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Case studies research in the bioeconomy: A systematic literature review

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Abstract: Case study research plays a crucial role in studying the development of the bioeconomy. The versatility of the empirical method coupled with the uncertainty surrounding the bioeconomy concept requires a consistent and comparable application of the method to obtain valid and generalizable results. To stimulate such systematization, we first need to know the state of case studies in bioeconomy research. This article reviews the recent literature with a qualitative content analysis facilitated by systematic text coding. Our results provide an overview of how the narratives of the concept of bioeconomy affect the versatility of the case study research. Based on the low density of the illustrated semantic networks, we conclude that future empirical research on bio-based phenomena should be more transdisciplinary and rely more on cross-sectoral approaches. Further work is also required in developing common research protocols that support transparency and replicability of case studies in the bioeconomy.

Keywords: circular bio-based economy; protocol; research methodology; resource management; sustainability

Global challenges regarding health, climate change, food security, energy security, cities, and migration urgently need solutions. The bioeconomy is a main alternative to fossil materials to address these challenges (European Commission 2018). Several national strategies and policies for bioeconomic development worldwide confirm its key role (Staffas et al. 2013; Kardung et al. 2021). Increasingly transformative policy initiatives, such as the European Green Deal or the target of net-zero emissions in the European Union (EU) by 2050 (European Commission 2019), require intense efforts and coordination to exploit the bioeconomy and available synergies in all sectors and policy areas.

Given the contemporary, context-dependent nature of related phenomena, the scientific case study research method plays a crucial role in developing the bioeconomy. When little is known about a complex social phenomenon, a starting point is the collection and analysis of empirical evidence to gain information and key insights into real-world cases, a well-established research method (Denscombe 2014).

Case study research is characterized by great versatility (Eisenhardt 1989; Cavaye 1996; Yin 2014). A case study contributes to the knowledge of the individual, group, organizational, social, political, and related contemporary phenomena. It is preferred over other re-

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search tools, such as experiments, when the researchers have little or no control over the events studied and the boundaries between a phenomenon and its context are unclear (Yin 2014). In support of the bioeconomy, several projects, and initiatives (e.g. BERST, BioMonitor, BioSTEP, S2Biom) have relied on case studies to advise on action plans, programs, and policies, to expand the general understanding of its sustainability, and to assess the effectiveness and maturity of possible bridging biotechnologies. Given the uncertainty surrounding the concept of the bioeconomy, however, this versatility can also threaten the method's consistent, comparable application.

Despite the emphasis placed on it, the bioeconomy concept is still a matter of debate, and a commonly accepted definition is lacking. As Bugge et al. (2016) and Vivien et al. (2019) have underlined, the literature contains several co-existing narratives of the bioeconomy concept. These narratives disperse bioeconomy research across many fields of science (Bugge et al. 2016) and lead to different, sometimes conflicting conceptions of economic policies and instruments needed to support the future bioeconomy (Vivien et al. 2019). As demonstrated later more exhaustively, case research reflects this richness and diversity. Many disciplines use it as a research approach to support various models of sustainability with empirical evidence. To meet different needs, therefore, bioeconomy narratives apply case research differently. This complicates the understanding of case study approaches, which can seem fragmented and inconsistent in the bioeconomy domain. The problem is sharpened by the lack of common guidelines and protocols on how to conduct case study research in this field.

In the context of bioeconomy, case study methodology suffers from a lack of systematization, that is, consistent, comparable application. Without systematization, it is difficult to contribute to the literature in a clear, operationally defined way (Yin 2014). The development of case study protocols can fill this gap by producing a comprehensive set of rules and procedures that make case study methodology more rigorous, forcing researchers to consider all the issues relevant to their research projects (Maimbo and Pervan 2005).

To stimulate case study protocols in a specific research domain, we first need to gain knowledge on the current state of case studies. The literature provides several examples of case study reviews that discuss the variety of approaches adopted in specific research fields. For instance, Cavaye (1996) and Dubé and Paré (2003) reviewed the state of case studies in the field of information systems, Runeson and Höst (2009) in the field of software engineering, and Barratt et al. (2011) in the field of operations management. To the best of our knowledge, however, we are the first to examine case studies approaches in the field of bioeconomy.

This paper assesses the state of case studies in the bioeconomy domain. More specifically, considering the uncertainty surrounding the bioeconomy concept (Bugge et al. 2016; Vivien et al. 2019), the main research question we address is the following: How do different visions of the bioeconomy influence case study approaches? In answering this question, our goal is to provide a review of the current state of case studies in the bioeconomy by focusing on the differences among three co-existing economic narratives. In this way, we aim to provide a basis for critical discussion to develop case study protocols for bioeconomy research. The increased effectiveness of case study research should positively influence the research agenda, the political debate, the emphasis placed on elements of interest for society, and the direction of innovation and value creation.

LITERATURE REVIEW – CONCEPTUAL FRAMEWORK

The scientific community interprets the concept of the bioeconomy and applies case study research in many ways. The bioeconomy narratives in the academic literature and the key elements characterizing case study approaches are described further as well as the attributes investigated and coded during the review of the selected articles.

Bioeconomy narratives

Despite the emphasis placed on it, the bioeconomy notion is still debated with little consensus on what it implies (Bugge et al. 2016). Divergent visions and interpretations of the bioeconomy characterize the literature.

Exploring the generic characteristics and nature of the term "bioeconomy", Bugge et al. (2016) identified three co-existing ideal visions of it: the bio-ecological vision, the biotechnology vision, and the bio-resources vision. The bio-ecological vision highlights sustainability as a central theme, including tensions and critical voices that focus on economic growth. Value creation is supported by promoting biodiversity, ecosystem conservation, ecosystem services provision, and soil-degradation prevention, emphasizing circular self-sustained productions and organic bio-ecological

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practices. This vision calls for more attention to transdisciplinary sustainability issues, taking the global scale as a starting point and including the negative externalities of bio-resources and biotechnologies. The biotechnology vision, in contrast, is primarily concerned with economic growth and job creation. It treats sustainability as subordinate since it *a priori* assumes positive effects from adopting biotechnologies. In this vision, investments in research and innovation play a central role as drivers of value creation, stimulating the applicability and commercialization of scientific knowledge in various sectors through the close interaction of universities and industries. Like the biotechnology vision, the bio-resources vision highlights cross-sectoral research involving innovation and collaboration as an important source of value creation. This third vision refers to both economic growth and sustainability, which are driven by the capitalization of bio-resources into new products and the establishment of new value chains. Issues related to the use and availability of biological resources, the cascading use of biomass, and waste management are predominant in this vision. Based on these ideal visions, it is not surprising that Bugge et al. (2016) argued that natural sciences and engineering perspectives influence bioeconomy research the most.

In accordance with these interpretations of the bioeconomy, Vivien et al. (2019) described three ideal types of bioeconomy narratives: *i*) an ecological economy; *ii*) a science-based economy; and *iii*) a biomass-based economy. The first interpretation echoes Georgescu-Roegen's (1977) definition that the bioeconomy is meant to be a development model that simultaneously ensures economic and ecological balance by incorporating environmental variables into economic resource management solutions. This interpretation stresses the importance of preserving a limited stock of accessible resources that are disparately and unequally allocated (Georgescu-Roegen 1977). Strict ecological constraints bind this bioeconomy type, promoting a standard of the sufficiency as a strategy for long-term development. Not surprisingly, economic policies and instruments supporting such a bioeconomy redistribute wealth equitably via ecological planning and limits. In the second bioeconomy narrative, in contrast, public policy strongly fosters a biological industrial revolution based on the establishment of biotechnologies as general-purpose technologies (Patermann and Aguilar 2018). This narrative is known as a "knowledge-based bioeconomy", as first advocated by the Organization for Economic Co-Operation and Development (OECD) (1998), or as a technology-driven bioeconomy, and it is often subject to social resistance, such as the case of genetically modified organisms. Because it aims to equate biology and life with biotechnology, Vivien et al. (2019) placed this narrative on the weak side of the sustainability debate. At a very early stage, as in the Cell Factory Key Action of the 5th Framework Programme (1998–2002), the European Union (EU) applied this second interpretation of the bioeconomy in research policy by encouraging the pragmatic mobilization of any research or technological development (Patermann and Aguilar 2018). Following empirical evidence gathered on ongoing developments, such as the assessment of indirect land-use changes caused by the promotion of agrofuels, the European Commission (EC) has stressed the central role that the sustainability debate must play in the bioeconomy. Therefore, the EU started to support the bioeconomy as a circular renewable carbon economy based on biorefining – the biomass-based bioeconomy. This new bioeconomy interpretation reflects the definition used by the EC (European Commission 2018), in which the bioeconomy includes all sectors and systems involving the economically viable use of biological resources and waste streams. Biorefining concepts also belong to this type of bioeconomy, which contributes to fossil-resource substitution via raw biomass fractionation and new bio-based value-added products. This interpretation lies between the sustainability models proposed by the bioeconomy narratives described above and seems to dominate them.

Case study research

As with the bioeconomy concept, there is no single interpretation of the notion of a case study. The case study method refers to an in-depth investigation of a contemporary phenomenon in its real-world context (Benbasat et al. 1987; Eisenhardt 1989; Merriam 1998; Yin 2014; Robson and McCartan 2016). The method is open to several interpretations and approaches: case study research can adopt a deductive or inductive approach, can investigate one or more cases, apply different sampling strategies, use multiple data sources, and select analysis techniques that best fit both the qualitative and quantitative evidence. Regardless of this versatility, some common practices are highly recommended when conducting a case study.

Define the research question and objectives. A common agreement across prominent case study methodologies (Eisenhardt 1989; Merriam 1998; Stake 1995; Yin 2014) is to start by defining a research ques-

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tion and objectives since they largely determine the nature of a case study (Yin 2014). The objective can be descriptive, exploratory, or explanatory; that is, case study research can be used for both theory building (inductive) and theory testing (deductive). A research question should have a well-defined focus and a clear objective as the groundwork for data collection and analysis (Eisenhardt 1989).

Select case and unit of analysis. Once research questions and objectives have been defined, it is important to specify the case and the unit of analysis. Following the contributions of Grünbaum (2007) and Yin (2014), we define a case as a "phenomenon" studied in its real context, where a phenomenon is understood as any fact or event liable to be directly or indirectly observed, such as the implementation of a business model or the consequences of a production system. The analysis of a phenomenon must handle complex social systems integrated with equally complex natural systems (Starik and Rands 1995; Boons and Wagner 2009). Such complexity forces researchers to be selective, looking for a system boundary that allows them to develop significant insights into the studied complexity (Flood 1999; Stewart 2001). This system is called the "unit of analysis", the heart of the case (Grünbaum 2007), which can be investigated in more detail using sub-units of analysis. For example, the implementation of a business model (case) could be investigated by analyzing a company (unit of analysis), which in turn can be represented by its manager or employees (sub-units).

Sampling strategies. Case study research requires a precise definition of boundaries, chosen units, and sampling strategy, as well as justifications of those choices based on the type, nature, and purpose of the study (Etikan 2016). These choices significantly influence the feasibility and validity of data collection and analysis. Both probability and non-probability sampling techniques can be applied in case research. In probability sampling, each unit is randomly selected (Battaglia 2008), whereas in non-probability sampling (such as convenience sampling and purposive sampling), units must meet certain criteria that justify the rationale of the sampling. For instance, in convenience sampling, the units meet practical criteria, such as easy accessibility, geographical proximity, availability at a given time, or willingness to participate (Etikan 2016). In purposive sampling, the selection of units is based on theoretical aims dictated by the nature of the research project (Riffe et al. 2014). Units can be chosen because they express the maximum possible variation, share similar traits, or simply because they are considered typical, unusual, or critical (Etikan 2016).

Data gathering. One strength of case study research is the opportunity to use both qualitative (e.g. interviews, observations) and quantitative (e.g. questionnaires) data-collection methods. Any finding or conclusion in a case study is much more convincing and accurate if it is based on heterogeneous sources of information (Eisenhardt 1989; Dubé and Paré 2003). Therefore, triangulation – the use of multiple sources aimed at corroborating the same evidence (Yin 2014) – is highly recommended (Eisenhardt 1989; Miles and Huberman 1994; Yin 2014). Triangulation allows building a richer, more complete picture of a phenomenon (Cavaye 1996). It can be implemented using sources of the same data type (e.g. qualitative, such as survey data compared with documents from the literature) or different types (e.g. questionnaires administered by an interviewer and field observations).

Data and context analysis. Case study research allows selecting the methods that best suit the research questions (Creswell et al. 2007; Greene and Hall 2010), making it possible to handle both qualitative and quantitative evidence. Data analysis "consists of examining, categorizing, tabulating, testing, or otherwise recombining both quantitative and qualitative evidence to address the initial propositions of a study" (Yin 2014). In this sense, case studies allow great flexibility and individual variation (Cavaye 1996). The description of adopted data-analysis strategies and techniques should demonstrate the objectivity of the process by which the data are developed into conclusions (Barratt et al. 2011) and allow an external observer to understand those conclusions better (Dubé and Paré 2003).

Understanding a real case involves important contextual conditions relevant to the case (Yin 2014). Context plays a key role in the analysis. For the bioeconomy, several studies (Sheppard et al. 2011; Talavyria et al. 2015; Wesseler and von Braun 2017) have identified the main forces driving the development of the bioeconomy and related phenomena. Kardung et al. (2021) summarized these forces by grouping them as supply drivers (technology and innovation, markets, and climate change adaption), demand drivers (consumer preferences, economic development, and demography), resource availability, and government measures. Researchers should not disregard detailed descriptions of context to ensure the robustness and generalizability of their findings.

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MATERIAL AND METHODS

We examine how various narratives of the bioeconomy affect case study approaches. Toward this end, we follow a five-step methodology (Figure 1). The description of each step follows.

The article-sampling strategy. Given the exploratory purpose of this study and the multidisciplinary nature of the bioeconomy, the sampling strategy focused on obtaining as many scientific journal sources as possible. For this reason, the Scopus database was selected. Due to its wide coverage of journals and articles, Scopus represents recent scientific literature well (Aghaei et al. 2013; Harzing and Alakangas 2016), especially the social sciences (Aksnes and Sivertsen 2019).

The samples were delimited according to the following keywords and their variants: *i*) "case study", "case study method", "field study", and "action research" to include all possible case studies; *ii*) "bio*", "bio-*", "green", and "circular" to select possible bioeconomy case studies; and *iii*) "bioeconomy", "economy", "supply chain", "value chain", "industry", and "sector" to focus on economic research. Considering the most recent complete year at the time of the sampling (2018) and extracting only English-language literature, the database provided 693 case studies in the field of bioeconomics. This significant number of articles provided a manageable, sufficiently exhaustive basis for an in-depth screening phase.

Screening phase. All the titles, abstracts, authors, journals, subject areas, citations, and keywords of the candidate case studies were tabulated. Two researchers independently read the abstract of each article to exclude articles that were not case studies and did not relate to the bioeconomy. The choices made independently by the researchers were consistent in 89% of cases. Any disagreement was discussed and eventually resolved. This process yielded 209 verified articles.

The articles from this sample were subjected to further screening to identify case studies in which the phenomena under investigation were the main objectives. In some cases, case study methodology is applied for instrumental purposes to facilitate understanding models, frameworks, or practical applications (Stake 1995). For example, a case study whose purpose is simulating, calibrating or demonstrating a model can be considered "instrumental" and usually has a narrow scope. This phase, which required reading the full texts of the articles, led to the exclusion of 117 articles and a final sample of 92 publications that were case study articles in the bioeconomy research field.

Coding phase. The 92 selected case studies were independently read several times by researchers. The following attributes were investigated: bioeconomy vision; research questions and objectives achieved; cases and related aspects under study; unit and sub-units analyzed; economic activities involved; sampling strategy and data sources adopted; and data and context analysis conducted. Whenever possible, any evidence (text passages, phrases, and paragraphs) of the attribute studied was collected and reported in an Excel spreadsheet. This spreadsheet was used as a support tool for the coding, categorization, and analysis phases. From all the evidence gathered, codes were first extrapolated. Codes are constructs that provide an interpreted meaning for each datum for subsequent categorization and other analytical processes (Saldaña 2013). Table 1 shows an example of this coding process.

Categorization phase. Based on Bugge et al. (2016) and Vivien et al. (2019) and on the sustainability model proposed by the selected case study, we defined the prevailing bioeconomy vision (or narratives). If the bioeconomy promoted in the paper was based on strict ecological constraints and environmental concerns took first priority, the case study was classified as having a bio-ecological vision (or "ecological economy" narrative). If the article emphasized a biotechnology-driven economy and promoted technological progress as a solution to all sustainability problems, it was categorized as having a biotechnology vision (or "science-based economy" narrative). Finally, if the article focused on the use of various types of biomass to replace fossil resources, promoting a biomass-based economy, it was categorized as having a bio-resources vision (or "biomass-based economy" narrative).

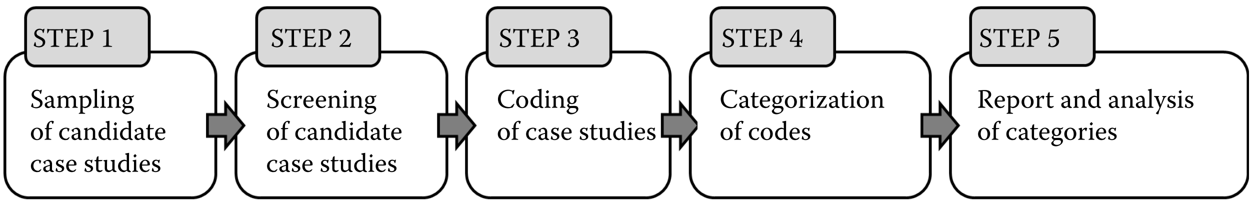

Figure 1. Methodological approach

Source: Own elaboration

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Table 1. Example of coding process

Raw data for the attributes based on Mengistu et al. (2018)	Attributes	Codes	Categories
This challenge stimulates the need to move from an economy based on fossil fuels to a biomass-based economy (…). The definition of biomass-based economy, also known as "bioeconomy", remains a matter of debate.	bioeconomy vision	biomass-based economy	bio-resources vision
For what purposes do farmers use maize biomass? How important are these decisions for household food security?	research questions	what, how	what, how
The maize sector (…) indicated some potential 'demand sinks' and new opportunities in the livestock and food processing sectors that would help to overcome market related constraints. We identified several challenges in realizing these opportunities.	sector	maize sector; livestock sector; food-processing sector	agricultural sectors; food; beverages; tobacco
The aim was to quantify maize biomass production and utilization, and thereby to examine the implications of biomass use on household food security. This paper examines the uses of maize biomass as a bioeconomy crop, and its implications and challenges for household food security.	research objective	quantify; examine	determine; examine
	related aspects	production; utilization; implications; challenges	status; implications; challenges
	case	maize biomass	biomass
Data were collected from a household survey covering 325 randomly selected farmers, interviews with key informants, and focus group discussions in two maize-belt districts, Mecha and Bako, in Ethiopia. Our key informants included maize growers, experts at the district agriculture office, researchers at the national maize research center, experts with the food and feed processing industries and poultry farm managers and owners.	unit of analysis	(two) districts	administrative district
	sub-units	households; farmers; experts; researchers; managers; owners	stakeholders groups
	data sources	survey; interview; focus group discussion	qualitative; quantitative
A multi-stage random sampling technique was employed to draw sample households. Firstly, Mecha district in the Amhara region and Bako district in (the) Oromia region were selected purposively. (…) Secondly, three peasant associations fromBako district and four from Mecha were randomly selected. Finally, a total of 325 maize farmers, 188 from Mecha and 137 from Bako, were selected randomly.	sampling strategies	multi-stage random sampling technique; purposive; random	non-probability; probability sampling tecniques
Data were analyzed using content analysis, descriptive statistics and an endogenous switching regression model.	data analysis	content analysis; descriptive statistics; endogenous switching regression model	qualitative; quantitative
The first section of the results gives a description of the sociodemographic and socio-economic characteristics.	context analysis	descriptive	clearly stated

Source: Own elaboration

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Once the prevailing bioeconomy visions were coded, the codes were grouped into categories to consolidate their meanings and descriptions. The basic categorization of the types of research questions concerned the series: "how", "why", "what", "where", and "whether". For the economic activities, the final wording corresponded to the categories in the International Standard Industrial Classification of All Economic Activities (ISIC) according to the procedure adopted by Food and Agriculture Organization (FAO 2019). We used R-4.0.0 software and WordNet for a computational strategy to group codes based on research objectives, cases and related aspects, and units of analysis. This approach revealed several groupings of synonymous words (synsets) and semantic relations that we verified and validated manually. A major advantage of this method is that it increases the objectivity and reliability of the qualitative analysis. Finally, the codes of the sampling strategies were categorized as either probabilistic or non-probabilistic sampling techniques, data sources and analysis as either qualitative or quantitative, and the context as either clearly or not clearly stated.

Reporting phase. The following section reports the results of the coding and categorization phases for each attribute according to the prevailing bioeconomy visions of the articles. As previously argued, the perception that research questions and objectives have the greatest influence on case study methodological versatility is shared by most involved scholars (Benbasat et al. 1987; Eisenhardt 1989; Merriam 1998; Yin 2014; Robson and McCartan 2016). Given that bioeconomy visions differ in aims and objectives (Bugge et al. 2016), one can conclude that different bioeconomy narratives justify different case study approaches. Moreover, other criteria might highlight methodological differences across case studies. However, different interpretations of the bioeconomy also lead to different conceptions of sustainability models, economic policies, and instruments needed to support them (Vivien et al. 2019). Therefore, using bioeconomy visions as a criterion, we can highlight the environmental, economic, and social implications boosted by different case studies.

Based on the Scopus All Science Journal Classification (ASJC) and the sectors that emerged from the categorization process, the cross-disciplinarity and cross-sectoral approaches of the case studies were investigated. The results were reported using circle semantic network graphs. Similarly, the emerging research objectives, cases and related aspects, units of analysis, and their links were visualized with edge-bundling graphs. Finally, we tabulated the results in terms of research questions, sampling strategies, data sources, data analysis, and context analysis.

RESULTS AND DISCUSSION

The selected articles covered 47 scientific journals and collected a total of 522 citations over two complete years (2018–2019), with an average of nearly three citations per year for each article. Nevertheless, more than 80% of total citations belonged to ten journals, which published around 60% of the selected case studies [complete list in Table S1 in electronic supplementary material (ESM); for the ESM see the electronic version]. Among the case studies, the bio-resources vision of the bioeconomy was the most widespread (40 out of 92), followed by the bio-ecological vision (31 out of 92) and the biotechnology vision (21 out of 92).

Subject areas and cross-disciplinarity. Based on Scopus ASJC, the journals from the sample covered 13 subject areas. Figure 2 reports these (as nodes) and illustrates the cross-disciplinary[1] nature of the case studies according to the bioeconomy vision. The size of each node depends on the number of different journals in that discipline. Each link between nodes represents the number of case studies published in journals that covered the subject areas connected by the link. In this paper, the number of nodes in the networks is used as an indicator of the interdisciplinarity degree of the case studies according to the bioeconomic vision. On the other hand, the number of links is used as an indicator of the transdisciplinarity of the case studies.

Figure 2 is quite revealing in several ways. First, a comparison of the three networks reveals that case studies with a bio-ecological vision adopt more cross-interdisciplinary approaches than case studies with biotechnology and bio-resources visions. The bio-ecological vision case study network covered 11 subject areas and 22 interactions among them. In contrast, the biotechnology vision covered nine disciplines, two of which were not interlinked with any

[1]Following Aagaard-Hansen (2007), we use the term cross-disciplinarity as a general designation for all research forms involving different disciplinary backgrounds; interdisciplinarity refers instead to the engagement of different disciplines to address common issues but still with a discipline-specific approach; transdisciplinarity identifies research that entails more integration across disciplines than interdisciplinarity.

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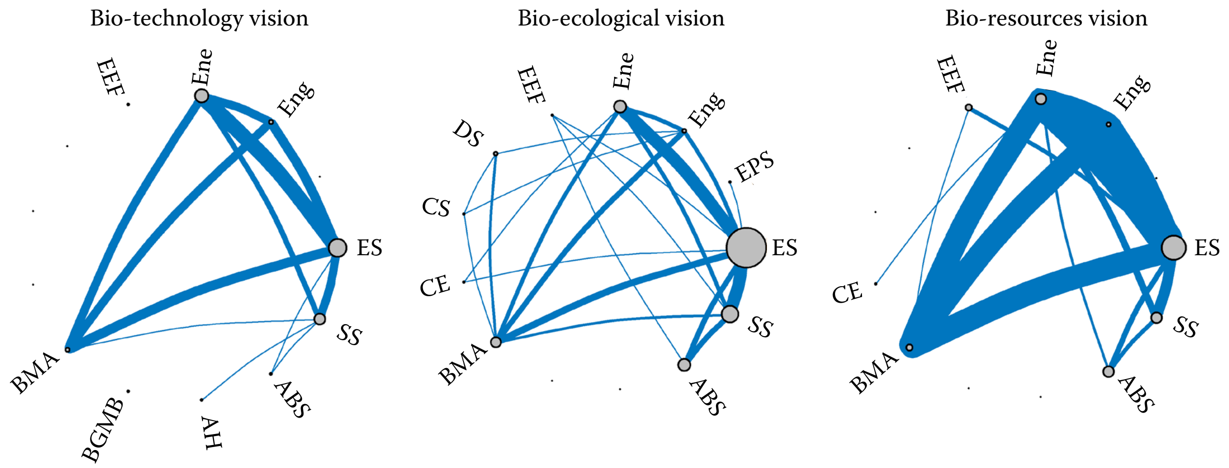

Figure 2: Cross-disciplinarity among bioeconomy case studies under different bioeconomy visions

ABS – agricultural and biological sciences; AH – arts and humanities; BGMB – biochemistry, genetics, and molecular biology; BMA – business, management, and accounting; CE – chemical engineering; CS – computer science; DS – decision sciences; EPS – Earth and planetary sciences; EEF – economics, econometrics, and finance; Ene – energy; Eng – engineering; ES – environmental science; SS – social sciences

Source: Own elaboration based on the reviewed literature published in 2018

other discipline, and 12 links. The bio-resources vision network included 14 links among eight disciplines.

Second, the figure shows that the selected case studies were more frequently related to environmental sciences regardless of the bioeconomy interpretation. The journals in the environmental thematic area were 19 (of 25 journals) in the bio-ecological vision, 11 (of 18) in the bio-resources vision, and 8 (of 13) in the biotechnology vision. Based on the number of links that each node had with others (degree of centrality), environmental sciences occupied the most central position in transdisciplinary approaches. Similarly, the subject area "energy" was central in the bio-resources vision and "social sciences" in the biotechnology vision.

Finally, it is apparent from this figure that most potential transdisciplinary approaches were not concretized in the case studies. The density of a network is a measure of the ratio of the number of existing connections to the number of total potential connections. Considering 13 nodes, 78 potential connections between disciplines were possible in each vision. In the bio-ecological vision, the network of case studies had the highest density of 28%; the bio-resources and bio-technology visions had densities of only 18% and 15%, respectively.

Sectors and cross-sectoral approaches. The sample of case studies covered 14 economic activities. Figure 3 illustrates these sectors (as nodes) and the cross-sectoral approaches captured by the sample case study according to the bioeconomy vision. The size of the node and the width of each link between nodes depends on the number of case studies related to those sectors.

A closer inspection of Figure 3 shows how the case studies focused on different economic activities according to each bioeconomy vision. Case studies with bio-ecological or bio-resources visions had similar profiles, involving 13 different branches of economic activities, while case studies with a biotechnology vision involved 10 sectors in total. The case studies with biotechnology visions focused on bioenergy-related economic activities (14 out of 21). The case studies with bio-ecological visions instead involved primarily agricultural sectors (14 out of 31) and forestry (11 out of 31). Finally, in the bio-resources vision group, the case studies referred most frequently to agriculture (24 out of 40), waste management (15 out of 40), and energy (13 out of 40). Regardless of the bioeconomy vision, agricultural sectors represented the most central node according to the degree of centrality of the network.

Regarding the density of the networks, the selected case studies showed more concrete cross-sectoral approaches than the cross-disciplinarity. Considering 14 nodes and a total of 91 potential connections, the case studies with bio-resources visions covered 63% of the potential interactions between sectors. Lower densities characterized the case study networks of the bio-ecological (38%) and biotechnology visions (17%).

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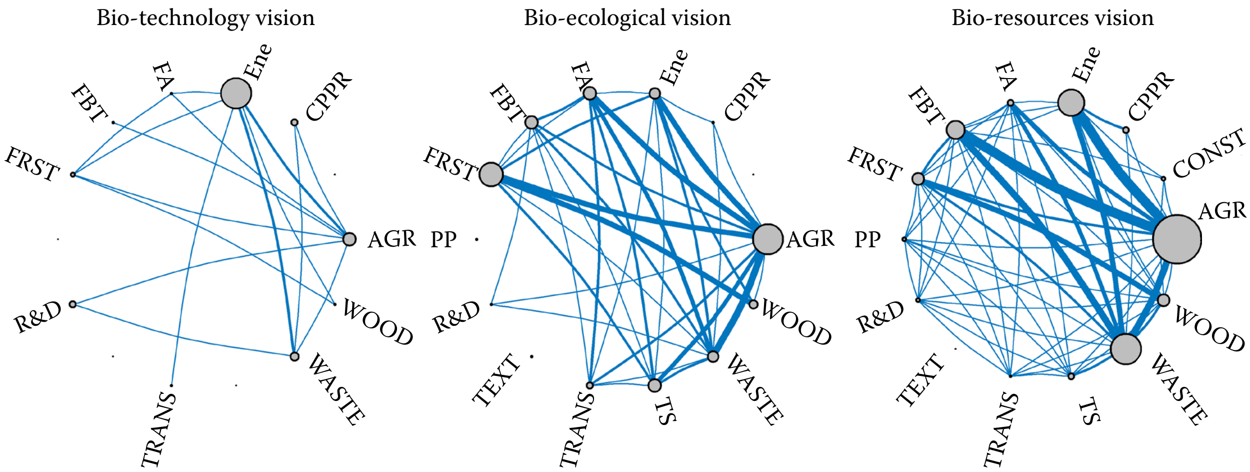

Figure 3: Cross-sectoral approaches among case studies under different bioeconomy visions

AGR – agricultural sectors; CONST – bio-based construction material; CPPR – bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels); Ene – bioenergy; FA – fishing and aquaculture; FBT – food, beverages and tobacco; FRST – forestry; PP – pulp and paper; R&D – research and development; TEXT – bio-based textiles; TRANS – transportation and storage; TS – recreation associated with ecotourism; WASTE – waste management; WOOD – wood products and furniture

Source: Own elaboration based on the reviewed literature published in 2018

Research questions. The selected bioeconomy case studies focused on the "what" and "how" questions (Table 2). The "what" questions [e.g. "What are the main challenges related to the emergence of novel bio-based value chains?" (Carraresi et al. 2018)] were predominant in the bio-ecological and bio-resources visions. This type of question generally defines an exploratory study (Yin 2014), with the aim of developing relevant hypotheses and propositions for further investigation. In contrast, the "how" question [e.g. "How do the economic costs of acquiring a biotechnology compare to the costs saved and additional benefits accrued?" (Kabyanga et al. 2018)] was the most common in the biotechnology vision. This question, as well as "why" [e.g. "Why is the use of biomass for energy different among countries?" (Bentsen et al. 2018)], is usually more explanatory (Yin 2014), providing grounds for modifications of a theoretical framework (Grünbaum 2007).

Research objectives, cases, and units of analysis. For all the selected case studies, it was possible to codify the research objectives, the phenomena studied and related aspects, and the analyzed units (Figure 4). For illustrative purposes, Figure 4 shows only nodes (categories) and edges (links between categories) shared by at least one pair of case studies within the same bioeconomy vision group. Each idiosyncratic form, specific to a case study and not shared by ar-

Table 2. Type of research questions

Research questions	Visions			Total
	biotechnology (n = 21)	bio-ecological (n = 31)	bio-resources (n = 40)	(n = 92)
Not clearly stated	4	9	10	23
Clearly stated				
What	9	16	19	44
How	10	11	13	34
Why	0	0	2	2
Where	0	0	1	1
Whether	1	2	1	4

A case study could have more than one research question, so the sum of the columns can exceed the number of case studies (n)

Source: Own elaboration

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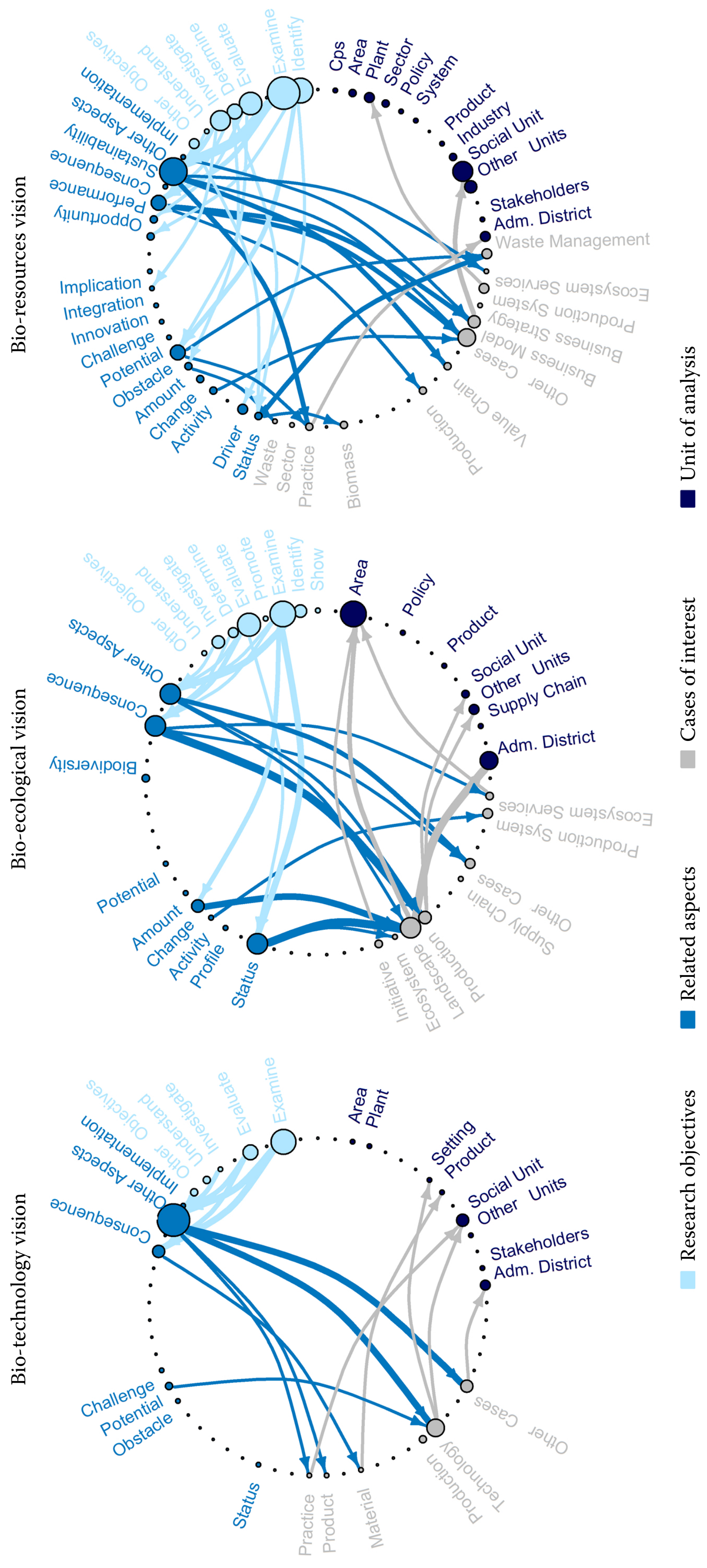

Figure 4. Research objectives, cases, and units of analysis

Adm. – administrative; Cps – consumption production system

Source: Own elaboration based on the reviewed literature published in 2018

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ticles, is grouped into a single node called "others". The size of each node and link is based on the number of case studies.

In terms of research objectives, less than half of the selected case studies (42 out of 92) had multiple research objectives. Regardless of the bioeconomy vision, case study research was adopted mainly to observe or inspect carefully or critically ("examine", 33 out of 92), estimate values ("evaluate", 26 out of 92), and ascertain facts or information ("investigate", 15 out of 92). For instance, case studies were used to examine the implications of biomass use (Mengistu et al. 2018), to evaluate the opportunities and barriers of bio-based production (Singlitico et al. 2018), or to investigate the integration of innovative technologies into bio-based production (Skvortsova et al. 2018). The bio-ecological and bio-resource visions also frequently used case studies to establish identities ("identify", 15 out of 92) and set limits ("determine", 10 out of 92). For instance, case studies were used to identify the contributions to the global environmental impact of bio-based production (Newton and Little 2018) and to determine the direct and indirect value of economic losses to ecosystem services (Toledo et al. 2018).

Compared to the research objectives, the studied phenomena and related aspects showed more heterogeneity across bioeconomy visions. In the biotechnology vision, the case studies focused on the case-specific aspects of mature biotechnologies (7 out of 21), such as alternative bioenergy digesters. Case-specific aspects were generally related to the opportunity to increase production and profitability. In the bio-ecological vision, case studies focused on the sustainability and circularity of agricultural and forest-land use (8 out of 31) and on the environmental impact of bio-based productions (5 out of 31), generally providing reference standards for ecological compensations. Finally, in the bio-resources vision, the case studies exhibited a predominantly process-oriented nature, focusing on several aspects related to business models and strategies (7 out of 40), production and production systems (7 out of 40), waste-management systems (6 out of 40), business practices (3 out of 40), and value chains (3 out of 40). As opposed to the bio-technology vision, these case studies focused on new and emerging phenomena to gather empirical evidence for potential future scenarios. To this end, the case studies also emphasize reducing uncertainty about the properties and availability of biological raw materials, such as biomass and waste.

Regarding units of analysis, half the total sample relied on three types of units: administrative districts (16 out of 92), geographical areas (15 out of 92), and social units (16 out of 92), including companies and households. Administrative districts and geographical areas were mainly approached by the bio-ecological vision, while social units were more frequently analyzed by the other two bioeconomy visions. The units were then split into sub-units involving different categories of stakeholders and individuals, including experts, technicians, policymakers, business members, managers, employees, unemployed, producers, farmers, out-takers, out-growers, end-users, residents, retirees, and students.

Sampling strategies. Forty-seven percent of case studies did not describe their adopted sampling strategies (Table 3). The rest described different non-probabilistic sampling (45 out of 49) and probability sampling (9 out of 49) strategies or a combination of the two (5 out of 49).

For all the bioeconomy visions, the case studies mainly used purposive sampling strategies. In the bio-ecological vision, this strategy was primarily based on the maximum-variation sampling technique (5 out of 12) to collect samples with the most heterogeneous characteristics possible, such as a sample of different ge-

Table 3. Sampling strategies

Sampling strategies	Visions			Total
	biotechnology (*n* = 21)	bio-ecological (*n* = 31)	bio-resources (*n* = 40)	(*n* = 92)
No logic offered	9	16	18	43
Non-probability				
Purposive	11	12	21	44
Convenience	1	1	2	4
Probability	2	3	4	9

A case study could have more than one sampling strategy, so the sum of the columns can exceed the number of case studies (*n*)

Source: Own elaboration

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ographical areas chosen for their different soil, climate, socio-economic, and legislative conditions. In the bio--resources vision, the most common purposive sampling techniques included critical and extreme case sampling (10 out of 21), such as the choice of industries with large quantities of waste streams or a company selected for its economic results and market position. In the biotechnology vision, case studies mainly relied on critical and maximum-variation sampling criteria (8 out of 11 purposively chosen units).

The probabilistic random sampling strategy involved four case studies, three of which shared a bio-ecological vision of the bioeconomy and adopted probabilistic sampling strategies to examine the status and use of ecosystems. The fourth, with a biotechnology vision, used a random sample to review the efficiency and implementation of a public-private program related to the bioenergy sector. If both non-probabilistic and random sampling techniques were adopted, the selection generally involved multiple phases, such as applying a stratified sampling or multi-stage random sampling technique.

Data collection. All the selected case studies described their data-collection methods. Most classified as having bio-resources or biotechnology visions relied on qualitative data sources, while in the bio-ecological vision, case studies relied more frequently on quantitative data sources.

Data triangulation was a common practice as well (Table 4). The case studies with bio-resources visions triangulated various data sources less than the other groups, however. Case studies that developed convergent evidence mainly combined qualitative and quantitative lines of evidence (37 out of 70) or triangulated different qualitative evidence (28 out of 70).

Data and context analysis. The trends observed for data collection reflected those of the data analysis. Most case studies with biotechnology or bio-resources visions adopted qualitative analyses, while quantitative analyses were the most common in the bio-ecological vision group (Table 5).

When adopting a qualitative analysis, case studies frequently indicated a generic qualitative analysis (19 out of 64); when a specific qualitative analysis was mentioned, content and thematic analysis were the most common. Among the quantitative analyses, life-cycle analysis was the most widely used (14 out of 48). Over 20% of the case studies combined qualitative and quantitative analysis.

Turning to context analysis, of the 92 case studies, 23 (25%) did not provide any information on the real-world contextual conditions pertinent to their cases.

Table 4. Number of bioeconomy case study articles (*n*) by data sources and triangulation

Data sources	Visions			Total
	biotechnology (*n* = 21)	bio-ecological (*n* = 31)	bio-resources (*n* = 40)	(*n* = 92)
Qualitative data sources				
Documents (literature)	14	14	23	51
Field visits	3	2	3	8
Focus groups	2	5	5	12
Interviews	15	15	24	54
Observations	4	5	4	13
Web and social networks	0	1	1	2
Workshops	2	0	2	4
Quantitative data sources				
Censuses	0	3	1	4
Databases	3	6	4	13
Maps	1	5	0	6
Questionnaires	4	11	10	25
Records	3	4	5	12
Reports	4	4	1	9
Data triangulation				
Yes	17	26	27	70
No	4	5	13	22

Source: Own elaboration

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Table 5. Number of bioeconomy case study articles (n) by data and context analysis

	Visions			Total (n = 92)
	biotechnology (n = 21)	bio-ecological (n = 31)	bio-resources (n = 40)	
Data analysis				
Qualitative	16	15	33	64
Quantitative	10	20	18	48
Context analysis				
Clearly stated	16	23	30	69
Not clearly stated	5	8	10	23

Source: Own elaboration

This trend was similar in each bioeconomy vision. The case studies that conducted context analyses described the geographical, economic, social, and legislative contexts of the analyzed units.

The effect of bioeconomy narratives on case study approaches. The case study methodology can provide important empirical evidence for a better understanding of the bioeconomy and its components. The exploratory results of this work demonstrate the versatility of case research in the bioeconomy domain. This flexibility varies according to different narratives of the bioeconomy concept. Table 6 summarizes the key categories that emerged for each attribute investigated.

The selected case studies highlight common patterns across the bioeconomy narratives. Among the scientific disciplines, the environmental science perspective was confirmed as the most central. Relationships with the environment and natural resources are integral, essential parts of the reality of any bioeconomic system. Similarly, among the branches of economic activity, primary production and agri-food systems play prominent roles in most bioeconomy strategies given their dependence on biological resources. Other common aspects

Table 6. Summary comparison of bioeconomy case studies by methodological attributes

	Case studies		
	biotechnology	bio-ecological	bio-resources
Disciplines	2 + 7 (12 links)	11 (22 links)	8 (14 links)
Highest degree of centrality	environmental sciences; social sciences	environmental sciences	environmental sciences; energy
Sectors	10 (15 links)	13 (34 links)	13 (57 links)
Highest degree of centrality	agriculture	agriculture	agriculture
Research questions	how (explanatory)	what (exploratory)	what (exploratory)
Research objectives	examine; evaluate	examine; evaluate	examine; identify; evaluate; investigate
Phenomena (case)	technology-oriented	environment-oriented	process-oriented
Unit of analysis	social unit	administrative district; geographic area	social unit
Sampling strategy	purposive (critical or maximum-variation sampling techniques)	purposive (maximum sampling techniques)	purposive (critical or extreme sampling techniques)
Data sources	qualitative	quantitative	qualitative
Data analysis	qualitative	quantitative	qualitative
Clearly stated context (%)	76	74	75

Source: Own elaboration

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concern research objectives and sampling choices. Regardless of a study's vision, the bioeconomy is an emerging field and is thus unexplored in many respects that must be examined carefully and critically. For the same reason, the purposive sampling strategy is the most widely adopted, as it relies on intentionally chosen units of analysis to clarify doubts inherent in the emerging bioeconomy. Finally, the many case studies describing context-specific features reinforce the high context-dependence of bioeconomic success. In addition to these common traits, the case studies exhibited several specificities related to their own visions of the bioeconomy.

The contemporary literature on the bioeconomy draws from case study research to gather new evidence of the spreading use of biotechnologies. Operational biotechnologies are examined and evaluated in detail primarily for explanatory purposes to answer "how" questions. To this end, case studies are specific and narrowly focused and, therefore, less cross-disciplinary and multi-sectoral than in other research fields. Empirical evidence is collected primarily qualitatively from companies that are key players in the biotechnology revolution. Critical sampling or maximum-variation techniques facilitate the analytical generalization of such evidence. The results obtained by these case studies could bolster the development of policies to support bioeconomic expansion, such as funds and subsidies to cover the initial capital costs of technological modernization (Fuldauer et al. 2018).

In the ecology-focused narrative, the case studies confirm the criticisms of the bio-ecological vision reported by Bugge et al. (2016). Through cross-disciplinary global-sustainability judgments, case studies primarily question environmental impact (Corcelli et al. 2018) and local land-use planning (Angelstam et al. 2018; Naumov et al. 2018) stemming from bioeconomic developments. In contrast to the other narratives, the ecological economy narrative steers case studies toward mainly quantitative exploratory assessments based on cases expressing the largest variability. Case studies thus succeed, for example, in promoting sustainable economic development and integrated landscape planning (Naumov et al. 2018) and in providing important reference standards for ecological compensation, which is useful to regional environmental policymakers (Wang et al. 2017).

Finally, consistent with Vivien et al. (2019), the bioeconomy narrative explaining fossil resource replacement through bio-resource capitalization appears to be the most common. Case studies in this area play important roles in anticipating future scenarios. By answering exploratory research questions, case studies shed light on the potential properties, opportunities, and obstacles of bio-based raw materials and innovative processes, focusing on circularity and recycling. For these aspects, case studies should not disregard multi-sectoral approaches based mainly on the qualitative analysis of critical or extreme cases. Evidence gathered in this way emphasizes, for example, knowledge creation, entrepreneurial experimentation, and market formation (Dautzenberg and Hanf 2008; Binz et al. 2014) and aids in the design of appropriate policies to support innovative systems and sustainable transitions (Purkus et al. 2018).

Practical implications and recommendation for future case studies. The existing literature is important when formulating new case studies. Researchers often draw from the most recent published research to choose key methodological elements for their case study analyses. However, as our findings imply, adapting the methodology to the research questions is a crucial phase, entailing that a full comprehension of the bioeconomy case study literature is necessary. To this end, we provide a key to understanding and properly coding case studies based on their methodological and context features, therefore enabling a more systematic detection of their bioeconomy visions.

Improved systematization across the described key attributes would facilitate corrective actions toward a more common logic of case studies in bioeconomy research. In essence, this article aims to encourage the development of case study protocols by highlighting all relevant issues that researchers should consider for their case research in the bioeconomy. A reasonable approach to tackle this need could be developing different research protocols specific to the bioeconomy vision. By developing case study protocols, research and innovation efforts can be directed to "the systematic approaches needed to achieve the aims of the Green Deal" (European Commission 2019). The Commission, for example, may foster the use of case study protocols in research projects for bioeconomic development. Such protocols must incentivize two aspects that are lacking in the case studies reviewed in this article.

The first aspect concerns greater methodological transparency. Several methodological gaps frequently occur without significant differences across bioeconomy narratives. First, authors should pay more attention to their descriptions of their research questions. One-quarter of the selected case studies underestimated the role that clearly stating the research questions plays in full comprehension of the focus of the study

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(Dubé and Paré 2003). The next step would be to apply sufficiently generalizable interpretations of cases and units of analysis. Less idiosyncratic forms of these elements are recommended to facilitate better integrations and comparisons of case studies. Furthermore, our findings recommend more attention to the motivation and logic of sampling strategies to improve the validity, generalizability, and comparability of case studies. For the same purpose, context analysis should be more systematic in the elements discussed. Finally, given the frequent use of generic qualitative analysis, the level of rigour that characterizes quantitative analytical procedures should also be extended to qualitative approaches.

The second aspect concerns the need for more cross-disciplinary, multi-sectoral efforts in bioeconomy case studies. Cross-disciplinary studies in which different research areas work jointly on a specific problem have great potential for creativity and innovation (Borge and Bröring 2017), which is also supported by the identification of cross-sectoral collaborations for value creation (Bauer et al. 2018). In general, any narrative can better leverage case research as a cross-disciplinary, cross-sector platform: strengthening networks of companies and research institutions; fostering the development of localized bio-based technology clusters (Golembiewski et al. 2015); promoting the development of sustainable production systems (Markard et al. 2012; Binz et al. 2014); exploring the potential for further convergence between agricultural activities and less-explored sectors (Carraresi et al. 2018), such as chemicals; and helping to tackle the challenges associated with bio-technology transfer, particularly between academia and industries (Borge and Bröring 2017).

These two aspects – better methodological transparency and greater cross-disciplinary, multi-sectoral efforts – would facilitate the integration of bioeconomic narratives. Instead of competing with each other (Vivien et al. 2019), such as promoting conflicting governmental policies (e.g. the intensification of biomass production and biodiversity conservation) (Naumov et al. 2018), the different bioeconomy visions can complement each other through integrated planning of applied empirical methods. Such synergies are supported and facilitated by the methodological standard that we propose.

In the absence of clear case research protocols for the bioeconomy, the present study provides an initial set of recommendations for future analysis, summarized in the following list: *i*) begin by clearly defining the research questions and objectives, bearing in mind that case research in the bioeconomy domain is primarily used for exploratory with "What" and "How" questions; *ii*) define the bioeconomic narrative to refer to, without assuming a common interpretation of the bioeconomy concept, thus providing a means for a better understanding of the case study; *iii*) select cases and units of analysis carefully, leveraging cross-disciplinary and cross-sectoral designs, knowing that environmental science and agricultural sectors will likely play prominent roles; *iv*) apply sufficiently generalizable interpretations of cases and units of analysis, avoiding idiosyncratic forms using a proper coding system from the previous literature; *v*) adopt a suitable sampling strategy based on the type, nature, and purpose of the study and justify it to improve the validity, generalizability, and comparability of the case study, *vi*) collect data emphasizing data triangulation, that is, use multiple sources to corroborate the same evidence, *vii*) demonstrate the objectivity of the process by which the data are developed into conclusions with a proper level of rigor for both qualitative and quantitative analytical procedures, *viii*) describe context-specific features extensively, recognizing the high context-dependence of any bioeconomy-related phenomena.

CONCLUSION

The primary purpose of this study was to provide a review of the current state of case studies in the bioeconomy by focusing on the differences among three co-existing economic narratives. Our findings have practical implications that should fuel the debate on the systematization of case study analysis in bioeconomy research. Often, dissimilarities among case studies with different bioeconomy visions are speculative. By looking at the literature, this paper provides evidence of common traits and differences in case study approaches across different bioeconomic narratives.

Overall, there is a need for developing common research protocols that support transparency and replicability of case studies in the bioeconomy domain. Such protocols can compensate for the methodological gaps that occur in the bioeconomy literature by incentivizing common research standards. In the same way, greater attention should be placed on transdisciplinary and multi-sectoral efforts as a way to accelerate progress toward the bioeconomy.

The results of this study are subject to some limitations. The main limitation concerns the selected sample of case studies. The choice of a single year was necessary to reduce the high number of case studies without limiting variety. A second limitation relates to a potential

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subjectivity bias. To mitigate this problem, we selected the articles independently and coded them using the systematic coding procedures described in the methodology section.

Further work regarding the current state of case study in the bioeconomy would be worthwhile. We believe that future studies could take advantage of the list of journals that emerged from our analysis to select a multi-year sample of articles and conduct quantitative analysis of the state of case studies in the bioeconomy. A multi-year sample would allow an examination of the level of interaction and integration across case studies. This would be a significant area of improvement in providing a conceptual framework of the sustainability and circularity of the phenomena studied. In addition, for a full discussion of the role of case research in the bioeconomy, a better understanding of instrumental case studies must be developed.

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