



Promises of Bioeconomic Change as a Strategy for Avoiding Socio-Ecological Transformation

The bioeconomy and its untenable growth promises: reality checks from research

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Abstract

This paper starts out from the observation that recent official bioeconomy strategies and policy concepts are markedly more moderate in their promises of economic growth compared to the high-flying expectations of a ‘biotech revolution’ promoted around the turn of the millennium. We argue that this stepwise process of moderation is partly due to a series of ‘reality checks’ to which various strands of research on the bioeconomy have (willingly or unwillingly) subjected these promises, forcing governments to move away from visions exposed as unrealistic and to adopt more humble ones. We identify four such ‘reality checks’, originating from research on (a) bioeconomy discourses and knowledges, (b) contestation and power dynamics among actors and competing interests in bioeconomy politics and policymaking, as well as on (c) the economic and (d) biophysical dimensions of existing bio-based economies. In conclusion, we argue that bioeconomy research should adopt a broader perspective that considers transitions toward bio-based processes and resources as but one element in a comprehensive social–ecological transformation of current modes of production and living, and that understanding the dynamics of societal conflict around that transformation is crucial for assessing the social possibility of bioeconomy visions.

Keywords Bioeconomy · Social–ecological transformation · Biotechnology · Growth promises · Green capitalism · Ecological modernization · Promissory discourses · Technological solutionism

Introduction

The notion of the bioeconomy has recently risen to prominence as both an analytical and a policy concept. Minimally defined as an economy based on substances and materials made from or produced by living organisms, it has always been closely associated with the concept of economic growth, albeit in highly contrary, even polarized ways. At one pole of the controversy is the tradition of Nicholas Georgescu-Roegen, the pioneer of biophysical economic analysis, who coined the term ‘bioeconomics’ in the early 1970s.

Arguing that economies cannot escape the limits imposed by the laws of thermodynamics and that a bioeconomy would be forced to abandon the fossil logic of linear resource extraction in favor of adaptation to the circular reproductive logic and temporality of its living substrata, he also became a founding figure for ideas of *décroissance*, or degrowth (Georgescu-Roegen 1971; Vivien et al. 2019). At the other pole is the highly promissory discourse around an impending “life science revolution” and the allegedly unprecedented growth potential of biotechnology that emerged in the wake of the digital technology hype of the late 1990s and is often traced to the writings of Life Science venture capitalist Juan Enríquez Cabot (Enríquez 1998; Enríquez and Goldberg 2000; see Petersen and Krisjansen 2015).¹

It was the latter spirit that the OECD built on when it moved to establish ‘bioeconomy’ as an international policy concept. Its 2009 strategy paper (OECD 2009) framed bioeconomy explicitly as a growth regime driven by advances

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¹ Actually, Enríquez never seems to have used the term ‘bioeconomy’. Only ‘biotechnomy’ is on record (Enríquez 2002).

in biotechnology. Many national governments and the EU soon followed suit and adopted strategies promising growth from bioeconomy (European Commission 2012; BMBF 2010; see Fund et al. 2015). However, compared with the OECD's techno-optimistic visions from less than 15 years ago, the most recent iterations of these strategies, particularly in Europe, appear significantly humbler in their growth promises, instead presenting themselves more as an integral part of efforts to develop a sustainable and climate-neutral economic model in line with the UN's Sustainable Development Goals (European Commission 2018; BMEL and BMBF 2020, cf. Holmgren et al. 2020).

Our argument in this article is that research on the bioeconomy from a broad variety of disciplines—including the research funded by those same governments as part of their efforts—has played a key part in effecting this shift away from a growth-centered and toward a sustainability-focused rhetoric.

Promises of marrying growth and sustainability have always faced critical scrutiny. Georgescu-Roegen was by no means the only scientist to question the idea that growth and unsustainable resource use can be decoupled and that long-term compound economic growth—which, at a hypothetical annual rate of 3%, implies a doubling of the economy's size every 23 years, or a tenfold multiplication every 80—on a post-fossil basis could be conceivable at all (Giampietro 2019; Haberl et al. 2020; Hickel and Kallis 2020; Wiedenhofer et al. 2020). Fully substituting bio-based and renewable materials and energy for the enormous and still-increasing volumes of fossil resources currently used while remaining on a growth trajectory is assessed as unrealistic by many experts (Hausknost et al. 2017; Grunwald 2020; Gawel et al. 2019).

There is good reason to believe that bioeconomic growth promises are biophysically unfounded. Yet, we want to argue here that exposing the biophysical limitations to bioeconomic growth is perhaps the most powerful, but not at all the only challenge that the promises have been subjected to. Apart from socio-political contestation by NGOs and other critical actors, which has been relatively weak in a policy field that was long hardly known to the broader public (Lühmann 2020; Riemann et al. 2022), what led to the newer strategy papers' more moderate rhetoric was a whole series of research-based 'reality checks' to the growth promises. Resulting from work in a broad variety of disciplines, focusing on widely different aspects of the bioeconomy, based on all kinds of conceptual and methodical approaches, and sometimes even contrary to researchers' own intentions, these reality checks have exposed the promised growth as either impossible or undesirable, or both. The more apparently the initial expectations became untenable in the face of mounting evidence from officially commissioned research, the greater the need became for governments to reiterate

their policies in a language centered around sustainability rather than growth.

In what follows, we first set the stage by giving a brief account of the promissory bioeconomy discourse since the turn of the millennium and the more recent process of its moderation, with a focus on Europe and particularly Germany. We then briefly introduce our conceptual tools and the procedure through which we arrived at our systematization of the very broad research literature on bioeconomy, before moving on to discuss the multiple 'reality checks' feeding into that moderation from research on bioeconomy as (a) a set of discourses and knowledges, (b) a contested field of actors and interests, (c) an economic sector and (d) a biophysical reality.²

Growth and bioeconomy policies in Europe: moderating expectations

The promissory character of the policy discourse around the bioeconomy has long been critically addressed by social scientists: It has been characterized as active 'future making' (Hilgartner 2007, p. 382), as a 'promissory discourse' (Petersen and Krisjansen 2015, p. 28), a 'promissory economy' (Sanz-Hernández et al. 2019, p. 113), and an 'economics of technological promises' (Giampietro 2019). Front and center among its promises has always been the claim that it would be a 'new engine of growth' (Petersen and Krisjansen 2015, p. 28), offering big rewards to biotech companies in terms of profits, workers in terms of jobs, and governments in terms of tax revenues.

The promissory impulse was more than evident in the early biotech-centered ideas of bioeconomy as promoted by the OECD, which built on utopian sci-fi visions unleashed by the sequencing of the human genome. Biotech promised to be the 'next big thing' after the 'digital revolution', with its proponents heralding it as 'the life science revolution' (Enriquez and Goldberg 2000). That promise survived the bursting of the dotcom bubble and provided the momentum for the OECD's seminal 2009 report on 'The Bioeconomy to 2030', which referred to the 'bio-revolution' as bringing a 'new wave of innovation, driven by the contributions of

² This article is based on pp. 1–28 of an earlier working paper (Eversberg and Holz 2020), published online at https://www.flumen.uni-jena.de/wp-content/uploads/2022/02/Working-Paper-Nr.2_22022022_final.pdf, <https://doi.org/10.13140/RG.2.2.30275.84007>. The original text was significantly shortened and streamlined, a new concluding section as well as the section on concepts and procedure added and a substantial number of further amendments and improvements were made. Most changes were prompted by the comments of three anonymous reviewers, whom we thank for their helpful and constructive remarks.

the biosciences to new and better products affecting every aspect of human existence’ (OECD 2009, p. 14). Although it extensively drew on sustainability rhetoric, the vision it presented conceived of bio-based processes and products not as alternatives to fossil-based ones, but rather as sources of *additional* growth.

In the EU, the OECD’s early debates inspired the concept of a ‘knowledge-based bioeconomy’ (KBBE) (Patermann and Aguilar 2018), which integrated the visions of the life sciences and biotechnology industry (Hausknost et al. 2017, pp. 3–4), but put greater stress on sustainability aspects, especially on substituting biomass for fossil resources (Patermann 2015). Ongoing criticism, particularly from the newly founded European Technology Platform ‘TP Organics’, a stakeholder forum of the organic sector officially recognized as an advisory body to EU research policy, significantly influenced the EU’s 2012 bioeconomy strategy ‘Innovating for Sustainable Growth: A Bioeconomy for Europe’ (European Commission 2012; Levidow et al. 2019). The compromise guiding its narrative—the idea of a globally competitive economy based on renewable biomass and ‘green growth’—presented a somewhat more moderate and less blatantly techno-optimistic version of the OECD’s biotech-centered promises.

With hindsight, the boom of the ‘promissory life sciences’ (Petersen and Krisjansen 2015) and the intensifying debates surrounding sustainability and the need to combat global heating were the twin seeds that current bioeconomy policy grew out of since the late 1990s. With escalating ecological crises, the core promise increasingly came to be that growth and sustainability could be reconciled after all (Hackfort 2015). By upholding the win–win narrative of green growth, bioeconomy policies offered a way to avoid facing the prospect that growth may be part of the problem rather than the solution (Grunwald 2020, 2016; D’Amato et al. 2017; Levidow et al. 2019).

The EU strategy’s 2018 update ‘A Sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment’ (European Commission 2018) marks a further step in at least rhetorically moderating the promises. ‘Growth’ has disappeared from the title, but figures as one out of five objectives framed in terms of the UN’s Sustainable Development Goals, next to food security, sustainable resource management, independence from fossil imports and climate protection (European Commission 2018, p. 26). It has thus been rearticulated as a key element within a greater promissory framework: bioeconomic growth is to drive job creation, enable ecological–economic ‘win–win-situations’, help reach the EU’s emissions targets and reduce resource consumption, all while basically leaving existing modes of production and living untouched (European Commission 2018, pp. 5–6). Couching the growth promise in terms of the SDG framework could thus also be

seen as an attempt to ultimately reinforce it by integrating criticism into a more elaborately reiterated ‘green growth’ strategy.

The German government’s new bioeconomy strategy (BMEL and BMBF 2020) takes the logic of rhetorical moderation even further. Its first sentence asserts: ‘Sustainability and climate protection are the central issues of the twenty-first century’ (BMEL and BMBF 2020, p. 3), while growth is merely mentioned in passing in the latter chapters. Overall, the earlier promissory optimism seems to have become untenable, forcing policymakers to edge toward at least rhetorically acknowledging a tension between growth and successful de-fossilization. However, instead of the growth promise having been abandoned altogether, what has occurred may be more accurately described as an inversion of the terms of the growth-sustainability connection: whereas earlier, growth had appeared as the central promise, made all the more attractive by the expected sustainability gains, the core promise now is that the bioeconomy can help make society sustainable, and bioeconomic growth is framed as a necessary element and condition for achieving that aim.

This change in rhetoric—albeit not necessarily in concrete measures and funding priorities (see Lühmann 2020)—reacts to political contestation and critical interventions from NGOs (Civil Society Action Forum 2019). Yet, debates around these strategies have been a domain of experts and largely went unnoticed by the public, rendering tangible pressure on policymakers from civil society effectively absent. It thus seems likely that the change in tone has also been driven by developments in bioeconomy research.

Reality checks: what they are and how we identified them

Conceptual clarifications: promises and reality checks

Since their inception, the promissory visions of bioeconomy concepts and strategies have been challenged not only by political critics, but also by research findings from a range of fields of inquiry, including research funded by the same governments that pinned high hopes on the bioeconomy’s growth potentials. Investigating the bioeconomy’s preconditions and implications in their biophysical, economic, social and political dimensions, this work has presented a series of challenges to the policies, requiring governments to include an increasingly broader set of concerns into their considerations, and contributing to the adoption of a rhetoric that presents the bioeconomy primarily as a sustainability project. Some challenges were intentionally mounted by researchers critical of the bioeconomic growth agenda, while others simply result from research findings that contradict its narrative.

Either way, research has confronted the promises with realities that could not support or accommodate them.

If a promise is a claim to the possibility and desirability of a certain vision of the future, then such reality checks can challenge it by highlighting realities that contradict either the desirability of that vision or its possibility, or both. ‘Realities’ here is not meant to refer to something like neutral, ‘objective facts’, but, broadly in line with Critical Realist thinking, can be taken to include not only ‘events’ observed in the world (‘the actual’), but also the ‘experiences’, perceptions or portrayals of those events by social actors (‘the empirical’) and the ‘causal mechanisms’ effecting them (somewhat confusingly termed ‘the real’) (Fryer and Navarrete 2022; Bhaskar 2008). Reality checks can challenge the possibility and/or the desirability of a promise in either of these dimensions of reality, or in several of them at once.

This understanding implies that social and socio-ecological realities are always the outcome of power relations, and that a reality check is never merely a discursive phenomenon, but a challenge to the power interests and strategies of the agents promoting a promise. It also implies that reality checks themselves present claims that are open to challenges.

Identifying reality checks in the research literature: procedure and heuristic

To discuss the reality checks on the bioeconomy’s growth promises in a systematic way, we have ordered existing research on the relation between bioeconomy and growth into several categories, each of which we found to have contributed its own type of reality check.

As a selection criterion for relevant literature, we sought to identify research that in some way addresses the relation between bioeconomy and economic growth, and that explicitly addresses ‘bioeconomy’ as a comprehensive economic or even societal ‘model’, rather than merely discussing specific processes or solutions without regard for their possible function within a broader context. This applied mostly to publications from the social and environmental sciences, while many contributions from natural science, engineering or marketing were excluded. Even where the latter mention ‘growth’, this normally refers not to growth of the overall economy, but merely to increases in turnover or profits of specific companies.

To define relevant categories within this very broad research literature, we started out from our previous knowledge of the bioeconomy debate and the works already known to us. Inspired particularly by the three layers of the bioeconomic ‘option space’ outlined in Hausknost et al. (2017)—strategic visions, stakeholder positions and biophysical models, we arrived at a fourfold segmentation into:

- a) *Research on bioeconomy visions, discourses and knowledges*, i.e., on representations of ‘the bioeconomy’ in language and knowledge and on the social effects of those representations. This corresponds to Hausknost et al.’s analysis of bioeconomy strategy papers and their ‘diverging visions’ (Hausknost et al. 2017, pp. 3–11);
- b) *Research on the political–institutional processes* that those diverging visions result from, i.e., on relations between different ‘stakeholders’ and on actors’ interests, power resources, strategies and coalitions in bioeconomy politics. This corresponds to Hausknost et al.’s discussion of stakeholder positions (Hausknost et al. 2017, pp. 11–14);
- c) *Economic accounts* of employment, productivity and value creation in the bio-based sectors of existing economies and projections of future potentials; and
- d) *Socio-metabolic studies* on the actual and potential dimensions, composition and changes of the material and energetic throughput of these economies. Hausknost et al. address this by including several biophysical modeling scenarios of a possible low-carbon bioeconomy in their bioeconomic ‘option space’ (Hausknost et al. 2017, pp. 14–16).

We assigned the works already known to us to one or more³ of these categories, and then proceeded to identify further relevant literature by searching online databases and ‘snowballing’ further titles from references in papers we already knew. This yielded a total of almost 300 works, all of which were assigned to the categories.

Within each category we sought to inductively identify relevant strands or ‘families’ of papers—held together by similar disciplinary perspectives and/or methodical approaches, or just by looking at similar things, engaging with each other and reaching similar conclusions—that addressed and/or in some way challenged the growth promises of the bioeconomy in a common way. The following section summarizes the ‘reality checks’ thus identified. Our aim is not to provide a comprehensive review of these broad and multifaceted literatures. Instead, we limit ourselves to giving a focused overview of relevant arguments by referring to key and recent publications, with a focus on the European and particularly German context.

³ This was intentionally non-exclusive: For instance, a paper could both distinguish different discursive visions of bioeconomy and investigate their contestation among stakeholders, or discuss both economic and biophysical indicators.

Challenging the growth promises: four core reality checks from bioeconomy research

Research on bioeconomy visions, discourses and knowledges

There is a plethora of scholarly work on how ‘the bioeconomy’ is constructed and represented in discourses and knowledges, and the social consequences of those representations. Several strands of literature approach these language- and knowledge-related dimensions of bioeconomy from different theoretical and methodical angles, and based on different types of material. These include analyses of discourses and policies that scrutinize, compare and comment on different bioeconomy strategies and related policy documents (e.g. Backhouse et al. 2017; de Besi and McCormick 2015; Kleinschmit et al. 2017; McCormick and Kautto 2013; Meyer 2017; Petersen and Krisjansen 2015; Staffas et al. 2013), literature reviews discussing different concepts of and approaches to bioeconomy present in the academic literature itself (e.g. Böcher et al. 2020; Bugge et al. 2016; D’Amato et al. 2017; Konstantinis et al. 2018; Pfau et al. 2014; Pülzl et al. 2014; Sanz-Hernández et al. 2019), and work from Science and Technology Studies (STS) that investigates how bio-based ‘resources’ are constructed and put to economic use as objects of knowledge and information (e.g. Allaire and Wolf 2004; Birch et al. 2010; Birch 2017a; Levidow et al. 2012, 2013; Mittra and Zoukas 2020).

The reality check from this kind of research concerns the level of societally relevant perceptions or concepts of ‘the bioeconomy’, i.e., of what Critical Realists call ‘the empirical’. It consists in showing that both the possibility and the desirability of bioeconomic growth are never a given: there are always other claims to possible and desirable futures, and the criteria of both are contested.

Analyses of bioeconomy discourses or policy frameworks make this point by highlighting differences and similarities in rhetoric or priorities of political bioeconomy strategies, with regard to the definitions of bioeconomy deployed, the implied relations between sustainability and growth, etc. To Backhouse et al. (2017), most bioeconomy strategies from the Global North and South rely on a shared belief in technology and ‘innovation’ as drivers of growth and means to overcome both social and environmental crises. Beyond that common creed, however, policy papers are found to articulate growth in diverse ways, often less as a central goal than a self-evident part of a deal promising job creation, rural development, competitiveness, sustainable industrial processes, etc. (see also McCormick and Kautto 2013). Pietzsch and Schurr (2020) also point to a diversity of motives, not all of

which necessarily rely on growth: bioeconomy strategies can focus on ensuring food security (Paraguay, Kenya), enabling growth by intensifying use of abundant natural resources (Finland), ensuring a steady bio-based resource supply for hitherto fossil-based industries (Germany, US), or on generating higher value added from natural resources as a ‘catch-up’ strategy in global competition (India, South Africa, Thailand).

Despite this relative pluralism, in Europe at least policy discourse long prioritized growth over sustainability: Kleinschmit et al. compare the German, Finnish, Dutch and French strategies’ framing of sustainability issues, judging their integration to be ‘weak and mainly rhetorical’ (Kleinschmit et al. 2017, p. 41). Environmental concerns were either presented as ‘challenges for the bioeconomy rather than as goals’, as a ‘standard’ to be met (Kleinschmit et al. 2017, p. 48), or as themselves best addressed by bioeconomic growth in a ‘win–win ideal’ (Kleinschmit et al. 2017, p. 49). They conclude that “Environment benefitting from economic growth” is the dominant frame across all political bioeconomy discourses’ (Kleinschmit et al. 2017, p. 50).

Although the emphasis on growth is often found to change over time, rearticulations in sustainability terms do not necessarily imply a shift away from techno-optimism: Hausknot et al. (2017, p. 4) note that the EU’s 2012 strategy ‘changed the framing [...] toward an overarching post-fossilistic sustainability agenda, within which biotechnology still has an important [...] role’, with research funding in particular remaining ‘dominated by a life sciences vision’.

Other studies openly challenge official policies for contradictions between their economic and sustainability-related goals, and implicitly question the growth orientation by claiming that ‘markets alone will not suffice to fulfill this path transition’ and calling for direct political intervention to both promote bio-based alternatives and prevent resource overuse (Gawel et al. 2019, p. 1).

There is also a growing number of literature reviews that survey, sort and summarize the constantly expanding scholarly literature. They demonstrate that in academic discourse, too, the concept of bioeconomy is semantically polyvalent and contested. Probably the most-cited such categorization is Bugge et al.’s (2016) tripartite segmentation into a ‘biotechnology vision’ aiming to greatly extend bio-based production in both scale and scope through efficient new technologies, a ‘bio-resource vision’ aspiring to substitute fossil by renewable resources and introduce circular production systems, and a sufficiency-oriented, agro-ecological ‘bioecology vision’ of bioeconomy. While the former two agree in seeking technological, globally integrated solutions and declaring growth and employment a ‘main concern’ (Bugge et al. 2016, p. 12), the ‘bio-ecology vision’ prioritizes low-tech and social innovation in regionalized systems catering to specific social and ecological needs.

Many reviews describe scholarly debate as structured by an opposition between ‘technology-driven’, growth-centered visions based on promises of life science innovation on one hand and ‘socio-ecological’ counter-concepts based on sufficiency and agro-ecology on the other hand (Priefer et al. 2017; Vivien et al. 2019; Pfau et al. 2014; Holmgren et al. 2020). ‘Bio-resource-driven’ or ‘biomass-based’ models or concepts of ‘circularity’ are usually located in between, but closer to the former (Befort 2020; D’Amato et al. 2019, 2017; Giampietro 2019).

While these categorizations effectively locate the different visions on a single continuum between support for and opposition to both growth *and* technology, Hausknost et al. (2017, pp. 5–6) have suggested treating both as independent axes, to come up with a two-dimensional bioeconomic ‘option space’. Although their empirical findings confirm that both dimensions are closely correlated in political and scholarly debates (Hausknost et al. 2017, pp. 11–12), this consideration opens up key perspectives for debate: next to the discursively dominant ‘sustainable capital’ vision at the optimistic and the ‘eco-retreat’ option at the critical pole, it allows for positions promoting agroecologically based growth (exemplified by TP Organics) as well as possible ‘planned transition’ pathways of employing advanced technology for sufficient ends by political decision.

A final strand of work on discourses and knowledges draws on insights from Science and Technology Studies, conceiving the bioeconomy ‘as an emergent, present, or sometimes promissory economic regime underpinned by particular socio-technical practices’ (Mittra and Zoukas 2020, p. 2). It investigates bioeconomic knowledges at a more fundamental level: in reconstructing how different practices and technologies of scientific and economic knowledge production and circulation are used to enable the commodification of life, it exposes the dynamics of power underlying the politics of representing the bioeconomy as a source of economic value.⁴ An oft-cited pioneering study was Allaire and Wolf’s (2004) analysis of two competing modes of agro-food innovation. Their account renders the ‘biotech-based’ and ‘agro-ecological’ models of bioeconomy intelligible as two different ways of turning living things into objects of knowledge and using that knowledge to produce, process and market them as commodities. The biotech-based model is based on ‘recompositional’ knowledge practices, in which living matter is conceived as abstract biological ‘resources’, consisting of chemical compounds that can be taken apart and rearranged at will into any desired product. Associated with the agro-ecological model are

‘integral’ forms of knowledge production and use, in which product and producer identities are built around the concrete qualities of the product and the characteristic marks that its origin leaves on it.

Subsequent work has further developed this understanding into a critical analysis of the bioeconomy debate as a whole. Birch et al. (2010) emphasize the close affinity between the abstract ‘recompositional’ conception and the equally abstract, exchange value-driven logic of neoliberal capitalism. They see the EU’s ‘knowledge-based bioeconomy’ (KBBE) as epitomizing this confluence of ‘specific technological choices and neoliberal accounts of nature’ (Birch et al. 2010, p. 2899): ‘technological innovation unlocks the renewable, biophysical characteristics of nature itself through genetic and bio-molecular knowledge, thus enabling the continuing expansion and accumulation of capital. This [...] provides a basis for creating *sustainable capital*, not just sustainable capitalism’ (Birch et al. 2010). This conception of ‘sustainable capital’ *dominates* official policies not by chance, but because it expresses an ‘elite master narrative’ that can do without democratic confirmation, or even broad public acknowledgement: it derives its power directly from being embedded in the way the KBBE formats, uses and commodifies life. The vision and narrative of building an economy around abstract life as a source of value thus become ‘self-fulfilling’, providing ‘the rationale for particular institutional and policy changes’ toward a deeper neoliberal reconfiguration of the social itself (Birch et al. 2014, p. 2). Still, the promise ultimately remains empty, an ‘empirical’ expectation regardless of actual possibility: following the financialized logic of neoliberal capitalism, the real business of biotech is generating expectations in the stock market. Therefore, much of the sector, though sucking in enormous sums in research funding and investor capital, has consistently failed to come up with products marketable at scale, effectively rendering it a ‘political economy of nothing’ (Birch 2017b, p. 916).

In sum, the recurring story in accounts of bioeconomy discourses and knowledges is one of a hierarchical tension between dominant conceptions promising to reconcile economic growth and (weak) ecological sustainability through technological innovation, and dominated, marginalized socio-ecological ideas seeking (strong) sustainability based on principles of agro-ecology and sufficiency. Although most authors intend to highlight the variability in the discourses and the availability of different policy options, they almost consistently find that sustainability concerns are time and again subordinated to technoscientific promises and economic power. From the vantage point of the STS-informed literature, this is hardly surprising, and confirms its assumption that under conditions of a financialized capitalist regime and its corresponding paradigm of technoscientific innovation, ‘sustainable capital’ is not a mere ‘option’, but

⁴ For a critical analysis that reaches very similar conclusions, but draws on Gramscian hegemony theory rather than STS, see Boyer et al. in this special feature.

a self-reinforcing trajectory imposed by elite power and a constantly deepening entrenchment of abstract modes of knowledge.

Research on political–institutional processes: actors, interests and strategies

A second field of inquiry concerns the actors and actor coalitions of bioeconomy politics and policymaking, the interests and strategies at play, and the relations among different ‘stakeholders’. These perspectives move beyond the concern with the words, images and expectations of bioeconomy debates, to focus on the ‘actual’ agents and processes of bioeconomy policymaking. It thus allows for critical scrutiny of how the claims to possibility and desirability made in promissory discourses relate to the interests, power resources and strategies of those promoting them. This category includes mappings and analyses of bioeconomy stakeholder networks in specific sectors or countries (Giurca 2020; Giurca and Metz 2018; Korhonen et al. 2018; Peltomaa 2018; Zeug et al. 2019), surveys among researchers (Bauer 2018; Biber-Freudenberger et al. 2020; D’Amato et al. 2019; Issa et al. 2019; Lovrić et al. 2020; Priefer and Meyer 2019; Zeug et al. 2021) and studies on the processes and power dynamics of bioeconomy politics and policymaking using the tools of Political Economy (Kröger and Raitio 2017; Levidow and Papaioannou 2014; Lüthmann 2020; Richardson 2012).

Hausknost et al. (2017) contribute to this field by mapping Austrian stakeholders’ positions in their two-dimensional techno-political ‘option space’ of the bioeconomy. They find interviewees from business interest groups and public administration to mostly concur with the dominant ‘Sustainable Capital’ vision and its optimism concerning both biotechnology and economic growth. In contrast, NGO representatives and a majority of researchers gravitate toward visions of ‘Eco-Retreat’ that are skeptical of both. For Germany, Zeug et al. (2021) arrive at similar findings.

Researchers using network analysis reach somewhat different conclusions: Giurca’s mapping of the German forest-based bioeconomy network sees ‘different interests and strategies’ at play that promote both ‘conflicting and consenting storylines’, with disagreements potentially endangering ‘the success of the bioeconomy project’ (Giurca 2020, p. 1; Giurca and Metz 2018). Korhonen et al. (2018) diagnose a deepening divide between policy coalitions in the Finnish forest-based bioeconomy. However, they see the main confrontation between two competing pro-growth coalitions: a ‘business as usual’ coalition of mainstream forest industry and some government actors versus an alliance of startup businesses and researchers promoting new technologies and innovative business models (Korhonen et al. 2018, p. 14). Across that divide, stakeholder groups shared a pro-growth, pro-technology outlook, considering sustainability

concerns or broader citizen participation as secondary (Korhonen et al. 2018, p. 10). This contrasts with a German study of stakeholders’ concerns with the Sustainable Development Goals (Zeug et al. 2019), which found that particularly those from industry perceived the bioeconomy as prioritizing social and ecological goals over growth. This discrepancy may be due to national specifics, to differences in survey design, or to the different role of NGOs in both samples. In sum, the implicit assumption of networks having a sense of common purpose rather than being fields of struggle and the often scant regard for dissident actors often seem to discourage network analysts from closer critical scrutiny of promissory policies.

The findings of survey-based studies on researchers and experts as a specific bioeconomy stakeholder group mostly mirror those of the literature reviews: they typically find that the ‘technology fix meets criticism and that there is a controversial discussion about possible ways to shape the transition process’ (Priefer and Meyer 2019, p. 1), depending on scientists’ disciplinary, theoretical and institutional backgrounds and the status of their projects. Less attention is normally devoted to how researchers’ involvement in biotech and bioeconomy firms, political and business consulting or the kind and extent of funding they receive relates to the concepts and strategies they advocate. Indeed, conflicting views are likely closely linked to disparities in economic, political and scientific capital: according to Levidow et al. (2019), the life sciences still dominate EU funding in terms of both sums and numbers of projects, and actively use this clout to promote technology- and growth-centered visions, while multidisciplinary approaches seeking to develop agro-ecological solutions remain rather marginal.

These limitations to the existing literature underline the diagnosis that ‘aspects such as actors’ power and resulting interest conflicts in the bioeconomy field have so far hardly been scientifically investigated’ (Böcher et al. 2020, p. 3) and that analyses on the ‘political processes of bioeconomy’ are largely lacking. The only work explicitly addressing these are studies in the Political Economy tradition. For instance, Levidow and Papaioannou (2014) investigate how the interests of scientists, industry and government shaped UK bioenergy policies, finding that the promissory concept of ‘advanced biofuels’ offered government and industry an opportunity to deflect criticism around the land requirements of cultivating energy crops. Kröger and Raitio (2017) discuss roles and strategies of different actor coalitions in the controversies around reframing the Finnish Forest Act in terms of bioeconomy, painting a rather different picture from the one offered by Korhonen et al.’s network analysis: to them, the dominance of a powerful ‘Forestry coalition’ including business and parts of government in the policymaking process led to a disregard for the sustainability concerns of the ‘Environmental Coalition’. The ‘more of everything’

pathway offered as a seeming compromise angered not just NGOs, getting even the environmental ministry to openly protest the bill's neglect of biodiversity protection. Even an official scientific evaluation confirming these concerns did not lead to substantial changes in the eventual law, due to the Forestry coalition's hostility to any regulation that might endanger future growth. Lühmann (2020) scrutinizes different actor groups' interests and strategies in the process leading to the EU's 2018 bioeconomy strategy update. Comparing the outcome of the review process with the prior demands of selected actors from business, agriculture, science and civil society, he finds that beyond the more sustainability-oriented rhetoric, actual priorities in terms of goals and measures were hardly altered. The growth- and techno-centric demands from business and science trumped counter-proposals from agriculture and civil society, and in the updated strategy 'the logic of growth [...] and its ecological consequences are never fundamentally questioned' (Lühmann 2020, p. 8).

Overall, this literature can challenge promissory policies by revealing that the future they promise is 'actually' desirable only to certain actors, who use significant power resources to present it as both possible and generally desirable. It can show who benefits and who loses from the actual events triggered in the name of a promise (e.g. funding decisions, regulation), illuminating the promises' instrumental nature and resulting tendencies to ultimately hinder or block serious transitions away from fossilist societal models. The intensity with which this is done varies with researchers' readiness to acknowledge the political dimensions of their research object and conceive the interactions between actors as part of power struggles rather than as contributions to some assumed shared goal. Although network analysis is being put to more openly critical use of late (Holmgren et al. 2022), the Political Economy perspective has so far provided the strongest case for how bioeconomy can become a vehicle for effectively promoting powerful economic and political interests at the expense of social and environmental concerns. It should also make socio-ecologically minded researchers wary, as findings such as those of Lühmann (2020) or Holmgren et al. (2022) indicate that what influence reality checks from research have had on renewed policies has affected mostly their rhetorical surface, while the essentials of how power and resources are distributed remain largely intact.

Research on the economic structure and development of the bio-based economy

Significant research efforts have been devoted to defining the contours of the bio-based sectors of the economy (Bringezu 2019; Ronzon et al. 2017; Ronzon and M'Barek 2018; Wesseler and von Braun 2017; for a critique, see Mitra and

Zoukas 2020) and tracking their development in terms of employment, value added and industry structure (Bringezu et al. 2020; Iost et al. 2019; Kuosmanen et al. 2020; Ronzon et al. 2020). It has often been noted that measuring 'the contribution of the bioeconomy is extremely complex because the boundaries between the bioeconomic and traditional sectors are not delimited' (Sanz-Hernández et al. 2019, p. 113). Such quantification thus requires *sectoral* definitions of the 'bio-based economy', as the totality of industries and activities producing and processing biological materials. This kind of work challenges the promises by putting things into perspective: most of these activities, like agriculture and forestry, are not new, but among the most traditional sectors of the economy, and on the whole it is hardly a growth sector at all. Compared to the much-hyped, but quantitatively minuscule high-tech bioeconomy of the biotech startups, they are relatively large in terms of employment and revenue, but not nearly as dynamic.

The EU's 2018 bioeconomy strategy update promises up to a million new jobs in the 'bio-based industries' until 2030, claiming that the biotech 'startup ecosystem [...] will play a leading role in realising this potential' (European Commission 2018, p. 5). Empirical evidence lends little support to such assertions: EU-commissioned research finds that in 2017, the EU's bio-based economy employed a total of 17.5 million people (8.9% of overall employment), generating 614 billion € in value added (4.7% of GDP) (Ronzon et al. 2020, p. 4).⁵ From 2008 to 2019, employment declined by 13.5%, while value added grew by 28%. Each percent of growth, that is, was bought by about 0.5 percent in job losses, mainly in agriculture. Numbers differ significantly between those (mainly Eastern/Southeastern) EU countries that primarily supply biomass, and the (predominantly Western/Northern) states that import and process it using advanced biotechnology, resulting in a widening productivity gap (Ronzon et al. 2020, p. 8). Rather than in boosting broad-based wealth in peripheral countries, the bioeconomy is seen as a potential 'buffer' to secure rural livelihoods 'in times of economic crisis', thus contributing to an 'innovative, inclusive, and climate-ready' economy, ensuring 'resilience' and the opportunity to 'balance economic and social objectives' (Ronzon et al. 2020, p. 10). This should not be misread as some kind of degrowth vision: it is conceived not as a positive alternative, but as a subsidiary stabilizer for the peripheries of a European economy that on the whole is to remain 'innovative, resource-efficient, and competitive' (Ronzon et al. 2020). Such a 'buffering' role of the bioeconomy is more

⁵ Updated data in the EU's *Knowledge Centre for Bioeconomy* at https://knowledge4policy.ec.europa.eu/visualisation/jobs-wealth-european-union_en. Figures for 2019 show that employment had slightly declined to 17.4 million (8.7%), while value added had risen in step with GDP to 657 billion € (4.7%).

akin to large-scale poverty management in the face of deepening intra-European disparities.

The pilot report of Germany's official bioeconomy monitoring (Bringezu et al. 2020) uses a broad sectoral definition of bioeconomy that includes all industries using at least ten percent bio-based inputs. This encompasses a large share of manufacturing and all food-related service employment (Bringezu et al. 2020, p. 38). According to this generous metric, 10% of Germany's workforce (4.4 million) in 2017 worked in the bioeconomy, with manufacturing and food services constituting the largest subsectors. Bioeconomic employment is expected to moderately shrink until 2030 (to 4.3 million), while value added is expected to grow at 2.6% per year—half a percent less than the overall economy (Bringezu et al. 2020, p. 47). Growth rates of over 3% are expected for bioenergy, catering and research and development, while agriculture and forestry are projected to expand at a significantly lower rate (1.5%) (Bringezu et al. 2020, p. 9).

Identifying the reality check in these figures requires some discussion. While projections do present modest overall growth of the bioeconomy in monetary terms as realistic, the data shows that employment growth would require a reversal of long-term trends—a feat that national and EU bioeconomy strategies promise will result from impending biotechnological breakthroughs. Yet employment in biotech firms itself is comparatively minuscule and unlikely to expand at rates that would make an overall difference, while in more labour-intensive sectors (agriculture, food processing), technological rationalization continues to make jobs obsolete. Even if some bioeconomic product innovations materialize, they are likely to mostly substitute existing processes and jobs, and bring further rationalization and job losses in the process. Economists typically respond with Schumpeterian arguments (Pyka 2017), claiming that growth and innovation in biotechnology will spark job creation in other sectors (such as education, digital technology and related services). That, however, is basically an article of faith, based on extrapolation from a twentieth century experience powered by exponentially expanding use of precisely those fossil resources that the bioeconomy aims to replace. If the EU's promise of a million jobs by 2030 was met, this would amount to 5.7% jobs growth—half a percent annually. Modest as this promise sounds, it seems hardly realistic considering the negative correlation between growth and jobs in the recent past.

Also, even though some expansion of the bioeconomy, especially of some specific subsectors, can be expected, these projections hardly merit the portrayal as a 'growth engine' for the economy as a whole. Seen in the context of the global societal challenge of transitioning to post-fossil economies, the gains in value added and (possibly) jobs that appear actually realistic seem nowhere near the scale that

would be required to even remotely make up for the losses to be expected from the necessary phasing out of an enormous range of fossil-based economic activities.

Empirical assessments of the state and prospects of Europe's bioeconomy are a sobering exercise, supporting the contention that 'the supposed biotechnology revolution is not perhaps as revolutionary and profitable as has been assumed' (Mittra and Zoukas 2020, p. 16). The reality check, often contrary to researchers' intentions, consists in questioning the promised future's actual possibility, by showing that the claimed desirable effects of bioeconomy are not borne out by events on its prosaic ground. The bioeconomy is demystified by exposing the promise-laden biotech sector as quantitatively marginal and highlighting the continuing centrality of mundane bio-based economic activities that remain indispensable to the population's subsistence, but are necessarily much less dynamic.

Research on the bio-based economy as a set of material and energy flows

The discrepancy between the contributions to economic growth that advocates attribute to the bioeconomy and those it actually appears able to deliver is highlighted even more strikingly by research on the flows of matter and energy, or the social metabolism, that make up its material substratum (Bringezu et al. 2020, 2021; Haas et al. 2015; Lewandowski 2015). Such analysis has become a field of study in its own right only recently, and unified evaluative frameworks are only gradually emerging (Egenolf and Bringezu 2019; Robert et al. 2020). For Europe, the first comprehensive accounts of the bioeconomy's biophysical structure, composition and dynamics have recently appeared (Bringezu et al. 2020; Gurría et al. 2022). In light of their findings, the claim that significant further biophysical expansion—and thus a contribution to overall growth despite necessary fossil shrinkage—could be possible at all appears as highly questionable. The research also illuminates the globally unequal distribution of biomass production and use, highlighting undesirable effects of further growth in terms of sustainability and socio-ecological justice.

Hausknost et al. (2017) consider this dimension by modeling three biophysically viable scenarios of a low-carbon bioeconomy for Austria. Characterizing each in terms of reliance on (bio-)technology and growth implications, they relate the actual possibilities suggested by these models to the visions of governments and stakeholders (Hausknost et al. 2017, pp. 14–16). This exposes a huge gap between promises and possibilities: biophysical modeling rules out 'Sustainable Capital' trajectories as unsustainable, indicating that viable pathways 'are necessarily tied to a rather substantial politics of sufficiency, without which the limited

biogenic resources will not suffice to keep a bioeconomy going' (Hausknost et al. 2017, p. 16).

Larger scale empirical accounts corroborate this. Data from the EU's Joint Research Center⁶ shows that Europe's total economically available biomass supply averaged around 1 billion tons in the period 2010–2017, with an annual growth of around 2%. However, 55% of that additional volume did not benefit any particular use, but ended up as 'unknown/losses'. For Germany, the monitoring pilot report finds that the country produced 185 million tons of biomass in 2015, and registered net imports of 7 million tons (3.8% of domestic production) (Bringezu et al. 2020, p. 9). Probably due to accounting differences, the EU database reports significantly lower domestic production numbers—just under 150 million tons—and substantially larger net imports (39 million tons), but ends up at almost precisely the same overall supply (194 million tons). From 2010 to 2017, that supply had grown by 23 million tons (1.8% annually), 18 million tons of which were lost or unaccounted for.

It is hard to conceive of the bioeconomy living up to promises of 'green growth' without substantial increases in biomass availability and use. Yet, the data cited provides no evidence for such increases, and the German report offers few indications from whence these should materialize: neither extending domestic cropland nor greater biomass imports appear as real options.

Regarding domestic potentials, between 14 and 49 million tons a year in side and waste streams appear available for future economic use (Bringezu et al. 2020, p. 36). However, most of these consist of materials of low energetic content, such as straw, manure or mowed grass. Biotechnological magic bullets that could deliver explosively rising outputs have so far failed to materialize, and the authors expect incremental increases in land productivity at best—in fact, ecologically induced needs to increasingly convert to organic agriculture and set more land aside for biodiversity conservation may well eventually lower it (Bringezu et al. 2020, pp. 51–53). Also, biofuels are no longer considered a growth sector, as EU regulation has ruled out conversion of cropland to energy crop cultivation and there is only limited potential for 'advanced biofuels' from waste streams, since these are expected to be needed for material utilization, e.g., in a de-fossilizing chemical industry (Bringezu et al. 2020, pp. 62–63). In sum, there may be scope for mobilizing some amount of extra biomass from residues and waste, as well as for more cascading use (i.e., material utilization of biomass in one or more products before eventually burning it). However, considering that the enormous amounts of fossil

materials currently used⁷ will need to be phased out in parallel, it is hard to imagine this eventually allowing for overall economic growth.

Aside from doubts about the actual possibility of bioeconomic growth, this research also raises troubling issues concerning both the long-term sustainability of prevailing modes of living and questions of global justice. The biotic material footprint of German domestic consumption is found to considerably exceed domestic capacity for biomass production (Bringezu et al. 2020, p. 10): its agrarian footprint (51 million ha) is about three times the amount of agrarian land cultivated in Germany (17 million ha) (Bringezu et al. 2020, p. 85). These net land imports have been driving substantial land use conversion in other world regions (Bringezu et al. 2020, p. 3), making Germany's mode of using biomass structurally unsustainable and impossible to generalize globally. In global perspective, achieving sustainability in an equitable way will require substantially altering both the current forms—e.g., livestock farming—and the global distributional patterns of biomass production and consumption. This in turn implies that transitioning to a post-fossil economy will require profound changes in the modes of production and living of affluent countries, aiming at sufficiency rather than growth (Ramcilovic-Suominen 2022).

This conclusion, of course, is not uncontested. In its 2018 strategy update (European Commission 2018, p. 1) and in its Green Deal (European Commission 2019, pp. 7–9), the EU has begun to increasingly promote the imaginary of a 'circular bioeconomy', in another attempt to renew the promise to 'move our societies beyond the limits to growth' (Leipold and Petit-Boix 2018, p. 1125) and reconcile growth and sustainability. Some veterans of biophysical analysis have taken this as an occasion to launch the most fundamental reality check to date, claiming its ultimate incompatibility with the laws of thermodynamics (Giampietro 2019; Giampietro and Funtowicz 2020). In critical realist terms (Bhaskar 2008), this amounts to questioning the possibility of bio-based circularity not merely in terms of the 'events' that constitute the 'actual', but even in terms of the basic causal mechanisms of the 'real'. Drawing on Georgescu-Roegen's bioeconomics, they argue that the circularity concept is inherently contradictory in acknowledging the dependence of any economy on nature while simultaneously promising a 'full decoupling

⁶ Available at https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html, see also Gurría et al. 2022.

⁷ Due to the vastly different characteristics of fossil and bio-based materials, quantifying this need for substitution is close to impossible. While it is important to keep in mind that tons of mass are not a good commensurate measure for substances of radically different energy intensity, a vague idea of the scale may be conveyed by the fact that for energy alone, the EU-27 drew on a supply of around 1.5 billion tons of oil equivalent from fossil sources, and another 200 million in nuclear, in 2015 (own calculation based on data available at <https://ec.europa.eu/eurostat/cache/sankey/energy/sankey.html>).

of the economy from natural resources’ (Giampietro and Funtowicz 2020, p. 64). Counter to such ‘policy legends’, they claim, only ‘a post-growth caring economy’ can ultimately be compatible with the laws of thermodynamics (Giampietro and Funtowicz 2020, p. 70).

Although Bringezu et al.’s (2020) report only discusses limits of possibility at the level of the actual, it may be seen as part of the process of scaling down expectations needed for wealthy societies to come to terms with this insight. While it is clear that the fossil sector needs to be discontinued, such accounts demonstrate the impossibility for bio-based sectors to provide substitute resources at anything like a comparable scale—especially since the existing bioeconomy itself will need to be thoroughly transformed in order to function in a sustainable, post-fossil way (Giampietro 2019; D’Amato et al. 2017).

Conclusion: from empty promise to societal conflict

Bioeconomy policies and strategies promise that biotechnological innovation and increasing biomass use can be engines of future economic growth. We have shown here how research on the bioeconomy’s social and ecological preconditions and implications has challenged the claims to the possibility and desirability of such growth by confronting them with irritating or irreconcilable realities on several levels. It has highlighted the contested nature of promissory visions in bioeconomy discourses and knowledge production, illuminated the interests, strategies and power relations at play in advancing the promissory policy narrative, exposed expectations of jobs growth and broad-based wealth creation through bioeconomy as hardly realistic in the face of its economic reality, and shown that the provision of biological resources cannot expand at a scale even remotely sufficient to allow for overall economic growth.

We did not intend to trace if and how exactly these reality checks were perceived by policymakers formulating recent governmental bioeconomy strategies. However, it stands to reason that the rhetorical moderation of these strategies was at least partly a reaction to researchers involved in evaluation and consultation processes voicing doubts about the growth potentials and questioning overly optimistic claims. The fact that this led to a change in rhetoric, but had little bearing on practical priorities is most likely due to the politico-economic power dynamics described in the literature on political–institutional processes.

Our observations also indicate directions for further research. The analyses on the interests and power relations undergirding the persistence of growth promises in bioeconomy policy and those on the lacking biophysical foundations of those promises certainly pose the strongest

challenges to bioeconomic growth optimism, but are also the least developed among the literatures discussed. This may in part reflect the difficulty of investigating these matters, but probably also results from the influence of economic and political power interests on research priorities. More work in both fields, and especially on the actual possibility and desirability of expanding biomass production through biotechnological innovation, seems urgently needed to counter the still-pervasive inflated claims.

While the viability of many promised biotechnological solutions remains highly questionable, ample evidence from multidisciplinary research shows that a secure food supply and reliable provision for basic needs from bio-based sources is actually possible—but only when conceived as part of far-reaching social and economic changes and based on mostly low-tech, often labour-intensive agro-ecological practices (e.g. Ollinaho and Kröger 2021; van der Ploeg 2021; Altieri and Nicholls 2020). More broadly, what deserves more serious attention within bioeconomy policy debates are the so-far scarcely discussed (Grunwald 2020; Hoehn et al. 2021; Ramcilovic-Suominen 2022) implications of degrowth debates and the sophisticated critique of mainstream sustainability discourses that their proponents have developed in recent years (D’Alisa et al. 2015; Hickel 2021; Kallis et al. 2018). Their thorough revision of the core tenets that ‘green growth’ ideas rest on has begun gradually entering the bioeconomy debate not only through radically provocative work such as that of Mario Giampietro (2019), but also through sober accounts like the one by Bringezu et al. (2020). The more bioeconomy policy is compelled to acknowledge the finiteness of the living nature that a sustainable bioeconomy ultimately has to work with, the more the heritage of its denied ancestor Georgescu-Roegen demands its due.

Ultimately, this touches upon the larger societal tension underlying all these debates and reality checks: namely, the conflict around how to deal with escalating global socio-ecological crises. Arguments around the possibility and desirability of bioeconomic growth are inevitably part of a broader field of socio-political contestation around social–ecological transformations of modern capitalist societies that will imply much more than just substituting basic materials. Situating bioeconomy debates in this broader field and conceiving them as one of many stakes in a conflict that involves all of society is a task researchers have only just begun to address (Holmgren et al. 2020). Analyses of socio-political conflicts and contestation—both in bio-resource-exporting countries of the global South (Backhouse et al. 2021) and in affluent societies of the North (Eversberg and Fritz 2022)—demonstrate that divergent imaginaries of bio-based economic transformations in the minds of broader populations cannot be separated from more fundamental disagreements around the necessity, shape and direction of social–ecological

transformations. This wider context of societal conflicts and struggles deserves greater attention within bioeconomy research, as it will eventually be crucial for what kinds of bio-based economic practices find democratic support and prove socially (or in Critical Realist terms, ‘empirically’) possible.

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