tool can offer a multi-perspective understanding of changes, for example, in governance, politics, culture, economy, and community health and wellbeing.

In another example, Aiello et al. [35] reported on how the social impact of social sciences and humanities research can be enhanced. They concluded that gathering empirical data, such as collaboration with stakeholders, use of projects' findings, and the effects of their implementation, is key to tracking the project's social impact. In yet another example, Germundsson et al. [56] developed a multi-dimensional assessment framework to evaluate the societal impact of agricultural research. The proposed framework was based on a systems view, considering impact as socially embedded. It incorporated the constructs of productive interactions rather than cause-and-effect relationships. These examples illustrate that successful evaluation frameworks need clear concepts, contextual methods, and adequate data volume and types, often benefiting from mixed qualitative and quantitative approaches.

The consideration of societal needs forms a cornerstone of the EU's scientific research policy, promoting investment in R&I for the benefit of its citizens. Accordingly, the evaluation of EU R&I programs has shifted from prioritizing publications and economic benefits to emphasizing the broader societal benefits, encompassing social, environmental, and economic returns [57] oriented towards sustainable development goals [58]. This comprehensive R&I evaluation paradigm builds upon the well-known 'Triple Bottom Line' (TBL) framework, which encompasses the social, environmental, and economic value of an investment. The TBL is frequently used to assess performance across these three sustainability pillars, commonly referred to as the "3Ps" (People, Planet, Profit) [59]. Our study contributes to tackling the lack of practical examples demonstrating how the social impacts of R&I can be assessed [38]. The TBL framework was utilized to assess benefits, offering a comprehensive lens through which these can be understood [60]. Importantly, we explicitly acknowledge that these benefits (either outputs, outcomes, or impacts) can be tangible, meaning they can be directly measured, or intangible, where the positive effects are evident but not easily quantified.

3- Methods

The methodology process is represented schematically in Figure 1.

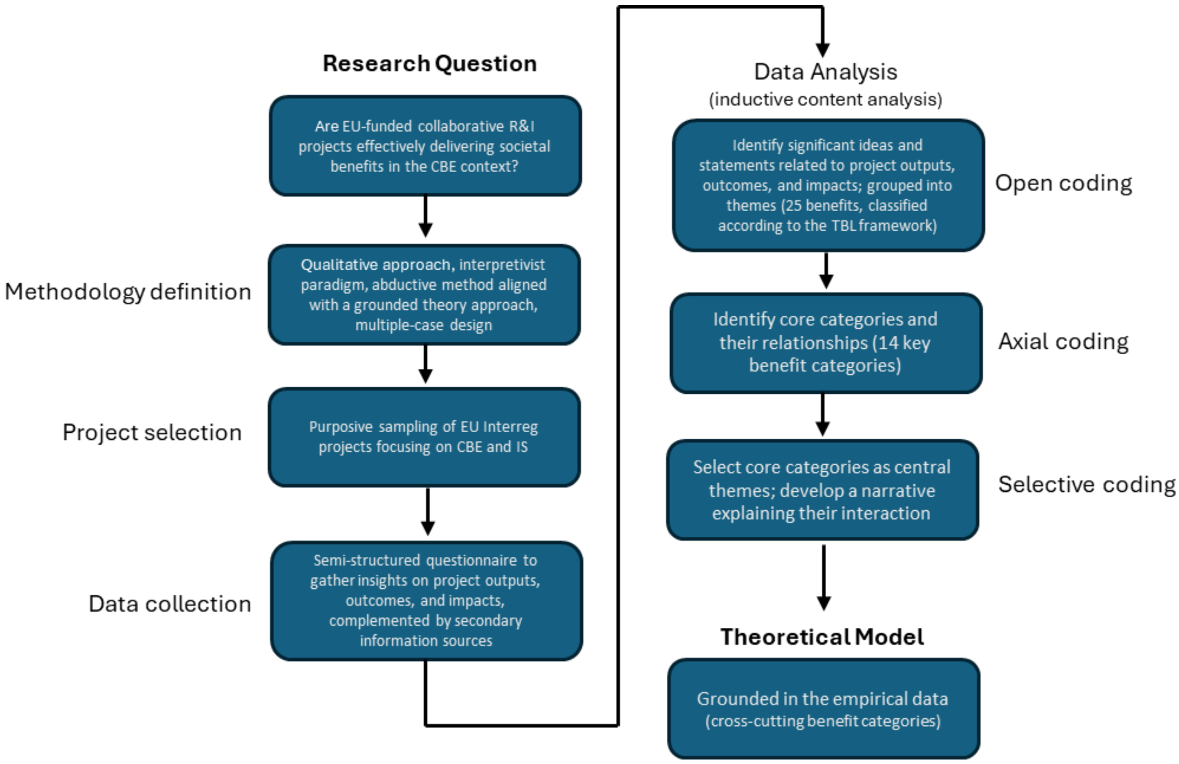

Figure 1. Methodology workflow

This study adopted a qualitative approach grounded in an interpretivist paradigm to explore the societal benefits of collaborative R&I projects focused on CBE in Europe. This research paradigm is especially apt for research problems that involve understanding subjective interpretations and exploring varied perspectives within social and cultural contexts [61]. This approach aligns with constructivist epistemology, which emphasizes the active co-creation of knowledge through interaction, rather than simply uncovering pre-existing truths [62]. A multiple-case design was used, which implies replication logic [63], within which a case is treated as an idiosyncratic expression of the phenomenon under study. We followed an abductive method aligned with a grounded theory approach for each individual case (following an open, axial, and selective coding process). The grounded theory approach followed the Strauss and Corbin school [64], which implies a continuous comparison approach to identify commonalities, thus ensuring a robust theory. The unit of analysis was the R&I project. Purposive sampling was used to select projects funded under the EU Interreg programs that specifically addressed CBE. This sampling method enables the intentional selection of participants who can offer valuable insights or distinct perspectives relevant to the research problem [65].

Accordingly, the projects selected for analysis had to meet specific criteria, including a collaborative nature at the cross-border level, with a primary focus on the valorization of biological waste and/or by-products, and a clear emphasis on establishing a symbiotic relationship between stakeholders. Projects that did not meet these criteria were excluded from the analysis. No time constraints were imposed on project selection, allowing us to capture a broader range of projects within this field. The case studies were identified from the www.keep.eu database using 'circular bioeconomy' and 'industrial symbiosis' as keywords. Data collection was implemented using a semi-structured questionnaire. To evaluate project benefits, the questionnaire addressed outputs, outcomes, and impacts using a three-dimensional approach. Project leaders were contacted via email, and if unavailable, other project partners were contacted. The total response rate reached 23%, resulting in five case studies (described in Table 1). To enrich our understanding of the projects' context beyond the self-reported data, and to triangulate the questionnaire findings, we concurrently utilized secondary information sources, namely scientific publications, project deliverables, datasets, and project-related news.

Table 1. Projects analyzed in the case studies

Project acronym	Core objective	Program	Period of implementation
TRIS	It aims to facilitate widespread adoption of IS across five European regions by promoting collaboration and resource exchange among businesses, ultimately enhancing their competitiveness and fostering regional economic growth.	2014 - 2020 Interreg Europe	01.04.2016 – 31.03.2021
CIRCTER	It aims to uncover the specific patterns of material use and flows within different regions to help identify how local material resources can be best utilized to support a successful transition towards a CE.	2014 - 2020 ESPON 2020	10.10.2017 – 27.09.2019
COASTAL Biogas	It aims to tackle the environmental challenge of coastal eutrophication by developing innovative anaerobic digestion solutions that utilize cast seaweed to produce clean biogas while simultaneously removing excess nutrients from coastal waters.	2014 - 2020 INTERREG VA South Baltic	01.07.2018 – 30.06.2021
BIS	It aims to promote widespread adoption of IS practices within the Baltic Sea region by encouraging strategic collaboration between various industries.	2014 - 2020 INTERREG VB Baltic Sea	01.01.2019 – 30.06.2021
ARDIA-Net	It aims to establish an Alpine Research Development Area focus on CBE and health economy, fostering strong value chains and boosting the Alpine economy.	2014 - 2020 INTERREG VB Alpine Space	01.10.2019 – 30.06.2022

Inductive content analysis was used with a focus on identifying benefits associated with project results. To analyze the responses and identify project benefits, an open coding exercise was conducted. This involved identifying significant ideas, phrases, or statements related to project outputs, outcomes, and impacts. These were then grouped into specific themes for better understanding, which in turn were classified into social, economic, and environmental benefits according to the TBL framework to assess the projects' overall sustainability performance. This initial process resulted in 25 distinct themes (benefits). A loop of examining, discussing, and revisiting the data (iterative process) was performed. This allowed us to refine the initial list of benefits by grouping them into broader categories that reflected more general benefits within the entire dataset. Accuracy and consistency were ensured by continuously reviewing and refining the emerging themes to enhance the analysis' validity and reliability.

To strengthen the study's reliability, we employed 'peer debriefing'. This involved engaging independent researchers not involved in the data collection or analysis. Data patterns and critical issues surrounding data collection, analysis, and interpretation of results were discussed [66]. Following open coding, core categories that serve as the main axis around which other codes revolve (axial coding) were identified. The relationships between the core code categories and other codes were explored by considering causal, intervening, and contextual conditions. This allowed us to refine the initial concepts and develop a more nuanced understanding of the phenomenon under study. This process ultimately led to the identification of 14 key benefit categories. Finally, selective coding was used to integrate all the previous coding stages to build a coherent theoretical model. Core categories were selected as central themes. A narrative was developed that explains how the different elements (codes and categories) interact. Thus, a theoretical model grounded in the data was developed that provides a thorough understanding of the research question.

4- Results

4-1- Emergence of Benefit Categories

Table 2 presents each of the 14 themes identified through the questionnaires' inductive, interpretive content analysis. It includes a brief explanation of what each theme represents, along with illustrative sentences drawn from the questionnaire data. These sentences exemplify the context in which the theme emerged from the data.

Table 2. Themes emerging from the content analysis

Designation	Abbreviation	Definition
Capacity Building	CB	Refers to the process of strengthening the skills and knowledge of individuals or organizations related to CBE & IS. This can involve training programs, workshops, and providing access to relevant tools or technologies. Example: *"Staff exchanges for junior staff to spend up to 5 working days in another partner organisation in a different region"*
Community Empowerment	CE	Refers to the process of enabling local communities to actively participate, learn, and receive support in shaping and implementing sustainable practices within their own communities. Example: *"In the case of the pilot call Innovation Express 2021 (3 out of the 4 regions belonged to the Alpine macro-region), the regional administrators could determine themselves funding priorities, beneficiaries, timing of the call and duration of the projects, among other features"*
Collaborative Learning	CL	Refers to a process where diverse stakeholders, such as academic researchers and practitioners, work together to learn from each other's perspectives and experiences related to CBE & IS. Example: *"Living Labs provided innovative arenas for both start-ups, SMEs and large companies to analyse, test and discuss their resource flows and the development of new products"*
Dissemination and Outreach	DO	Refers to the strategic communication and sharing of research findings, knowledge, or best practices with a variety of audience. It involves both: disseminating information to peers, practitioners, or policymakers through scientific publications, reports, or presentations; and utilizing workshops, community events, or social media to raise awareness and encourage public participation in the topic. Example: *"Scientific papers, reports and other deliverable documents", "24 press releases, 2 videos", "Roadshow events"*
Informed Decision-Making	IDM	Refers to the process of enabling individuals or organizations to make well-informed choices related to sustainable practices. This is achieved by providing guidance, assistance, and access to relevant information. Example: *"A 'Guide for Industrial Symbiosis Facilitators' is made available for the next generation of Industrial Symbiosis cluster managers, also beyond the project partnership."*
Knowledge Sharing	KS	Refers to the exchange of knowledge and information among individuals or groups within an organization or community. It utilizes various channels like presentations at events and the use of digital platforms to facilitate knowledge accessibility and dissemination. Example: *"Study visits (delegates can go and see what is happening 'on the ground' to support their own work on IS)"*
Knowledge Transfer	KT	Refers to a strategic process that leverages the knowledge gained from a project and transmits it to a specific recipient or group. The goal is to enable the practical application of this knowledge by the recipient, fostering its replication or adaptation in other project contexts or within different organizations. Example: *"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 Odsherred Municipality.*
Market Potential	MP	Refers to the process of identifying and exploiting the commercial viability of a product or service derived from a project. It involves recognizing the inherent value proposition and implementing strategies to enhance product/service attributes, performance, and market competitiveness. Example: *"This technique [tractor with grating bucket] is estimated to be applicable to 70% of the coastal areas where seaweed can be collected."*
Networking	Ntw	Refers to the process of building relationships and fostering collaboration among individuals and organizations with a shared interest in promoting sustainable practices. Example: *"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."*
Policy Development	PoD	Refers to the systemic process of creating, implementing, and evaluating policies to encourage the implementation of sustainable initiatives. Example: *"One Policy Forum"*
Product Development	PrD	Refers to the iterative process of creating, improving, or optimizing products, services, or new technological solutions. This development focuses on solutions that enhance the circularity and efficiency of bio-based systems. Example: *"One improved and one new concept/solution for nutrients removal."*
Sustainable Business Practices	SBP	Refers to the strategies and operations that businesses implement to minimize their environmental footprint while maximizing positive societal impact. It includes developing sustainable business models, waste valorization, resource optimization, and environmental protection. Example: *"1,522 tons of cast seaweed were co-digested in [Biogas Company] resulting in: removal of 51.6 tons of nitrogen from the Baltic Sea, removal of 1.25 tons of phosphorus from the Baltic Sea, production of 229 400 normal cubic meter of renewable methane, reduction of 550 tons of CO_2-equivalents"*
Stakeholder Engagement	SE	Refers to the ongoing process of actively involving and collaborating with a diverse range of stakeholders (e.g., public, local community, policymakers, decision-makers) to foster a shared understanding of the benefits and opportunities associated with CBE & IS initiatives. Example: *"1 Stakeholder Session during EU Macro-regional Strategies Week 2022"*
Sector Resilience	SR	Refers to the ability of sectors involved in CBE & IS to absorb, adapt to, and recover from various disruptions and challenges. It includes proactive strategies that promote adaptability and innovation and diversify resources and skills. Example: *"The cooperation schemes developed through ARDIA-Net strived for putting regions in the driving seat of the design of these schemes (...) and it also represented a rapid reaction to pandemic-related issues"*

Figures 2 to 4 categorize the outputs, outcomes, and impacts across the People, Planet, and Profit dimensions of the general TBL framework.

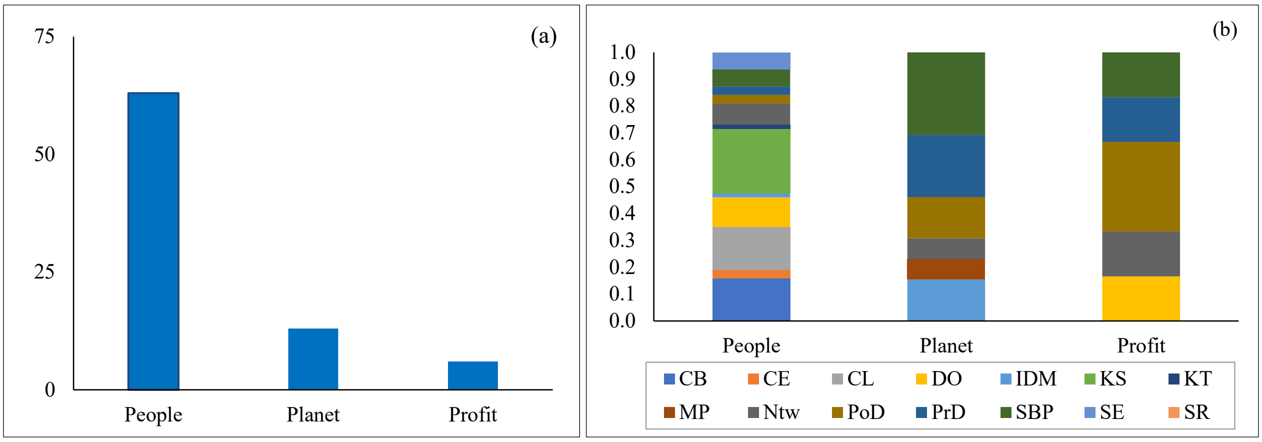

Figure 2. **Outputs across the TBL dimensions: (a) Frequency of outputs and (b) Relative frequency of emerging benefits**

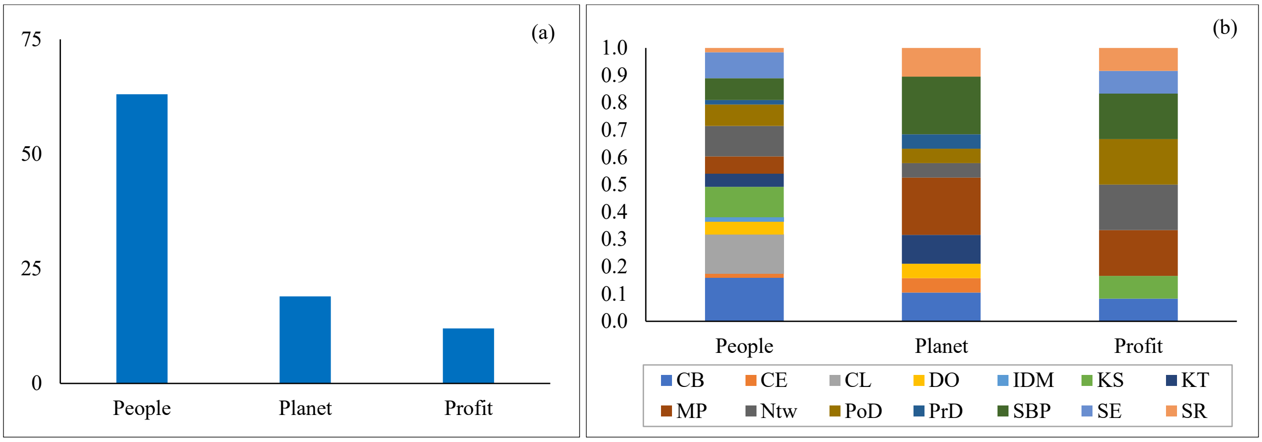

Figure 3. **Outcomes across the TBL dimensions: (a) Frequency of outputs and (b) Relative frequency of emerging benefits**

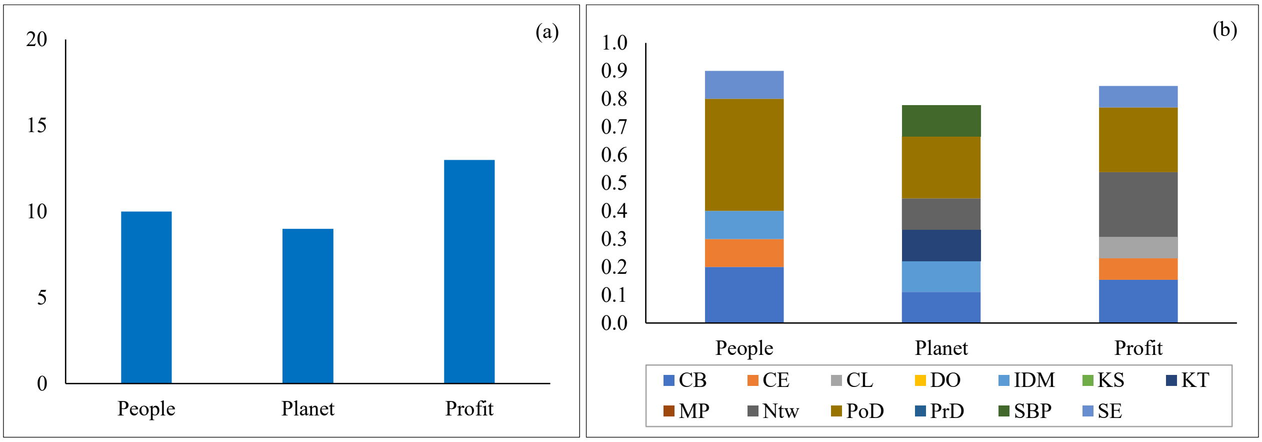

Figure 4. **Impacts across the TBL dimensions: (a) Frequency of outputs and (b) Relative frequency of emerging benefits**

Figure 2-a depicts the output frequency associated with each TBL dimension, showing a clear dominance of outputs under the social ('People') dimension. Figure 2-b shows that the main benefit driving the People dimension in outputs is Knowledge Sharing, followed by Collaborative Learning and Capacity Building. This is exemplified by the following statement: "Study visits (delegates can go and see what is happening 'on the ground' to support their own work)" [BIS project].

Mirroring the outputs trend, Figure 3-a shows a high frequency of outcomes in the social dimension. Figure 3-b reveals Capacity Building and Collaborative Learning as leading benefits contributing equally to project outcomes, as exemplified in the following statement: "Good practices and building capacities for cross-regional cooperation in the Alpine Region" [ARDIA-Net project].

Unlike outputs and outcomes, impacts tend to be more balanced across the three sustainability dimensions, with a slight tilt towards the 'Profit' dimension (Figure 4-a). Policy Development emerges as a key benefit consistently influencing all three sustainability dimensions, while Networking also stands out in the Profit dimension (Figure 4-b). This is illustrated in the following statement: "[the project ultimately aimed to have policymakers utilize its results] in developing circular economy strategies, plans, and projects" [CIRCTER project]. It should, however, be mentioned that there is a significant level of uncertainty associated with the evidence collected for the impacts category. Impacts tend to be noticeable only in the long term (often years after the project ends [60]), and project leaders tend to provide 'expected' impacts aligned with the project proposal that preceded its funding approval.

5- Discussion

The results of this study shed light on the multifaceted nature of impact derived from collaborative R&I projects in the CBE area. The empirical data reveals that benefits extend beyond traditional outcomes to encompass crucial areas such as Capacity Building, Community Empowerment, Collaborative Learning, Networking, Knowledge Sharing, Policy Development, and Sustainable Business Practices. These categories represent key pathways through which collaborative efforts translate into broader societal, economic, and environmental impacts [52, 54, 67].

5-1- The Effective Delivery of Societal Benefits in the CBE Context

The five collaborative R&I projects analyzed are framed in Interreg priorities underpinned by European strategies such as the Green Deal, the Bioeconomy Strategy, and the Circular Economy Action Plan that prioritize the CBE as a tool to achieve a climate-neutral future [31]. Overall, the characteristics of Interreg, as an interregional cooperation program, align closely with our findings. The program's core mission to reduce disparities in development and quality of life among Europe's regions [68] and a clear emphasis on social benefits strongly resonate with our observations.

Bix Germundsson et al. [56] systematized 'communication and cooperation between actors', 'social learning and capacity building', and 'dissemination of results' as categories of benefit indicators in research projects. These categories are aligned with the emergence of Capacity Building, Community Empowerment, Knowledge Sharing and Networking, but also with Collaborative Learning, Dissemination and Outreach, and Stakeholder Engagement. According to Merino & Carmenado [69], Capacity Building significantly impacts project sustainability, ultimately contributing to economic growth and social development. De Paula & De Abreu [70] investigated the importance of institutional Capacity Building in driving the development of IS. Their research emphasizes the critical role of investing in strengthening the institutional environment. This strengthens the ability to effectively manage natural resources and waste, which is a necessary foundation for establishing eco-industrial parks. These parks, in turn, can be instrumental in implementing Sustainable Business Practices. The relationship between Policy Development, Sustainable Business Practices, and circular economy has been illustrated by Fassio & Minotti [71] in the context of the concept of the cities of the future. More specifically, their research investigated how circular economy principles and metrics (indicators and strategies) can be applied to design urban food policies. The demonstration of Policy Development as an impact of EU-funded projects within the CBE domain has also been highlighted by Brandão & Santos [23] for Horizon 2020 R&I projects. Their work underscores the contribution of these projects to the generation of policy documents aimed at promoting bio-based products. Li & Lange [72] underscore the critical role of Community Empowerment in planning, design, and decision-making processes for achieving sustainability goals. Their research emphasizes that incorporating this approach can improve outcomes and accelerate the transition to net-zero carbon emissions.

Our results strongly emphasize the social (People) dimension of Interreg project benefits, particularly in the short and medium terms. This focus manifests in themes such as Collaborative Learning, Capacity Building, and Knowledge Sharing, which contribute to the People dimension in various ways. This is exemplified in the "Establishment of local stakeholder groups (IS Labs) to share project outputs and develop local activity" [TRIS project] as an output. These IS Labs directly address the TBL's social dimension by fostering Knowledge Sharing through shared project outputs and promoting collaboration and local involvement through their group structure. The importance of Knowledge Sharing between team members and external partners has already been highlighted by previous research as a key factor in successful collaborations [73]. Evidence such as "Good practices and built capacities for cross-regional cooperation in the Alpine Region" [ARDIA-Net project] showcases the tangible outcomes achieved through Capacity Building and Collaborative Learning efforts. Enhanced capacity and competence fostered by Capacity Building enable stakeholders to participate effectively in cross-regional cooperation. This, in turn, facilitates Knowledge Sharing and lays the groundwork for successful joint projects. By prioritizing Capacity Building and Collaborative Learning, the projects directly address the People pillar of TBL, as they focus on empowering stakeholders with the necessary skills to collaborate effectively across the Alpine Region boundaries. This aligns with Bäck & Kohtamäki's [73] research, which identified motivation and mutual trust as crucial elements that drive the dynamic process of joint learning within R&I collaborations.

Conversely, the analysis of impacts reveals a shift towards a more balanced distribution of benefits across economic, environmental, and social dimensions compared to outputs and outcomes. This agrees with Barbosa et al. [30], who found that collaborations between universities and industry have wider positive effects on the economy and society beyond the immediate outputs. Policy development and Networking emerge as key benefit categories in the economic dimension. This aligns with Protogerou et al. [31], who identified that collaborative projects lead to the development of long-lasting policies and networks. These, in turn, positively impact financial growth and sustainability. Policy Development emerges as a key driver influencing social and environmental dimensions. In the social dimension, a key example of Policy Development is the following evidence: "European legislators' agreement on funding regulations for the 2021-2027 period that ensures an increased role for macro-regional strategies by one side, and a strengthened cooperation component now mandatory in all EU regional development funds", which "results in a much-strengthened role of cooperation actors and a recognition of the work done in transnational or cross-border projects so far" [ARDIA-Net project].

In the environmental dimension, the CIRCTER project exemplifies another strategy, aiming to have policymakers utilize its results "in developing circular economy strategies, plans, and projects" [CIRCTER project]. The project investigated how different regions manage materials throughout their lifecycle – from use and design to production and waste. This research aimed to inform European regions and cities by providing data that could be used to develop policies and practices promoting a circular economy. In the economic dimension, this focus on Policy Development is exemplified by evidence such as "The cooperation schemes developed through ARDIA-Net strived for putting regions in the driving seat of the design of these schemes. In the case of the pilot call Innovation Express 2021 … the regional administrators could determine funding priorities themselves, beneficiaries, timing of the call, and duration of the projects, among other features; and it also represented a rapid reaction to pandemic-related issues." [ARDIA-Net project].

Our study also evidences previous reports that impact is more complex to quantify than outputs and outcomes due to its inherent long-term perspective [60]. This is evident in evidence 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 summary, our study shows that collaborative R&I extends its scope beyond academic achievements by aligning activities with broader societal needs and environmental considerations, empowering individuals, fostering collaboration, and enriching knowledge. Collaborative R&I projects are shown to be an effective approach to fostering circular-oriented innovations, particularly in fields such as the CBE. They play a crucial role in the validation of sustainable business practices and their market uptake [74]. Collaborative R&I provides the opportunity to expand and diversify research networks [46]. The European Framework Programmes have been particularly successful in incorporating smaller and peripheral communities into wider networks, strengthening research integration and cohesion [41]. Collaboration helps in keeping and expanding existing relationships [39] and is effective in bringing diverse stakeholders together, fostering synergistic collaborations among institutions, businesses, and public authorities. Benefits derived from these relationships include trust, commitment, communication, and positive relationships themselves [21, 43]. Familiarity among partners can lead to greater commitment and trust [7]. Collaboration can also facilitate inclusiveness and co-creation, fostering transparency, respect, and mutuality [21]. Collaborative R&I projects contribute to building human capital and enhancing science and technology capital [43]. Individual empowerment is also noted as a societal benefit. Collaborative projects can help in achieving critical mass, overcoming fragmentation caused by distance and limited resources, bringing together different perspectives, experiences, skills, and knowledge, and breaking down specialist silos and restrictive organizational boundaries. Also, collaborative learning is fostered. The role of collaborative R&I projects in influencing policy decisions [19] is reinforced, leading to policy alignment with societal needs and investment priorities.

5-2- Theoretical Model Development

To comprehensively analyze the distribution of emerging themes across outputs, outcomes, impacts, and TBL dimensions, we cross-referenced frequency occurrence. This process enabled us to pinpoint and identify the cross-cutting themes that emerged from the data and provided valuable insights into the interconnectedness and overarching patterns within the themes. Seven cross-cutting benefit categories were identified: Capacity Building, Community Empowerment, Knowledge Sharing, Collaborative Learning, Networking, Policy Development, and Sustainable Business Practices. These categories are unique in that they can manifest across outputs, outcomes, and impacts and potentially contribute to all three sustainability dimensions depending on the specific project context. To delve deeper into the interconnectedness of the seven key benefit categories, we developed a theoretical model, depicted in Figure 5.

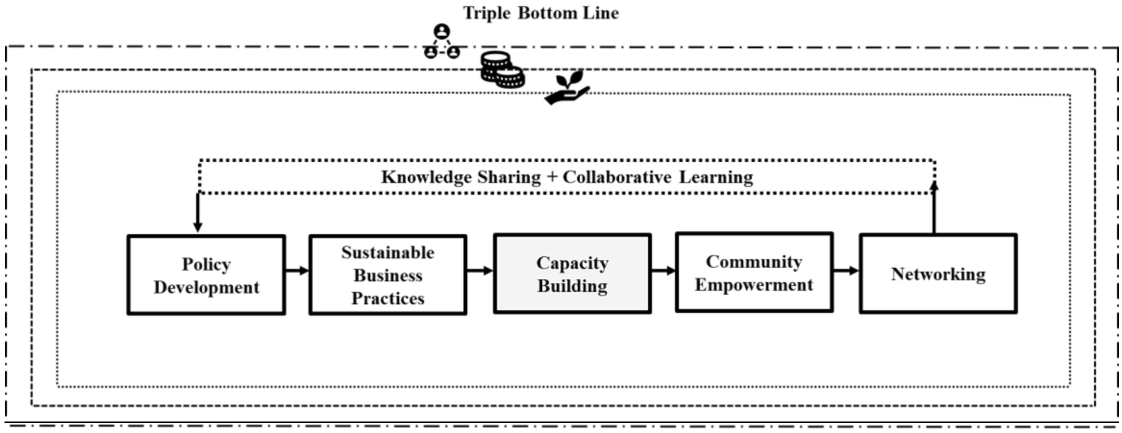

Figure 5. Theoretical model for the benefits of collaborative R&I projects in the CBE area

We positioned capacity building at the model's core, acting as the bedrock foundation. This strong foundation empowers local communities, fostering the creation of effective collaborative networks. These networks amplify knowledge sharing and collaborative learning and influence the development of coherent public policies that promote sustainable business practices. The cycle is further reinforced by these supportive policies and sustainable practices, which contribute to strengthening individual and organizational capacities. The intertwined nature of these elements creates a symbiotic cycle where each element reinforces and uplifts the others, culminating in outputs, outcomes, and impacts that span all the TBL dimensions. This theoretical model mirrors the complex interdependencies and feedback loops among these benefits [21, 47], highlighting that achieving significant societal impact is not a linear process but rather depends on fostering synergistic interactions across multiple dimensions [52, 54]. This holistic view underscores the importance of considering the interplay of diverse factors within collaborative settings [54] when assessing their contribution to the transition towards a thriving CBE.

The manifestation and influence of these benefits tend to shift over different time horizons. In the short to medium term, benefits are heavily concentrated in the social dimension, presenting as outputs and outcomes such as Capacity Building, Collaborative Learning and Knowledge Sharing among stakeholders. These contributions are often immediately visible within the project's lifespan or shortly thereafter. However, the analysis of long-term impacts reveals a more balanced distribution across social, environmental, and economic dimensions. Benefits such as Policy Development and Networking emerge as particularly significant in this timeframe, consistently influencing all three sustainability dimensions and demonstrating potential for broader, enduring change. These benefits are typically slower to materialize and may only become fully visible years after a project concludes. The proposed theoretical model posits that the emerging cross-cutting categories interact synergistically over time, building upon initial social benefits to facilitate the realization of wider-ranging impacts across all TBL dimensions. This underscores that while immediate benefits are often social, their translation into significant societal, environmental, and economic impacts is a longer-term process.

The COASTAL Biogas project case study illustrates the dynamic interplay of benefit categories. Coastal eutrophication, caused by excess nutrients in the water, harms marine ecosystems. The COASTAL Biogas Project sought to address this challenge by developing a groundbreaking solution – using cast seaweed in biogas production through anaerobic digestion. By developing technical resources and training (CB), the project empowers the local community (CE) with knowledge (KS) of seaweed co-digestion technology and its benefits (CL). This empowered community can then actively participate in project implementation, potentially leading to further innovation. The project's demonstrated environmental and economic benefits can attract investors and foster stakeholder collaboration (Ntw). This collaboration can create sustainable seaweed co-digestion businesses and advocacy for supportive policies (PoD). These policies, in turn, can incentivize wider adoption of the seaweed co-digestion technology, creating a more sustainable business environment and further empowering other communities to replicate this success (beyond Odsherred Municipality).

The proposed theoretical model goes beyond traditional economic-focused metrics by employing a multi-dimensional approach to benefit categorization that emerged inductively from empirical data. Its impact on science policymaking extends beyond the specific context of this study and provides valuable insights for designing new funding instruments, evaluating project proposals, and assessing post-project impacts. When designing new funding instruments, whether at the supra-regional, regional, or national level, funders can incorporate these themes as evaluation criteria or establish dedicated funds for projects that prioritize these elements. In evaluating project applications, funders can give precedence to projects that exhibit a robust dedication to the five cross-cutting themes. This preference can manifest in evaluation criteria that emphasize the presence and quality of these elements within project plans. Furthermore, how projects contribute to these cross-cutting themes can be monitored to critically assess the benefits they are expected to deliver. Additionally, the identified symbiotic cycles, where these themes mutually reinforce each other, can be closely examined. Understanding how these elements interconnect can help assess the sustainability of project results and their broader benefits for communities and sectors. Therefore, post-project assessment can highlight how this interconnection continues to benefit society at large. From a practitioner's perspective, the framework provides a foundation for directing R&I activities. It can help ensure that project activities are aligned with the desired benefit themes, allow stakeholders to understand how achieving one benefit might impact or be impacted by another, and prioritize the most important benefit areas for the project's success. This can be crucial when deciding resource allocation, project timelines, and potential trade-offs.

5-3- Limitations and Future Work

The study's reliance on project leader perspectives introduces the possibility of subjectivity and bias. Future work will include collecting data from project stakeholders such as community representatives. Additionally, the specific sample and focus on a relatively early post-project stage may limit the generalizability of findings and the ability to capture long-term impacts fully. Forthcoming research will include a longitudinal study to collect more detailed and accurate data on the impact of each of the projects studied after an adequate period after their closure (e.g., five years). Future work will also involve the theoretical framework validation in R&I project contexts other than Interreg programs and the CBE area to evaluate its generalizability.

6- Conclusions

This study contributes to the ongoing discussion on how to assess the actual benefits of R&I projects by laying out a new multi-dimensional methodological approach grounded in empirical data that extends the still prevalent use of scientific and economic output metrics. Moreover, it tackles identified research gaps by contributing a practical example of how the societal impacts of R&I can be assessed and providing empirical evidence in the CBE area.

A comprehensive analysis of benefits generated by publicly funded collaborative R&I projects in Europe within the CBE area is developed. The analysis revealed a strong alignment between public investment priorities, project goals, and benefits. Our findings highlight that the core benefits of these projects significantly derive from the collaborative nature of the R&I endeavors. Interreg projects excel at generating social outputs and outcomes, with a trajectory towards a more balanced distribution across all TBL sustainability dimensions in the long term. Themes such as Policy Development and Networking suggest the potential for influencing policies and fostering long-term environmental and economic benefits.

Seven key benefit themes emerged that transcend dimensions and timeframes and act as drivers for successful Interreg collaborative R&I projects in the CBE area: Capacity Building, Collaborative Learning, Community Empowerment, Knowledge Sharing, Networking, Policy Development, and Sustainable Business Practices. By integrating these themes throughout policymaking, funding instrument design, and project delivery, policymakers, funders, firms, researchers, and other relevant stakeholders can develop more impactful R&I initiatives that accelerate the transition to a thriving CBE. Moreover, policymakers can use the proposed framework to move towards comprehensive program reviews and revamp funding mechanisms to prioritize projects that integrate all five benefit categories. Project developers can use it to adopt a holistic approach, tailoring designs to context while ensuring relevant categories are adequately addressed.

7- Declarations

7-1- Author Contributions

Conceptualization, J. M. R. C. A. S., and A.B.; methodology, J. M. R. C. A. S., and A.B.; validation, J. M. R. C. A. S., and A.B.; formal analysis, J. M. R. C. A. S., and A.B.; investigation, J. M. R. C. A. S., and A.B.; resources, J. M. R. C. A. S.; data curation, A. B.; writing—original draft preparation, J. M. R. C. A. S., and A.B.; writing—review and editing, J. M. R. C. A. S., and A.B.; visualization, J. M. R. C. A. S., and A.B.; supervision, J. M. R. C. A. S.; project administration, J. M. R. C. A. S.; funding acquisition, J. M. R. C. A. S. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7-3- Funding

This work was supported by national funds through FCT/MCTES (PIDDAC): CIMO, UIDB/00690/2020 (DOI: 10.54499/UIDB/00690/2020) and UIDP/00690/2020 (DOI: 10.54499/UIDP/00690/2020); and SusTEC, LA/P/0007/2020 (DOI: 10.54499/LA/P/0007/2020).

7-4- Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Polytechnic Institute of Bragança (protocol code P489126, approved 21/05/2023) for studies involving humans.

7-5- Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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