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The 'bioeconomics vs bioeconomy' debate: beyond criticism, raising research fronts

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Abstract:

The case for solving the environmental crisis through a bioeconomic transition is gaining momentum. However, the content and aims of such a transition remain unclear, as this could target an economic sector, the analysis of economic activities, or society as a whole, especially in its relationship to the biosphere. This last possible object of transition – society – is where values, models and goals come into conflict. This study examines this confrontation through the lens of the 'bioeconomics vs bioeconomy' debate, in which proponents of bioeconomics have raised an arsenal of critiques against what they consider the simplistic promises of public and private promoters of the bioeconomy. We discuss these critiques, which are mainly macro in scale and/or narrative-centred, and argue for a complementary research effort that supports transition initiatives. This research could take place on three fronts: better understanding bioeconomic systems, evaluating bioeconomic transitions, and identifying how to implement these transitions.

Keywords: socio-technical transition; strong sustainability; agroecology; societal metabolism; sustainability trade-offs

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15 transitions, and identifying how to implement these transitions.

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18 Introduction

19 Despite their similarity, the terms 'bioeconomy' and 'bioeconomics' follow two different conceptual
20 and operational paths, with little mutual permeation. In simple terms, since the late 2000s, the
21 former has been a popular paradigm for environmental policies, emphasizing the need for
22 substituting fossil-resource-based energy and materials. In contrast, bioeconomics is a 50-year-old
23 scientific paradigm that aims to anchor economic thought in biophysical foundations.

24 Today, these two paradigms are coming into conflict in an asymmetrical struggle. The bioeconomy-
25 based rationale for policymaking largely ignores any bioeconomic antecedent and drives a colossal
26 research effort (Lüthmann, 2020). On the other side, proponents of the bioeconomics paradigm
27 actively denounce bioeconomy strategies and public policies as a delusion (Giampietro, 2019) or as a
28 'hijacking' (Vivien, Nieddu, Befort, Debref, & Giampietro, 2019). This conflict is not surprising since
29 the two paradigms point to virtually opposite directions for solving the environmental crisis. The
30 bioeconomy adopts a pathway of economic growth supplied by large amounts of biomass (wood,
31 crops, organic waste, manure, etc.) and the use of biotechnology in multiple sectors. In contrast, a
32 bioeconomics programme (Georgescu-Roegen, 1971) argues for degrowth structured around new
33 societal values (e.g. sobriety) and new social organization (e.g. conviviality), as well as low-tech
34 innovations (e.g. agroecological practices). Of course, this is a schematic presentation of an
35 antagonism that is more complex, and there are a spectrum of positions between the two: in terms
36 of policymaking, the OECD, the US and the EU have different concepts of the bioeconomy that
37 change over time (Levidow, Birch, & Papaioannou, 2012; Meyer, 2017); in the academic sphere,
38 bioeconomics scholars oscillate between promoting a 'soft' or 'hard' transformation (Béfort et al.,
39 2020; Vivien et al., 2019).

40 The idea of a 'bioeconomic transition' is nonetheless rapidly gaining ground (e.g. Asada, Krisztin,
41 di Fulvio, Kraxner, & Stern, 2020; Béfort et al., 2020; de Schutter et al., 2019; Lynch, Klaassen,
42 van Wassenaer, & Broerse, 2020; Palmer, Burton, & Haskins, 2020; Wydra et al., 2021). Just like
43 many other sustainability related concepts, many questions remain unsolved while words

44 disseminate in scientific and policy arenas. The ‘bioeconomic transition’ hence offers diverse
45 understandings, among which: the rediscovery of the multiple uses and sources of biomass after
46 decades of specialization (Colonna et al., 2019; Daviron, 2019); a push for coordinating multiple
47 innovations based on living organisms and establishing a new strategic economic sector around these
48 (e.g. Wydra et al., 2021); a call for broad changes in lifestyles and consumption standards to slow
49 down the environmental crisis (e.g. de Schutter et al., 2019). While such plurality is inherent to the
50 democratic exercise in which multiple values meet and mutually enrich or oppose each other, it also
51 contributes to expanding the diversity of approaches to the bioeconomic transition. The results of
52 these different approaches are linked to specific assumptions and lead to incomparable analyses.
53 Still, they flow between the scientific sphere and the political arena and generate in the end
54 confusion about the ins and outs of different innovations flying the flag for a bioeconomic transition..
55 This confusion also acts as a barrier for stakeholders to position different types of innovations and
56 initiatives within a broader transition process.

57 Clarifying the ‘bioeconomics vs bioeconomy’ debate could help settle certain points for a wide range
58 of stakeholders – researchers included – in the aim of encouraging a more sustainable economy. This
59 could raise awareness of the counterproductive side effects of many promoted solutions, as well as
60 provide incentives to explore new policy and research directions that fit the magnitude of current
61 social and environmental challenges. To this end, this study has two aims. First, it defines the
62 ‘bioeconomy boom’ as a multifaceted and multidirectional process for transition, which, in many
63 cases, is a fallacious project for reducing society’s footprint on the planet, including fossil fuel use.
64 Second, it draws from the large critical arsenal focusing on the bioeconomy to put forward a set of
65 proposals for initiatives with the objective of ‘strong sustainability’ (Ekins, Simon, Deutsch, Folke, &
66 De Groot, 2003; Neumayer, 2003). Based on a normative and reflexive approach to sustainability
67 transitions (Susur & Karakaya, 2021), we (1) present the competing arguments for a bioeconomic
68 transition, (2) describe the different critiques of the dominant bioeconomy paradigm, and (3) identify
69 avenues of research to support a transition that is strongly sustainable.

70 The examples in this paper relate largely to agricultural biomass production, valorisation and
71 consumption, due to the authors’ domain of expertise (agriculture and agroecology, from the
72 perspectives of farming systems and ecological economics). The agricultural sector is a good entry
73 point to offer insights into the bioeconomic transition more generally as it combines significant
74 biomass production and extensive land coverage, subject to controversies in terms of the allocation
75 between food, feed, fibre and fuel uses. Agriculture also embraces diverse products and production
76 systems, including closed-loop systems, such as integrated crop–livestock systems.

77 [1. Competing claims about the bioeconomic transition](#)

78 The definition of the bioeconomy has been the subject of numerous academic contributions,
79 especially in the last 10 years (Bugge, Hansen, & Klitkou, 2016; Hausknost, Schriefl, Lauk, & Kalt,
80 2017; Levidow et al., 2012; McCormick & Kautto, 2013; Meyer, 2017; Vivien et al., 2019). Many
81 classifications have been proposed (see Table 1 for a selective review), revealing the role of
82 narratives and their political content. Our intention is not to provide an additional typology of
83 definitions and visions of the bioeconomic transition, but to attempt to give the context for our
84 analysis of the ‘bioeconomy vs bioeconomics’ debate.

85 *[Tab. 1 Here]*

86 Within the existing literature on the bioeconomic transition, a first macrolevel of distinction lies in
87 *what* is being transformed: an economic sector (1.1), the economic science paradigm (1.2), or society
88 as a whole in its relationship with the environment (1.3).

89 *1.1. First object of transition: an economic sector*

90 In most strategic planning literature, the bioeconomy corresponds to an *economic sector* that
91 includes the activities that produce, transform and value living matter. This definition has been
92 promoted by international organizations such as the OECD and deployed in EU and national
93 strategies. For instance, Wreford et al. (2019) interpret the bioeconomic transition in New Zealand as
94 the emergence of a *new* bioeconomic sector consisting of high-value products, such as biotechnology
95 or pharmaceuticals, and waste-recovery processes, which is expected to take precedence over an *old*
96 bioeconomic sector (food, fibre and energy). A similar conception is found in a Dutch case study by
97 Bosman & Rotmans (2016), which describes a pyramid of biomass value: low-value/high-volume
98 biofuels at the bottom, and high-value/low-volume pharmaceuticals and fine chemistry at the top.

99 When the bioeconomic transition is conceived as the emergence of a new economic sector, one
100 element of division lies in what are considered the most valuable products, economic sectors and
101 production processes (Bauer, 2018; Dietz, Boerner, Foerster, & von Braun, 2018). In some cases, the
102 transition is considered to be driven by the challenge of substituting fossil fuels with bioresources,
103 encouraging an energy-centred transition; in other cases, new technologies based on living
104 organisms are promoted as they offer high added value (Bauer, 2018). The food sector often
105 occupies a marginal position and is mainly regarded as a provider of potentially valuable waste or as
106 a land-use competitor.

107 *1.2. Second object of transition: the economic thought*

108 Another conception of the bioeconomic transition consists of setting a new *scientific paradigm that*
109 *reinvents economic thought*, based on Georgescu-Roegen's bioeconomics (Georgescu-Roegen, 1971;
110 Mayumi, 2009). Bioeconomics is an attempt to reframe economic science and embed it within the
111 theory of biological evolution and thermodynamic principles. The goal of the transition is a paradigm
112 shift in the analysis of economic activities: from the economy being an independent and self-
113 reproducing system (i.e. a machine with its own laws) to being embedded in resource systems and
114 institutions (hence affected by biological, physical and social laws). An important feature of
115 bioeconomics literature is the renewal rate of funds (Couix, 2020). Funds are considered the agents
116 of a transformative process, delivering services but not transformed in the process (Georgescu-
117 Roegen, 1971): e.g. the soil for the transformation of seeds into harvestable crops; the mill for the
118 transformation of grain into flour. Both the soil and the mill need energy to carry out the
119 transformative process, which occurs only at a specific rate. This rate can eventually grow with the
120 aid of add-ons or technological advances, but the latter would in turn require new material and/or
121 energy inputs, relying on the use of other funds.

122 Most bioeconomy literature overlooks the bioeconomics paradigm, despite its anteriority and pivotal
123 role in heterodox economics (and especially ecological economics: see Costanza, Stern, Fisher, He, &
124 Ma, 2004; Melgar-Melgar & Hall, 2020; Röpke, 2004). Hence, a sense of usurpation has coloured the
125 recent writings of the heirs of bioeconomics (Giampietro, 2019; Vivien et al., 2019). Their main
126 grievance is that this omission has led governmental bioeconomy development strategies to neglect
127 the insights brought by bioeconomics theory (see section 2).

128 *1.3. Third object of transition: human societies*

129 This leads into the third possible object of the bioeconomic transition: *society and its relationship to*
130 *the environment*. Here, the normative assumptions of the different bioeconomic narratives come
131 into conflict, as the direction of change, its ends and its means become central. Vivien et al. (2019)
132 point out that the different bioeconomic narratives embed incompatible visions of societal
133 relationships to living organisms, especially in terms of reliance on technology and the management

134 of uncertainty and feedback from ecological systems. They also show that narratives support either
135 'weak' or 'strong' sustainability conceptions, i.e. the possibility or impossibility of substituting natural
136 capital with manufactured capital. The merit of these authors is to tackle the question of the purpose
137 of the bioeconomic transition: continuous economic growth or the survival of the human species
138 (requiring degrowth). Most studies are more ambiguous, remaining on the level of narratives (see
139 Tab. 1). In these cases, the debate appears mainly around the means and models for a bioeconomic
140 transition. Of these, Levidow et al. (2012) distinguish a life-science, biotechnology-based bioeconomy
141 and an agroecological, integrative bioeconomy: two visions that compete in the policies of
142 international organizations. Bugge et al. (2016) reveal three main strands in bioeconomic research
143 works: a biotechnology vision, a bioresource vision or a bioecology vision.

144 The debate surfaces mainly in terms of the societal-related transition (1.3), although not
145 independently of the other two objects of the bioeconomic transition (economic sector, 1.1, and
146 economic thought, 1.2.). For instance, the bioeconomics paradigm supports a political programme
147 that includes the abandonment of weapons, the development of organic agriculture, more moderate
148 lifestyles and an end to excessive consumption (Georgescu-Roegen, 1979). This programme
149 continues to stimulate discussion in the scientific community and has been adopted by the political
150 degrowth movement. It has links with non-mainstream narratives of a societal bioeconomic
151 transition that highlight sufficiency, moderation and biophysical limitations (Hausknost et al., 2017;
152 Levidow, 2015b; Vivien et al., 2019). By contrast, the mainstream narratives of international
153 organizations and national strategies point at the emergence of the bioeconomic sector (of green
154 chemistry, bio-sourced materials, bioenergy production among others), seen as the corner stone of a
155 societal model valuing 'green' employment and 'green' growth. The question of the sector's ability to
156 mitigate the environmental crisis is often not asked; risks of making it worse are kept off the radar
157 (Ruault, Dupré la Tour, Evette, Allain, & Callois, 2022). The result can resemble a dialogue of the deaf,
158 yet the 'bioeconomics vs bioeconomy' debate is worth detailing to gain a more critical and
159 differentiated understanding of the bioeconomic transition.

160

161 [2. The 'bioeconomy vs bioeconomics' debate](#)

162 Although this debate is asymmetric, with the bioeconomy currently having the upper hand, it exists
163 because both philosophies share common ground. They focus on a common object of transition:
164 society and its relationship to the environment. The rationale behind bioeconomics is intrinsically
165 normative and fixes ecological sustainability, universal needs and social justice as the aim of the
166 transition. In contrast, the rationale behind the bioeconomy focuses on the emergence of
167 innovations and their capacity to be scaled up, giving less importance to ecological and social justice
168 goals. Another commonality is that they both take a macroscale, global approach, whether referring
169 to planetary boundaries, decarbonization of the economy, energy efficiency, or economic
170 competitiveness.

171 The debate consists in fact of a list of bioeconomy critiques emerging from different fields, all sharing
172 the aim of contesting the capacity of the bioeconomy to solve or even temper the environmental
173 crisis. 'Bioeconomics', although it fostered the most vivid reactions to bioeconomy strategies,
174 would be too restrictive: other critiques raised by evolutionary economics, regulation theory,
175 industrial ecology, innovation and sustainability research, among others, are also included in our
176 analysis and extend or complement the bioeconomics argument in several respects. But for clarity,
177 in this study, we define the debate as between:

- 178 • a *bioeconomic*s transition: a societal transformation in which the economy is re-embedded
179 within planetary boundaries and ecological constraints
- 180 • a *bioeconomy* transition: a political priority on expanding the use of bioresources and/or
181 biotechnology to emancipate economic development from fossil fuel use.

182 In the followings, we list up the different strands of critiques addressed to the idea of a bioeconomy
183 transition. There is no formal answer to these critiques since they are hardly considered by
184 bioeconomy proponents; to them, core challenges are the feasibility, efficiency and social
185 acceptability of the bioeconomy transition, not its validity. Nonetheless, the tension between the
186 two types of transition is insightful and paves the path to defining new research fronts.

187

188 *2.1. The bioeconomy transition as the continuation of the industrial regime*

189 The notion of “regime” is manifold, and disentangling it is not the purpose of this article. The
190 conceptualizations used to critically analyse the bioeconomy transition include: socio-technical
191 regimes (Befort, 2020; Magrini, Béfort, & Nieddu, 2019), accumulation regimes and food regimes
192 (Allaire & Daviron, 2017; Levidow, 2015b), and socio-metabolic regimes (Giampietro, 2019; Haas,
193 Krausmann, Wiedenhofer, Lauk, & Mayer, 2020; Vivien et al., 2019). Any regime is characterized by
194 structural interactions between subsystems, self-reinforcement processes, and power relations that
195 allow it to change only under specific circumstances. Changes from one regime to another are
196 alternatively called transitions (e.g. socio-technical transitions, socio-metabolic transitions) or crises.
197 Roughly speaking, the industrial regime can be described as a specific mode of socio-ecological
198 organization aiming to emancipate Western societies from the constraints of biomass and living
199 systems as energy suppliers (Giampietro, 2019; Krausmann, Fischer-Kowalski, Schandl, &
200 Eisenmenger, 2008). The ascendancy of the industrial regime relies on the expanding use of fossil
201 fuels in every productive sector (including agriculture), on technological breakthroughs for the
202 extraction and use of these fuels, and specific modes of labour organization and consumption (Allaire
203 & Daviron, 2017; Krausmann et al., 2008). Some authors draw links between the increasing
204 dependence of Western societies on energy and the expansion of capitalism (Allaire & Daviron, 2017;
205 Görg et al., 2019), or even consider that capitalist ideology constitutes the original driver, before
206 industrialization, of the environmental crisis (Moore, 2017). The general critique we examine here is
207 that the bioeconomy transition is not able to challenge the current industrial regime, which is based
208 on an extractive mode of resource use and the objectification of the natural environment.

209 One set of critiques express doubt about the transformative capacity of bioeconomy policies and ask
210 for substantial add-ons. This line of critique recalls that of ‘greenwashing’, highlighted by Birner
211 (2018). For instance, Béfort et al. (2020) warn of the risk that bioeconomy policies would result only
212 in a change in raw materials and the mere ‘biologicalization’ (p. 439) of the productive system. In a
213 longer-term perspective, Allaire and Daviron (2017) observe the evolution of Western society’s
214 relationship to biomass: they note changes in hegemonies, labour organization and political attitudes
215 towards modes of biomass production and use, but not such profound changes as to prompt the
216 destabilization of the current regime. They write: “*The chemical industry, which played such an*
217 *important role in the emergence of the agricultural model of the 20th century, sees biomass as a new*
218 *source of raw materials, just as coal and oil used to be, with the risk of transposing the same mining*
219 *logic to it”* (p 76, translation from French by authors).

220 This critique views the current regime as locked in place, hence gradual or one-off changes are like a
221 drop in the ocean. Without restrictions and incentives to change modes of resource extraction,
222 processing and consumption, a bioeconomy approach cannot solve the environmental crisis
223 generated by accelerated industrialization since World War II (Béfort et al., 2020). In the case of
224 agricultural biomass production, Vanloqueren and Baret (2009) call for public intervention to open
225 up the development of agroecological innovations in contrast to the technological regime that
226 prevails in agricultural research. Magrini et al. (2019) point to the risk that giving too much incentive
227 to one dominant agricultural transition model may prevent, through various reinforcement
228 mechanisms, other legitimate development options and hence shrink the future adaptability of
229 agricultural systems.

230 Other scholars adopt a more pessimistic view: they argue that bioeconomy policies not only recast
231 but reinforce and even extend the harmful extractivist logic of the industrial regime. For example,
232 Pahun et al. (2018) show how easily nature changed status through the (re)discovery of its multiple
233 uses from 'overexploited' to 'mis-exploited', becoming an object of intensification and (genetic)
234 optimization. Birch, Levidow, & Papaioannou (2010) and Levidow (2015b) assert that the early
235 bioeconomy agendas and narratives in Europe and the OECD, especially those of the 'knowledge-
236 based bioeconomy', succeeded in introducing a neoliberal, productivity-led vision of natural
237 resources and associated knowledge. Another study identifies the emergence of a new type of
238 capital, 'sustainable capital': *"Regardless of labour's role, some natural resources are seen as*
239 *inherently sustainable and/or eco-efficient because they are renewable (...) Life itself is characterized*
240 *as capital, forever renewable and forever productive. Thus nature is meant to sustain capitalism*
241 *through its own inherent renewability"* (Birch et al., 2010, pp. 2902–2903). More than ten years later,
242 the diagnosis of Tordjman (2021) extends this, contending that nature has become a new 'fictitious
243 commodity' (sensu Polanyi). These different authors warn that the bioeconomy transition has gained
244 social and political acceptance through two important characteristics – renewability and natural
245 origin – erroneously used as synonyms of sustainability. In this line of critique, the bioeconomy
246 transition is therefore not only insufficient and unconvincing; it signals the worsening of the
247 environmental crisis.

248 *2.2. The bioeconomy transition rests on fallacious hypotheses*

249 Bioeconomy policies are based on two main pillars: substitution and decoupling. These arguments
250 are not exclusive to bioeconomy policies and fuel as well circular economy principles. Because
251 circular economy and bioeconomy are more and more considered as a whole (e.g. the OECD
252 directorate for Science, Technology and Industry, speaking about 'circular bioeconomy', Philp &
253 Winickoff, 2018), we will also use insights from the circular economy literature.

254 Substitution is a shortcut for the substitution of non-renewable resources with renewable ones. Very
255 often, it covers only the substitution of fossil fuels with renewable energies. The substitution
256 principle is often driven by the consideration of the depletion of fossil fuels and/or their increase in
257 price rather than an ecological objective, and has led to biofuel policies in Europe and the US (Dietz
258 et al., 2018; McCormick & Kautto, 2013). From an industrial point of view, substitution involves the
259 use of biomaterials and the development of biorefineries to generate bioenergy and new products
260 (Bauer, 2018; McCormick & Kautto, 2013), which also means, from an economic point of view,
261 capturing a market share from non-renewable products and fossil fuels. In a review of different
262 bioeconomy strategies (OECD, EU, various German landers, Sweden and the US), Meyer (2017)
263 considers that these differ only in the extent to which they envision substitution: 'unspecified bio-

264 based economy', 'reduced dependence on fossil resources' and 'moving towards a post-fossil age' (p.
265 9). A similar argument underlies the policy of developing reuse activities, i.e. activities in which inputs
266 are waste streams from another activity: the hypothesis is that secondary products will substitute for
267 primary products (Zink & Geyer, 2017), hence lowering the extraction of resources and the
268 generation of waste.

269 The second pillar – decoupling - refers to the decoupling of the relationship between two variables:
270 non-renewable/vulnerable resource use or ecological impacts and Gross Domestic Product or well-
271 being (see e.g. the OECD Environmental Strategy, the UNEP report Decoupling Natural Resource Use
272 and Environmental Impacts from Economic Growth, the EU Roadmap to a Resource-efficient Europe,
273 or the UN Sustainable Development Goals). The general idea is summed up in the motto “doing more
274 with less”, which is expected to be enabled by technological innovation (at least). Decoupling posits
275 that there is room for improvement in efficiency: optimizing processes would allow limiting our
276 environmental footprint per capita without compromising our consumption levels. Decoupling
277 generally associates with multiple and cascading uses of resources – be they 'bio' or not – and
278 innovations in technologies (e.g. precision agriculture, DeLay, Thompson, & Mintert, s. d.) or logistic
279 chains (for instance industrial symbioses, Earley, 2015). Once again, bioeconomy and circular
280 economy appear to be the two sides of the same coin (Giampietro, 2019). Indeed, as far as the full
281 circularity of the economy seems unreachable, the bioeconomy is expected to provide the necessary
282 inputs to the productive system, so that renewability is achieved within an imperfect circular
283 economy (Temmes & Peck, 2020). At the same time, recycling within bioeconomic sectors is
284 expected to overcome potential problems of biomass availability and waste generation (Philp &
285 Winickoff, 2018).

286 The criticisms of substitution and decoupling are either due to their implications (e.g. land-use
287 changes or intensification, see section 2.3) or because they are considered fallacious. Sections 2.2.1
288 and 2.2.2 focus on the latter, which echoes the core principles of the bioeconomics paradigm.

289 2.2.1. *Substitution*

290 The hypothesis of substitution is a first challenge. As Asada et al. (2020) emphasize, the idea that the
291 growth of the bioeconomic sector will be beneficial, especially in terms of lowering the dependence
292 of our economies on fossil fuels, is hardly ever questioned. Indeed, their models, as well as historical
293 data compiled in the field of social ecology (Krausmann et al., 2009), do not provide confirmation of
294 bio-based energies replacing fossil fuels. We try here to provide explanations to this absence of
295 substitution at the global scale, based on bioeconomics and ecological economics research.

296 First, in terms of thermodynamics, any material conversion requires funds (Couix, 2020; Georgescu-
297 Roegen, 1971). Currently, many of these funds are manufactured, and hence depend on fossil fuels
298 and raw materials to build and maintain them. A lasting demand for these resources is unavoidable
299 in the context of developing a bioeconomy (e.g. developing biogas value chains requires to use non-
300 renewable and polluting materials, to build production units, ensure transportation etc.). Having said
301 that, partial substitution, as opposed to perfect substitution, could still be achieved. However,
302 rebound effects (Alcott, 2005) constitute another limitation of substitution. Zink and Geyer (2017)
303 explored the case of substitution of primary products with secondary products. They named 'circular
304 economy rebound' cases when circular economy activities provoke a raise in product consumption,
305 and hence undermine the theoretical benefits of these activities on resource use and the
306 environment. Indeed, the authors point out that the use of secondary products does not guarantee a
307 decrease in primary production as if it was a communicating vessels situation. Logistic chains and the

308 market structure are not necessarily suited for this substitution (Zink & Geyer, 2017). Similarly, we
309 can expect biofuel and biomaterial consumption to grow substantially, but by satisfying the overall
310 growth in demand through new distinct markets and supply chains, and not by superseding fossil
311 fuels, plastics and minerals. The consequence would be of two markets growing independently, with
312 their environmental costs added to one another. Thus, substitution appears at least a questionable
313 hypothesis, which deserves more investigation.

314

315 2.2.2. *Decoupling*

316 Modelling and empirical data provide evidence that decoupling (in terms of material resource use
317 and carbon emissions from GDP) is not occurring in the long run on a global scale (Hickel & Kallis,
318 2020; Ward et al., 2016a). First, pollution and resource depletion transfers across space explain this
319 absence (see 2.3) ; second, the relationship between efficiency and lower consumptions of energy
320 and materials is questionable. Indeed, rebound effects apply to the decoupling hypothesis as well.
321 These effects were initially described for productivity gains in the development of steam engines in
322 the second half of the 19th century (Alcott, 2005). Because machines were more productive, they
323 became more economical, which favoured their spread and resulted in increased consumption of
324 coal (Jevons' paradox). Indirect pathways are also possible when the energy difference between the
325 old and the new technology is reinvested in the production of bigger, more powerful or more
326 numerous artefacts. As in the case of steam engines, productivity gains should also take place within
327 biorefineries (Levidow, 2015a), possibly leading to an unexpected boom of demand for input
328 materials. If we consider that increased exploitation of natural resources - even when they fall into
329 the category of renewable resources – can undermine ecosystem functioning (Navare, Muys,
330 Vrancken, & Van Acker, 2021), then bioeconomy and circularity do not allow economic growth,
331 independently from pressuring the environment and ecological renewability. Decoupling might
332 therefore apply at the level of resource stocks, but not at the level of biological renewability.

333 Another argument against decoupling is – once again - that of thermodynamics. The bioeconomics
334 paradigm observes any productive process (Georgescu-Roegen, 1971; Mayumi, 2009) as a chain of
335 material and energy transformations to generate usable products and services for humans
336 (Georgescu-Roegen, 1971; Mayumi, 2009). These transformations require low-entropy energy input
337 and produce high-entropy energy output, in the form of heat, for instance. This dissipation of energy
338 (often accompanied by the production of polluting emissions) is unavoidable. At the same time, the
339 development of human societies has rested upon the production and use of exosomatic tools
340 (Bobulescu, 2015; Georgescu-Roegen, 1971), from two-sided rocks to computers, which multiply the
341 possibilities for doing and knowing of our species in comparison to endosomatic tools (e.g. our arms,
342 brain and legs). Hence, the historical development of humanity is bound up with an increase in
343 energy density and power intensity (Smil, 2008).

344 Drawing on the works of Georgescu-Roegen, Giampietro (2019) interprets the Industrial Revolution
345 as a rupture, in which previously circular production processes based on natural processes became
346 linear. This linearization relies on the depletion of fossil fuels on the one hand, and the accumulation
347 of waste and pollution on the other, i.e. an escape from the low functioning rate of living systems.
348 This makes possible much more rapid exosomatic-led development ('growth'), but in parallel the
349 environmental impact of this continuous destocking process makes the quest for GDP biophysically

350 unsustainable. He concludes: *“a massive increase in the weight of biological processes in the*
351 *economy will slow down the pace of growth of the contemporary economy”* (Giampietro, 2019, p.
352 154). So, rebound effects show that efficiency does not prevent increases in resource consumption
353 and polluting emissions; and thermodynamics shows that relying on natural processes involves
354 degrowth. Both seriously undermine the possibility of decoupling, at least of a decoupling based on
355 efficient productive systems and wide use of biological processes.

356

357

358 *2.3. The bioeconomy transition generates new sustainability problems*

359 While a bioeconomy transition attempts to solve fossil fuel dependency and waste production
360 through substitution and more circularity, some critiques argue that although the expected
361 advantages are valuable, they are bound to have countereffects elsewhere that are potentially more
362 detrimental to the environment. This strand of criticism is certainly the best known and the least
363 bioeconomics-centred; its main arguments are outlined below.

364 First, biomass has a lower energy potential than fossil fuels. Although plant biomass is best valorised,
365 in energetic terms, through direct burning (Ioelovich, 2015), its net calorific values are still in this case
366 two to three times lower than that of hydrocarbons (forestresearch.gov.uk). The energy return on
367 investment of bioenergy (bioethanol or biodiesel) is an order of magnitude less than that of oil and
368 gas (biofuels are around 20 times less efficient: Hall, Lambert, & Balogh, 2014). For these reasons,
369 turning to biomass and biofuel requires access to large quantities of raw materials. Without
370 neglecting the potential of exploiting by-products and waste, major biomass extraction from crops
371 and forests appears necessary. Based on this observation, only two options would allow the
372 decarbonization of the production processes of our energy-demanding economies: exploiting more
373 land for biomass and bioenergy provision or intensifying land use. The impacts would vary depending
374 on the previous land type (e.g. ‘marginal’ land, biodiversity-rich habitats, food or feed crops), and the
375 farming/forestry choices made. Each of these pathways has specific weaknesses, which Lewandowski
376 (2015) has extensively reviewed. Often they generate new environmental problems (e.g. biodiversity
377 loss and ecosystem simplification, weakening of food- or feed-production capacity, soil and water
378 degradation, greenhouse gas emissions), as well as social problems (e.g. low revenue for farmers,
379 increased power asymmetry within global markets) (Lewandowski, 2015).

380 Worse still, geographical transfers (from one place to another) compound the displacement of
381 problems (from one sustainability issue to another). This geographical transfer occurs mainly due to
382 land-use spillover, i.e. “processes by which land use changes or direct interventions in land use (e.g.
383 policy, program, new technologies) in one place have impacts on land use in another place”
384 (Meyfroidt et al., 2020, p. 15). Such spillovers can allow countries implementing a bioeconomy
385 transition to claim good environmental performance while externalizing their environmental costs
386 elsewhere. This type of transfer has allowed, for instance, Western countries to profess successful
387 decoupling trends (see section 2.3) that are now being demystified by indicators that integrate
388 imports and novel flow-modelling methods (Bruckner et al., 2019; Hickel & Kallis, 2020). As an
389 illustration, EU non-food bio-products embody almost as much land area outside as inside its own
390 territory. (14.6 Mha of EU cropland vs 13.6 Mha of extra-European cropland: Bruckner et al., 2019).
391 In contrast, more than half of Indonesia’s non-food cropland ‘flees’ the country as biofuels and

392 textiles processed and consumed in other countries (estimates from the LANDFLOW-EXIOBASE
393 model, Bruckner et al., 2019).

394 A second expectation of bioeconomy policies is to solve, or at least reduce, the waste burden of our
395 consumption levels via cleaner production processes and the development and spread of recycling
396 and circular economic solutions. There is evidence that the ideal of the circular economy is far from
397 taking precedence over linear processes, and that on a global scale, we continue to follow cumulative
398 trends in terms of waste and materials (Haas, Krausmann, Wiedenhofer, & Heinz, 2015; Haas et al.,
399 2020). Moreover, even if circularity was able to overcome the challenge of its deployment and
400 rebound effects (see section 2.2), effectively reducing the accumulation of waste and resource
401 extraction, detrimental side effects would still be possible.

402 A case study that foreshadows the challenges of a 'circular bioeconomy' is that of biogas in Germany,
403 where since 2000 it has expanded at a rapid rate through public incentives and subsidies. One side
404 effect reported by Hennig and Latacz-Lohmann (2017) has been price inflation in farmland rent
405 where biogas units had been set up, while Lajdova et al. (2016) noted competition with feed plants
406 for animals. In France, where biogas expanded later than in Germany and limitations have been set
407 for energy crops, most anaerobic digestion units are supplied with manure and intermediate crops,
408 which could theoretically alleviate some of these drawbacks. Nevertheless, the transformation of the
409 agricultural biomass value chains results in winners and losers. Among the latter can be ecological
410 funds, such as soil when it loses natural organic replenishment, and environmentally friendly
411 agricultural practices such as organic farming when the supply of neighbouring manure is diverted
412 towards digestion units (Marty, Dermine-Brulot, Madelrieux, Fleuet, & Lescoat, 2021). More
413 complex indirect effects of diverting biomass flow can also cause sustainability problems. For
414 instance, while introducing alfalfa in crop rotations had been one of the few agroecology successes in
415 the Aube area of France, this practice was undermined by the development of digestion units, which
416 compete – in terms of input flows – with the dehydration units necessary to cost-effective alfalfa
417 production (Marty et al., 2021). These examples show that even if there were fewer limitations to
418 decoupling and substitution, a new wave of sustainability problems, perhaps worse, might have to be
419 faced.

420 Most of the critiques mentioned take an academic, discursive perspective, and, with few exceptions,
421 without paying much attention to innovations that emerge in the real economy. While such
422 macroscale debate is fundamental, we also consider that another question deserves attention: the
423 bundle of local initiatives that represent potential innovations shaping the emergence of a new, as
424 yet undefined, bioeconomic regime.

425 It is even possible that the macroscale, theoretical critique of the bioeconomy might be deleterious
426 to the bioeconomics ideal. This approach surely boosted the revival of the bioeconomics paradigm
427 but refrained its spread and development through support for local innovations. The next section
428 highlights some insights and research fronts that a bioeconomics perspective could provide,
429 following the call of Béfort et al. (2020) to downscale and operationalize both societal debate and
430 research.

431

432 [3. From a conceptual critique towards operational research fronts](#)

433 Today, many EU member states have translated European bioeconomy policy into national policy,
434 with regional governments the new level for implementing bioeconomy measures. In France at least,

435 this process is largely top-down. A recent report from the French Ministry of Agriculture (CGAAER,
436 2019) calls for a more consistent and integrated vision of the bioeconomy at a regional level and
437 promotes the creation of a specific governance body supervised by government agencies. At the
438 same time, a number of specific local and/or bottom-up strategies have been developed according to
439 local conditions and participating stakeholders – these include initiatives such as contracts for the
440 ecological transition, local food projects, zero net energy territories, etc. These do not necessarily fit
441 into the mould of the EU and national bioeconomy strategy, although they are expected to be
442 consistent with it.

443 Like many national strategies, French bioeconomy strategy promotes economic development based
444 on the production, transformation and commercialization of bio-based products, lying in the
445 mainstream of a bioeconomy transition. However, the French strategy also makes references to a
446 bioeconomics transition. It states (though mainly in a context that justifies the development of the
447 bioeconomy) an obligation of: the preservation of natural resources and functions, sustainability for
448 present and future generations, and respect for planetary boundaries. These ambiguities offer an
449 opportunity to address a wide scope of issues.

450 The malleability in the political use of the term ‘bioeconomy’ further increases when we turn to local
451 initiatives and collective action in France. Plans to relocalize agri-food systems or to foster ‘energy
452 sobriety’ (reducing or avoiding energy consumption) echo a bioeconomics transition. At the local
453 scale, initiatives tend to be heterogeneous and weakly coordinated, with a vaguely defined
454 overarching direction that develops as they unfold. Nonetheless, these initiatives get more
455 bioeconomy research support, since this gets more publicity and national funding. The result is that
456 somehow, the asymmetry of the ‘bioeconomy vs bioeconomics’ debate translates into research
457 support being provided to collective action. Thus, identifying research fronts might help to make this
458 debate more symmetrical, enriching it and producing more connections between local initiatives and
459 bioeconomics insights. These research fronts are listed in Table 2, alongside the critiques they intend
460 to address.

461
462 [Tab 2 here]

463
464 Below we discuss these research fronts grouped by three major topics: understanding bioeconomic
465 systems, the operationalization of insights from bioeconomics research, and the handling of
466 transitional dynamics.

467 468 *3.1. Research front type 1: Exploring and understanding ‘bioeconomic systems’* 469

470 *3.1.1. Systemic lock-ins and levers of change*

471 Most representations of bioeconomic systems have a ‘cradle-to-grave’ logic emphasizing the
472 efficiency of transformation processes (e.g. lifecycle assessments). They offer a value-chain approach
473 to bioeconomic transitions, but neglect the ecological challenges posed by biomass production,
474 especially agricultural biomass (Raghu, Spencer, Davis, & Wiedenmann, 2011; van der Werf,
475 Knudsen, & Cederberg, 2020). As a result of this shortcoming, the use of ‘marginal’ lands and
476 intensification processes (e.g. Clark & Tilman, 2017) become one-size-fits-all solutions for
477 bioeconomy strategies. New frameworks aiming to better integrate the multiple effects of
478 agricultural practices, spatial differences, and ecological dimensions are emerging (Nitschelm, Aubin,
479 Corson, Viaud, & Walter, 2016; Raghu et al., 2011; van der Werf et al., 2020; Wohlfahrt et al., 2019);

480 these help to form a broader understanding of ‘bioeconomic systems’ as socio-ecological systems
481 anchored in territories, and not mere above-ground value chains. Another blind spot in most
482 bioeconomic system representations is value-chain interactions, which add to the complexity of
483 characterizing and directing changes. Accounting for bioeconomic value-chain networks
484 (Lewandowski, 2015) – exceeding the sole agri-food sector and its stakeholders – or modelling
485 interactions between the production, use and recycling nexus of biomass value chains within a
486 specific territory (Wohlfahrt et al., 2019) are promising research directions to overcome this gap.

487 If a better understanding of bioeconomic *systems* is required to take into account production
488 practices, their ecological effects and anchorage in the local area, an understanding of the
489 bioeconomic *transition* does not require the exact same lens. Many lock-ins situations, when new
490 pathways are difficult to introduce even when environmental performance is acknowledged, are
491 linked to value chains and socio-technical regimes. For instance, due to several self-reinforcing
492 mechanisms – including economies of scale, network externalities, increasing returns of information,
493 or institutional support (Magrini et al., 2019), the extension of crop diversification faces difficulties in
494 France, although its agronomic and environmental performance exceeds that of cash crops (Meynard
495 et al., 2018; Magrini et al., 2019). The analysis of agricultural models by Plumecocq et al. (2018)
496 exemplifies the entanglement between farming practices, farmers’ value systems, as well as
497 commercialization and distribution options. Farming systems based on the use of exogenous inputs
498 (whether chemical or organic) generally contribute to globalized commodity-based food systems
499 valuing food security and efficiency. In contrast, biodiversity-based farming systems, drawing on
500 ecosystem services as inputs for their crops, are more often included in local food production and
501 distribution systems (Morel, Revoyron, Cristobal, & Baret, 2020; Plumecocq et al., 2018). Such
502 coevolution can be an advantage, as it could be expected that changes in the configuration of value
503 chains and R&D investment might drive more ecological farming practices and mindsets.

504 At the opposite extreme to value chains, consumption and diets are increasingly emphasized as key
505 drivers to unlock a bioeconomics transition (Priefer, Jörissen, & Frör, 2017). Many large-scale scenarios
506 include the decreasing consumption of meat as a prerequisite for achieving global food sufficiency
507 compatible with sustainable farming practices (see e.g. the ‘Ten Years For Agroecology’ report, Poux
508 & Aubert, 2018) and land-use boundaries (Zanten et al., 2018). Yet these consumption-led transitions
509 can serve as windows of opportunity for dominant actors, whose aim is not a profound change in
510 their production modes. The well-documented case of the conventionalization of organic food is an
511 alert that alternative pathways can be absorbed by the industrial regime, losing their transformative
512 power (Buck, Getz, & Guthman, 1997; García, Guzmán, & Molina, 2018).

513 Although we are gaining insights into the nodes to unlock a bioeconomics transition, at least in the
514 agri-food sector (for a review, see Table 2 in Morel, Revoyron, Cristobal, & Baret, 2020), this
515 knowledge also emphasizes the need to invest more research effort in institutional and coordination
516 issues. Aligning push and pull factors of change (in this case, push coming from socio-technical
517 landscapes and pull from local niches) is for instance defined as key to scale up and maintain the
518 diversification of crops (Magrini et al., 2018; Roesch-McNally et al., 2018). One conclusion derived
519 from this has been to enlarge the type of stakeholders and the design process to what Meynard et al.
520 (2017) call coupled innovation: collaborative ‘open innovation’ including various domains (such as
521 genetic, technological, organizational, institutional) and designers (farmers, agronomists, food
522 industries, consumers, the energy sector, etc.). Other scholars (Morel et al., 2020) have shown that
523 some agroecological models stand ‘outside’ the dynamics of the agri-food regime: they rely on a
524 reduced number of stakeholders and voluntary exclusion from commodity value chains in order to be

525 economically viable. In this case, recommendations could favour institutional arrangements allowing
526 peer-to-peer or horizontal diffusion instead of scaling up.

527 Overall, a better understanding of the resources that can unlock and secure shifting towards more
528 sustainable economies in the long run is a major challenge. As with agroecology, a combination of
529 material, cognitive, technical and socioeconomic resources are all factors favouring successful
530 transitions (Moraine, Lumbroso, & Poux, 2018). Continuous efforts to track and document the
531 diverse changes occurring within bioeconomic systems, as well as their determinants, are therefore
532 critical.

533

534 *3.1.2. Sustainability transfers and trade-offs*

535 The need to adopt a systemic approach to bioeconomic transitions matters in order to identify
536 where, in complex biomass value chains, the strategic levers for change occur, as well as to
537 document sustainability transfers and trade-offs across time, space and sustainability goals.
538 Competing claims on biomass and land use have become an issue of focused attention since the side
539 effects of biofuels – which hardly contribute to global energy production – became visible (Bruckner
540 et al., 2019; Lewandowski, 2015). The biofuel production experiment emphasizes the need to
541 document potential trade-offs *ex-ante* rather than *ex-post* and reveal the blind spots that continue to
542 compromise our understanding of the impacts of the bioeconomy.

543 Globalization counteracts many regional sustainability policies (e.g. ecotaxes) due to the bypass
544 routes it creates (e.g. increases in imports from countries without ecotaxes). Interregional trade-flow
545 accounting has started to encompass the consumption- and production-based human footprint and
546 to demystify the decoupling thesis about material, water, carbon or biodiversity footprints
547 (Zuindeau, 2007; Wiedmann, 2009; Hertwich & Peters, 2009, 2009; Peters, Minx, Weber, &
548 Edenhofer, 2011; Hoekstra & Mekonnen, 2012). Tracking material and energy flows across distant
549 regions also sheds light on the growing power asymmetry between world regions as well as between
550 cities and their hinterland (Bahers, Tanguy, & Pincetl, 2020). Interregional flow accounting should
551 therefore be essential when assessing the contribution and impacts of bioeconomic transitions in a
552 context of globalization (Bruckner et al., 2019). Standardizing methods is, however, the key to foster
553 adoption by international organizations (Brinkman, Wicke, Gerssen-Gondelach, van der Laan, & Faaij,
554 2015; Lewandowski, 2015).

555 Second, there is a need to develop prospective knowledge in order to put different bioeconomic
556 transition options – e.g. based on bioeconomy or bioeconomics – in perspective. The development of
557 spatially explicit land-use models is crucial (Schulze et al., 2015) to learn how supply and demand for
558 biomass and land-use changes interact in different bioeconomic scenarios, and lead to competition
559 between spaces for biodiversity protection, climate change mitigation, food security, and other
560 sustainability goals (Kraxner et al., 2013; Bryan et al., 2015; Choi et al., 2019). These models show
561 how increasing bio-based substitutes for unrenovable resources results in ecological feedback,
562 geographical transfers and indirect land-use changes; they can also help target critical spatial
563 hotspots (Seppelt et al., 2013) and point out when and where changes in living standards are the only
564 resort to reduce the human ecological footprint (Bryan et al., 2015; Heck et al., 2018; Escobar & Britz,
565 2021).

566 Integrated or complex system modelling (Bazilian et al., 2011; Giampietro, 2003; Halog & Manik,
567 2011) are also key tools to deal with unintended or counterintuitive effects (e.g. rebound effects)
568 (Lewandowski, 2015; Therond, Duru, Roger-Estrade, & Richard, 2017; Wohlfahrt et al., 2019).
569 Integrated models combine cross-source knowledge about a given system; they are labelled

570 'complex' when they are able to represent emergent patterns (e.g. agent-based models, feedback
571 loops). For example, Wohlfahrt et al. (2019) developed an integrated modelling framework to assess,
572 in a systemic and ex-ante approach, the implementation of the bioeconomy at the level of a territory.
573 The concept of the water-energy-food-environment nexus (Bazilian et al., 2011; Therond et al., 2017)
574 could further inspire integrated models designed to observe trade-offs across sustainability domains.
575 In the case of food consumption, for instance, 'climate-friendly diets' (vegan or vegetarian) were
576 sometimes found to increase water use (Jarmul et al., 2020). Currently there is still little knowledge
577 about the impacts on water resources and nutrient availability – and not only biomass availability –
578 of competing bioeconomic transition options (Lewandowski, 2015; Rosegrant, Ringler, Zhu, Tokgoz, &
579 Bhandary, 2013).

580

581 *3.2. Research front type 2: Frameworks and proxies to operationalize insights from* 582 *bioeconomics*

583 Comparing the fitness of different scenarios to planetary boundaries (Rockström et al., 2009) should
584 be a widely shared objective. Scholars investigating circular economy policies have stressed the
585 importance of absolute measures of resource use and waste production as normative indicators,
586 rather than ratios (e.g. the share of production coming from recycled or bio- resources) (Akenji,
587 Bengtsson, Bleischwitz, Tukker, & Schandl, 2016; Haas et al., 2015, 2020). Bioeconomics-based
588 frameworks can be of interest to this end. One example is the MuSIASEM (Multi-Scale Integrated
589 Analysis of Societal and Ecosystem Metabolism) framework, which introduces compatibility checks
590 with internal constraints (e.g. demographic composition and human labour available) and external
591 constraints (capacity of the biophysical system to ensure the production of resources and
592 assimilation of waste over the long run) (Giampietro, Mayumi, & Bukkens, 2001; Giampietro,
593 Mayumi, & Ramos-Martin, 2009). Recent developments in this framework have targeted imbalances
594 between the internalization and externalization of resource/emission pressures, helping to highlight,
595 for instance, the irreducible dependence of EU agriculture on 'virtual' flows of land and water, hence
596 the impossibility of extending this model to other parts of the world (Renner, Cadillo-Benalcazar,
597 Benini, & Giampietro, 2020).

598 Indicators reflecting that a society's metabolism is consistent with human and biophysical limits
599 should become the benchmark against which bioeconomic transition options are assessed. At the
600 same time, as the associated methodologies are complex and data intensive, it would also be
601 advisable to invest research efforts in developing proxies. For instance, a thermodynamics approach
602 (e.g. each conversion of matter or energy dissipates energy) adopted by degrowth scholars (D'Alisa,
603 Demaria, & Kallis, 2014) to look for proxies that assess the size of societal metabolism (e.g. number
604 of links and value chains? Amount of heavily processed products in the average shopping basket?
605 Pace of growth of material infrastructure?). Urban metabolism scientists have paved the way by
606 comparing city configurations and lifestyle characteristics with material footprints (Lablonovski &
607 Bognon, 2019; Kalmykova, Rosado, & Patrício, 2016).

608 A second research front regarding evaluative frameworks supporting a bioeconomics transition is to
609 explore how socioeconomic performance is assessed. To change the course of growing human
610 demand for materials, bioeconomic transitions should find alternatives to GDP – a self-reinforcing
611 measure of material consumption (Ward et al., 2016b; Hickel & Kallis, 2020). Promising options lie in
612 more comprehensive and multidimensional social welfare and human development indicators
613 (Fleurbaey, 2009; Andreoni & Galmarini, 2014), and an approach of environmental and
614 intergenerational ethics (Gough, 2015). It has been shown that the free pursuit of self-interest does
615 not mechanistically lead to higher social benefit (Frank, 2011; Johnson, Price, & Van Vugt, 2013),

616 hence individual-centred metrics (including well-being, happiness or capability) often have low social
617 accuracy (Gough, 2015). Of these post-GDP metrics, human-scale systemic development methods
618 (Cruz, Stahel, & Max-Neef, 2009) distinguish universal and irrevocable human needs (e.g.
619 subsistence, protection, freedom, etc.) from need satisfiers, which are highly variable and dynamic
620 across cultures, space and time. While considering the satisfaction of human needs as an imperative,
621 the nature, impacts and distribution of need satisfiers could be questioned and acted upon in
622 consequence. However, driven by solvency, markets continuously fulfil the material demand of the
623 wealthiest, offering new satisfiers and positional goods (that provide status symbols in hierarchized
624 societies), ultimately “at the expense of the environment” (Greenhalgh, 2005). A key research front
625 for a bioeconomics transition is the quest for assessing, monitoring and promoting low-material but
626 socially rich development pathways.

627

628 *3.3. Research front type 3: Objectives and pathways for a bioeconomics transition*

629

630 *3.3.1. Exploring and debating the end purposes of bioeconomic transition initiatives*

631 A research front with broad consensus among authors is to shed light on competing narratives about
632 the bioeconomic transition (see Tab. 1) to enrich the debate and empower stakeholders. Efforts on
633 this subject have produced quite clear accounts of the different imaginaries of the bioeconomy
634 (technology or ecology intensive; based on a rationale of eco-efficiency or sufficiency, etc.) and their
635 respective positions in arena (Bugge et al., 2016; Hausknost et al., 2017; Levidow et al., 2012; Meyer,
636 2017; Vivien et al., 2019). Yet there remains a lack of clarification about the final aims, underlying
637 values and sustainability commitments of these different narratives. The positioning of
638 agroecological models offered by Plumecocq et al. (2018) and Therond et al. (2017) could inspire
639 analyses of bioeconomic models in terms of legitimizing principles, their relationship to strong vs
640 weak sustainability, as well as to underlying conceptions of well-being (individual or social, related
641 solely to material accumulation or more diverse human needs and capabilities). This exercise could
642 apply to international and national strategies as well as to regional policy and local initiatives, as
643 guiding frameworks and stakeholder discourse do not overlap (Bauer, 2018).

644 The underlying idea is that societal change, especially in values and in perceptions of human–nature
645 relationships, is a vehicle for macrolevel change (or ‘landscape’ change in a multilevel perspective:
646 Geels, 2011). There is therefore a need to connect local stakeholder discourse with scientific
647 knowledge, institutions and societal models (Befort, 2020; Lewandowski, 2015; Wohlfahrt et al.,
648 2019). To fill this gap, participatory methods could be helpful, such as quantitative storytelling
649 (Saltelli & Giampietro, 2017), deliberative sustainability assessments (Allain, Plumecocq, &
650 Leenhardt, 2020; Frame & O’Connor, 2011) or participatory scenario development (Bauwens,
651 Hekkert, & Kirchherr, 2020). ‘Soft’ modelling methods, so called because they rely more on discourse
652 than on computational ability, can also help pinpoint the consistency and contradictions of
653 bioeconomic narratives (Bennich et al., 2021; Heimann, 2019). All these methods could contribute to
654 overcoming the framing biases and restricted knowledge introduced by the rationale of a
655 bioeconomy transition. They could foster people’s capacity to grasp the future bioeconomy traced by
656 leading institutions, while helping them to build alternative futures. In parallel, it also seems
657 necessary to downscale the bioeconomic models embedded in national and international strategies
658 and question their fit with local trajectories (e.g. industrial transitions) and specificities (Béfort et al.,
659 2020).

660

661 *3.3.2. Policy issues raised by the transition process: coordination and temporality*

662 Even once the values and end purposes of a bioeconomic model are made clear and assessed against
663 biophysical limits and societal needs, the horizon remains blurry. It is also important to understand
664 trajectories and processes of change in a context of ever-shifting targets and weakly-specified levers
665 of change (production practices, consumption and lifestyles, size of value chains, etc.). Two
666 governance factors of the transition process are especially important to emphasize: the coordination
667 of stakeholders/activities and the management of transition temporalities.

668 Recent accounts of bioeconomic innovations highlight the numerous organizational obstacles and
669 uncertainties that new value chains face: for example, those of biogas (Åkerman, Humalisto, &
670 Pitzen, 2020; Marty et al., 2021). Likewise, innovative business models, such as product–service
671 systems (PSS), which raised high expectations, have created partial disillusionment. The initial idea
672 was that shared PSS (e.g. a bike-rental service) could substitute for individually owned goods, hence
673 reducing overall material demand. However, the environmental gains from PSS have proven limited,
674 except when they lead to more structural changes driven by ‘functional results’ (e.g. providing a
675 comfortable working temperature with passive solar design, for example, rather than providing
676 heating or air-conditioning equipment as an end) (Tukker, 2004). It has been shown that the
677 implementation of ambitious PSS quickly faces socio-technical lock-ins, although proactive system
678 governance, acting to push the demand, for example (Hannon, Foxon, & Gale, 2015), can help to
679 remove these. Regulatory and normative policies are pointed out as necessary to embed the
680 required changes into everyday behaviours and new societal values to secure long-term changes
681 (Mont, 2004). Also, specific competences to coordinate people holding plural value and knowledge
682 systems appear necessary to trigger any transition process: some advocate for the production of
683 inspiring narratives while listening and learning from arising resistances (Kristof, 2020), others for
684 value-articulating tools (Chamaret, O’Connor, & Douguet, 2009; Matos Castaño, van Amstel,
685 Hartmann, & Dewulf, 2017). The governance factors and processes that could help to activate
686 systemic changes remain a major research front.

687 Insights gained in the field of design (and co-design) for sustainability (Ceschin & Gaziulusoy, 2016)
688 could help change the focus from product or even value-chain innovations to a multilevel perspective
689 of system innovation (e.g. socio-technical regimes) and help define more inclusive and effective
690 institutional arrangements (Mont, 2004). Such a conception of co-design is gaining popularity in the
691 case of agroecology, for instance (see 3.1). A specific challenge, rarely tackled, is that of transient
692 economic activities necessary in the transition stage to mitigate the effects of past and current
693 economic systems (e.g. to remediate environmental damage), but expected to become useless or
694 marginal in a less environmentally impactful economic system (Ruault et al., 2022). The management
695 of transition temporalities also involves linking the dismantling of unsustainable activities with the
696 development of other more sustainable activities when the transition from one to the other is
697 impossible. As Rogge & Johnstone (2017) point out in a study on the energy transition in Germany,
698 phase-out policies, by giving credibility to the political commitment to the ecological transition, can
699 both encourage private investment in sustainability innovations and make room for the diffusion of
700 competing alternatives.

701

702 Conclusion

703 Behind every innovation vaunted by bioeconomy strategies, one could denounce its side effects,
704 counterproductive mechanisms and hidden agendas. However, this message alone is too simplistic
705 and unbalanced: although a blatant lack of reflexivity characterizes bioeconomy discourse,
706 bioeconomic policies are not a monolith of initiatives with the aim of fuelling capitalist growth and

707 deaf to ecological and societal alerts. If criticism and deconstruction of the bioeconomy are not
708 followed by an operational research agenda, this may unwittingly contribute to building a preference
709 for the status quo. Experimenting with changes is needed – although caution must be taken not to
710 create a cure worse than the disease or to employ soothing words that obscure the extent of the
711 crisis. The ways to prevent this are reflexivity about innovations, collective debate about their final
712 aims, and awareness about the trade-offs they produce.

713 The aim of this article is twofold: to reveal certain fallacies regarding the mainstream bioeconomy
714 transition and to outline constructive research proposals to redirect the course of this transition.
715 These proposals include coupled economic-biophysical models, absolute metrics of sustainability,
716 renewed well-being frameworks, consideration for entire value chains and value-chain networks
717 (including production practices and consumption modes), as well as pathways for developing low-
718 material and socially rich innovations while phasing out the activities, knowledge, technologies and
719 values that maintain and reinforce the current industrial regime. Many of the research fronts we
720 focus on are already underway, within and outside bioeconomics scholarship, yet they lack
721 coordination. For instance, accounting frameworks, indicators and proxies allow the critical analysis
722 of the bioeconomic transition as a research object, but are weakly adapted to and little used within
723 deliberative settings for defining socially and ecologically desirable transition narratives and
724 pathways.

725 There is an undeniably long and difficult road before research can effectively support a bioeconomic
726 transition leading to a more sustainable society. And without wider institutional change, research has
727 little, if any, transformative capacity. In this sense, the ball is in the court of politics. The power
728 balance that favours soft transition options by focusing on instruments of the bioeconomy
729 (biotechnologies, biorefineries, etc.) while blurring normative sustainability goals is the first obstacle
730 to overcome. The development of the bioeconomy is seen as a central part of many current
731 ecological transition policies (EU green deal, the US Green New Deal, Paris Agreement
732 commitments), since it offers a seducing promise – yet to be realized - of employment, innovation,
733 economic wealth, climate change mitigation and renewability. Instead of focusing on this global
734 promise and its plausibility, we could turn our attention to local level experiments, through
735 dedicated research settings. Innovation and change often come from the bottom, making it vital to
736 support local initiatives while striving to frame and assess achievements and progress against
737 ambitious standards at the macro and institutional levels within a strong sustainability perspective.
738 This might be the case with agriculture: although alignment with national and international strategies
739 is an undeniable driving force, many changes also incubate at farm level and spread through
740 horizontal exchanges. While the negotiation of the national strategic plans for the CAP 2023-2027 is
741 still underway at the end of 2021, the transformative power of bottom-up agroecological initiatives
742 should not be overlooked.

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Selected references	Position of the authors / Aim of the work	Source material	Objects of the analysis (<i>What is depicted?</i>)	Analysis areas (<i>What is it contrasted with?</i>)	Resulting clusters
Levidow, Birch, & Papaioannou, 2012	To clarify the economic and techno-scientific paradigms underlying the EU discourse on the bioeconomy; to de-naturalize the dominant life-science vision of the bioeconomy	EU strategy documents and stakeholder interviews	Visions of the bioeconomy embedding a desirable reality, societal objectives and a strategy to reach it	<ul style="list-style-type: none"> Economic and sociotechnical imaginaries Paradigms of agri-food engineering, product quality and knowledge 	<ul style="list-style-type: none"> Life-science vision: bioeconomy as a transition from a fossil fuel to a bioresource economy allowed by converging technologies and global value chains Agroecology vision: bioeconomy as a means for sustainable and equitable provision of food, fibre and energy, based on diversified low-input agricultural systems and short supply chains
Pfau, Hagens, Dankbaar, & Smits, 2014	To list the possible contributions of the bioeconomy to sustainability as well as its risks, and the conditions for a sustainable bioeconomy	Corpus of articles retrieved from a specific keyword request on five databases	The way scholars qualify the link between the bioeconomy and sustainability	<ul style="list-style-type: none"> Contributions of the bioeconomy to sustainable development Conditions under which these contributions are made possible Problems that impede the achievement of sustainability 	<ul style="list-style-type: none"> Bioeconomy as inherently sustainable Bioeconomy as beneficial for sustainability under certain conditions Bioeconomy as a potential source of benefits and problems Bioeconomy as a threat to sustainability
Bugge, Hansen, & Klitkou, 2016	To explore the content of the term 'bioeconomy' in academic literature	Corpus of articles retrieved from a specific keyword request on the WoS Core Collection	The way scholars conceive of the bioeconomy (' visions ' of the bioeconomy concept)	<ul style="list-style-type: none"> Aims and objectives assigned to the bioeconomy Value creation Drivers and mediators of innovation Spatial focus 	<ul style="list-style-type: none"> Biotechnology vision: bioeconomy as a means for growth and job creation, through the development, application and diffusion of biotechnology, taking place in innovation clusters Bioresource vision: bioeconomy as a means of reconciling economic growth and sustainability through cross-sectoral innovation allowing the conversion and valorisation of biomass and waste Bioecology vision: bioeconomy as a means for sustainability, requiring the enhancement of biodiversity conservation and ecosystem services, as well as localized food systems
Hausknost, Schriefl, Lauk, & Kalt, 2017	To define and explore a techno-political space for the bioeconomy; to highlight discrepancies between official documents, stakeholder discourse and biophysical constraints	Policy documents, stakeholder interviews and scenarios from biophysical modelling	Societal master narratives: the specific visions of societal development conveyed by different bioeconomic narratives and scenarios	<ul style="list-style-type: none"> The technological dimension of bioeconomy narratives (from industrial biotech and agroecology) The socio-economic goal assigned to the bioeconomic transition (from capitalist expansion to sufficiency) 	<ul style="list-style-type: none"> Sustainable capital: bioeconomy as a technology-led transition that sustains economic growth Eco-growth: bioeconomy as the realization of the economic potential of agroecology and organic farming Eco-retreat: bioeconomy as a systemic transition that decreases human activities, from

					<p>production to consumption, within planetary boundaries</p> <ul style="list-style-type: none"> • Planned transition: bioeconomy as a contraction of material consumption driven by states and achieved through the efficiency gains offered by biotechnology
Meyer, 2017	To draw attention to the overoptimistic promises of bioeconomy strategies	International and national (European, esp. German) policy documents	Visions: The political and operational content of bioeconomy strategies	<ul style="list-style-type: none"> • The foci of the strategies in different domains (technology, knowledge, economy, space) • Framing these in terms of the problem tackled, sustainability, land use, agricultural models and resource utilization 	<ul style="list-style-type: none"> • Biotechnology-centred vision: life science and biotechnology drive innovation and improve economic competitiveness • Transformation-centred vision: biomass conversion and utilization allow transforming the economy from fossil-fuel dependent to bio-based • Ecology-centred vision: Agroecological engineering favours sustainable production of quality food, ecosystem services and nutrient cycling, and social innovation, such as local production/consumption networks, reduces biomass demand
(Bauer, 2018)	To disentangle the apparent consensus on the bioeconomic transition; to open up the diversity of different and conflictual discourses	Statements extracted from Swedish press articles, strategic documents and innovation projects	Narratives based on the clustering of statements (Q methodology applied to 20 individuals)	<p>Q analysis resulting in three factors representing archetypal narratives, revealing three lines of debate:</p> <ul style="list-style-type: none"> • Types of products stimulating the development of the bioeconomy (energy products vs new advanced products) • Politics of knowledge (spreading and applying current knowledge vs investing in the creation of new knowledge) • Governance (state intervention vs business-centred innovation) 	<ul style="list-style-type: none"> • F1 'Let firms innovate at their own pace': Bioeconomy as business-led innovations, especially from the forest industry, ensuring growth and sustainability. • F2+ 'Energy is the key issue': Bioeconomy as driven by the challenge of global climate change, requiring state incentives and technology investments to substitute petroleum with bioproducts. • F2- 'The bioeconomy, an endless frontier': Simple substitution will not suffice to manage global problems; new knowledge and R&D is required, especially in the chemical industry. • F3 'A green intervention agenda': Bioeconomy through public policy interventions (research, objectives, policies targeting the demand for bioproducts, finance) to transform industrial and economic structures that the market alone cannot address.
Vivien, Nieddu, Befort, Debref, & Giampietro, 2019	To allow ecological economists to re-appropriate and enrich the bioeconomy debate	Documents (scientific publications and grey literature); stakeholder	Narratives: the formalization of stakeholder expectations, driving strategic resource allocation (production	<ul style="list-style-type: none"> • Nature/economy relationships • Socio-technical relationships • Sustainability model • Governance model 	<ul style="list-style-type: none"> • Type I Bioeconomy: Human activity is reduced within the biological and physical limits of the biosphere and coevolves with ecological systems, while technology is regarded with prudence and put under democratic control.

		interviews; reports from participant observation at bioeconomy conferences	of strategic documents, funding of research programmes etc.). Narratives are seen as an entry point to stakeholder strategies.		<ul style="list-style-type: none"> • Type II Bioeconomy: Biotechnology fosters a new economic growth cycle, and living systems become the factories of the socioeconomic system. • Type III Bioeconomy: Biomass raw materials enter biorefineries, which spread and allow a transition towards less fossil-fuel-dependent and more circular economies.
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Table 1 : Selected overview of classifications of bioeconomic narratives and visions

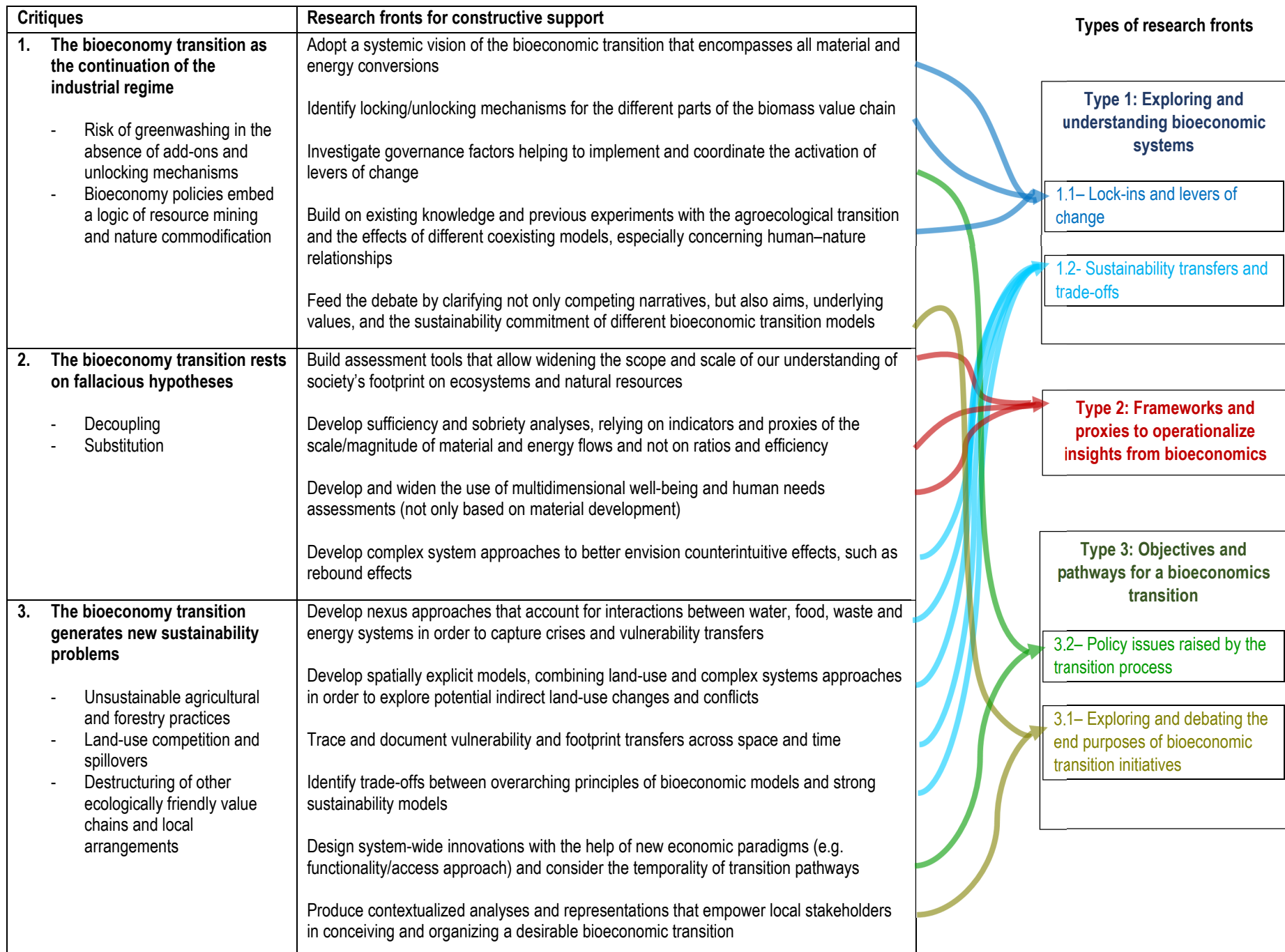


Table 2: The bioeconomy vs bioeconomics debate in terms of critiques and research fronts