Sustainable Production and Consumption 30 (2022) 584–595

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Bioeconomic fiction between narrative dynamics and a fixed imaginary: Evidence from India and Germany

Jonathan Friedrich[a,b,*], Katharina Najork[b], Markus Keck[c], Jana Zscheischler[a]

[a] Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany
[b] Institute of Geography, University of Göttingen, Göttingen, Germany
[c] Center for Climate Resilience, University of Augsburg, Augsburg, Germany

ARTICLE INFO

Article history:
Received 21 July 2021
Revised 15 December 2021
Accepted 23 December 2021
Available online 26 December 2021

Editor: Dr. Lilian Pungas

Keywords:
Imaginations
Capitalism
Sociotechnical change
Transformation
Future visions
Future studies

ABSTRACT

Bioeconomic ideas and visions have received increasing attention from scientists and policy makers to address socioecological challenges. However, the role of imagined futures in the design of bioeconomic innovations and transitions has hitherto been widely neglected. In this study, we therefore explore the role of imaginaries of the future to understand how they shape bioeconomic innovations and transitions. We thereby build on insights from economic sociology and compare two distinct case studies from Germany and India. Based on our results, we inductively develop an analytic model that describes the co-constitution of imaginaries, fictional expectations, narratives, and innovation dynamics. Our results show that narrative dynamics are caused by irritations in the political and discursive landscape; these irritations prompt economic actors to stabilize, adapt, or reject their own bioeconomic conceptions, while the underlying imaginary of a technological fix remains fixed. We discuss this reductionist imaginary and instead plead for an imaginary of a socioecological fix that reintertwines technologies with their underlying societal, cultural, and ecological factors. We conclude that this will support sustainability scholars and policy makers in remaining vigilant against premature mental and institutional lock-ins that could lead to a colonization of the future with severe negative implications for society's ability to mitigate and adapt to global environmental change in the future.

© 2022 The Authors. Published by Elsevier Ltd on behalf of Institution of Chemical Engineers.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

1. Introduction

In recent years, the notion of a "bioeconomy" or "biobased economy" has become popular among scientists and policy makers as an innovative economic model for addressing the grand societal challenges that accompany global environmental change (Folke et al., 2021; Giampietro and Funtowicz, 2020). Given the wide spectrum of aims and fields of application accompanied by this notion, some authors even propose that the bioeconomy be perceived as a "panacea" by policy makers for obstacles to ultimately reconciling the efforts to meet the Sustainable Development Goals (SDGs) within the limitations of the planet's life support systems (Giampietro, 2019). As the aim and scope varies, so do definitions of the concept of bioeconomy (Bugge et al., 2016; Hausknost et al., 2017; Vivien et al., 2019). For instance, the European Union (EU) and the organization for Economic Co-operation and Development (OECD) have published bioeconomic strategy papers that have very different goals and include entirely different theoretical approaches. To bring some order to the situation, we refer to Bugge et al. (2016), who identified three major visions of the bioeconomy, namely, the "bio-technology vision", the "bio-resource vision", and the "bio-ecology vision". The "bio-technology vision" aims to create economic growth and jobs through the commercialization of new technologies, while the "bio-resource vision" seeks to combine economic growth and sustainability by converting and upgrading biological resources. The "bio-ecology vision" is ultimately driven by the goal of fostering sustainability, biodiversity, and ecosystem conservation through the development of integrated production systems and high-quality products. According to Hausknost et al. (2017), the "bio-technology vision" emerged first, while the other two visions followed later.[1]

Like other technical and organizational innovations, bioeconomic models are based on specific "imagined futures" (Beckert,

* Corresponding author.
E-mail address: jonathan.friedrich@zalf.de (J. Friedrich).

[1] Please note that further differentiations of the "bioeconomy" have recently been published by Hausknost et al. (2017) and Vivien et al. (2019). However, in their results, these authors do not differ substantially from Bugge et al. (2016); this is why we rely only on the latter.

https://doi.org/10.1016/j.spc.2021.12.026
2352-5509/© 2022 The Authors. Published by Elsevier Ltd on behalf of Institution of Chemical Engineers. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

2013, 2018). Imagined futures are basically visions of how the future might look like; they are explicitly or implicitly entailed in scientific studies, reports and strategy papers and help policy makers, producers and consumers develop a more concrete idea of what can be expected or not. The role of imagined futures has thus far been widely neglected in the research on sustainability transitions associated with sociotechnical change (Feola, 2020; Knappe et al., 2019; Longhurst and Chilvers, 2019). Retrospective studies on bioeconomies and sustainability transitions have discussed how the introduction of specific innovations can lead to mental or institutional lock-ins, thus creating path dependencies that are difficult to change afterwards (e.g., Beck et al., 2021; Friedrich et al., 2021a; Graupe, 2020; Trencher et al., 2020; van den Bergh et al., 2015). However, the critical role of imagined futures in the emergence of new path dependencies and a resultant "colonization of the future" (Beckert, 2018) has yet to be accounted for. With this study, we aim to help resolve this gap.

With a specific focus on the notion of bioeconomy, we provide a comparative analysis of two "diverse" (cf. Seawright and Gerring, 2008) case studies from India and Germany. The first case study offers an example of the "bio-resource vision" of the bioeconomy (Bugge et al., 2016) and discusses innovations that aim to solve the manure surplus and the associated issues of the eutrophication of water bodies and the loss of biodiversity in Germany (Friedrich et al., 2021a). The second case study relates to the "bio-technology vision" of the bioeconomy (Bugge et al., 2016) and discusses the innovation of genetically engineered (GE) cotton that is resistant to Lepidopterans[2]; the aim of this innovation is to increase production while reducing the need for pesticides in India (Najork et al., 2021). While these two case studies might seem unrelated at first, we argue that it is precisely their differences that allow us to identify exploratory commonalities among different imaginaries underlying the bioeconomic sector. Additionally, the two case studies help identify context-related specificities that involved actors pursue to achieve their ends. For this purpose, the concept of imagined futures (Beckert, 2018) provides the theoretical background, while we focus on narratives of economic actors as an analytical category that is empirically accessible and in which imagined futures are becoming visible. By offering an inductively compiled generalizable model of narrative dynamics, we will show how these narratives, which are used to legitimize specific technologies, alter in response to changes in the discursive level of society. With this aim, we will answer the following research questions:

1 What specific narratives do actors develop to effectively present their bioeconomic innovations to the public?
2 How do actors adjust these narratives to changing conditions and discourses?

2. Imagined futures and the bioeconomic transition

In this paper, we argue that an analysis of the ongoing transition toward a bioeconomy needs to consider imagined futures, as these constitute the driving force of capitalism in the form of cognitive resources for identifying new opportunities for capital accumulation (Beckert, 2013, 2018). By outlining possible trajectories for future outcomes, imagined futures, together with fictional expectations and interest-driven narratives, help to bridge much of the prevalent uncertainty in economic decisions and enable relevant actors to navigate in their specific contexts. At the same time, these imaginations of the future shape (bioeconomic) innovation design and guide sociotechnical transitions, thereby causing intended and unintended consequences (Geels, 2020; Jasanoff and Kim, 2009, 2013).

As decision situations in economic contexts in general and in (sociotechnical) innovation processes in particular are fundamentally marked by uncertainty, (Beckert, 2013, 2018) declares imagined futures to be a crucial precondition for innovation processes (see also Beckert and Bronk, 2019). Since the details and events of the future can never be fully anticipated or calculated, Beckert argues that actors build upon fictions about possible future states to draw conclusions in their decision-making processes. These fictions must be rather broad to allow room for maneuvering and creativity but must be "plausible enough that [they] could become true" (Esposito, 2007, p. 13). Fundamentally, imagined futures serve to suspend disbelief and equip economic actors with a perpetual capability to overcome paralysis and act purposefully despite omnipresent uncertainty about future events (Beckert, 2013, p. 226; Beckert and Bronk, 2019, p. 8). By taking the shape of imaginaries of some future state of the world that is cognitively accessible in the present, these fictions motivate actors to develop innovations that, in turn, continually reproduce the capitalist system (Beckert, 2013).

The mental representations of the imagined future states accessible to actors are referred to by (Beckert, 2013, 2018) as "fictional expectations." These expectations are fictional in the sense that they represent potential future states as if these states were being realized (Beckert and Bronk, 2019). While these expectations differ from literary fiction in their scope and ramifications, these expectations are likewise anchored in specific narratives (Beckert, 2013; Beckert and Bronk, 2019) that render these expectations tangible to initiators and believers alike, structure their expectations, and create incentives for initiators and believers to act purposefully. Fictional expectations published by state agencies, e.g., can thus be read as signals for economic actors; these signals create an atmosphere of security for investments and for research and development activities (cf. Beckert, 2013). Conversely, such fictional expectations, by guiding innovation processes, help create future states that are hitherto only imagined (Jasanoff and Kim, 2009, 2013; Jasanoff, 2015). Therefore, fictional expectations and sociotechnical innovation co-constitute each other – an issue that standard economics has, for a long time, failed to account for (Beckert, 2013; Beckert and Bronk, 2019). Fictional expectations not only accompany the design and diffusion of innovations but also inevitably constitute them by creating the cognitive and imaginative substratum of what could be possible. Conversely, the design of innovations recalibrates fictional expectations in that the resulting new artifacts and knowledge influence the content and shape of fictional expectations. This inevitably also applies to bioeconomic innovations (Bröring et al., 2020; Friedrich et al., 2021a).

Fictional expectations are at the interface of subjective and collective imagination (Beckert, 2018) and are a product of society's imaginaries that have culturally evolved and express normative knowledge of how societies should deal with social or ecological issues (cf. de Witt et al., 2017; Schlaile et al., 2017, 2021). While accounting for imaginaries (as social structures at the discursive level) and fictional expectations (as tacit knowledge at the individual level), we add "narratives" as empirically accessible modalities that occupy a middle ground between the former two. Table 1 defines the three aforementioned notions in detail.

In the following, we provide an analysis of the two bioeconomies mentioned above. While the notions of imagined futures and fictional expectations provide the theoretical background of our study, we direct our empirical focus toward the concrete nar-

[2] Lepidopteran insects include butterflies and moths. The most damaging pests in the production of cotton are bollworms, including the pink bollworm (*Pectinophora gossypiella*), the American bollworm (*Helicoverpa armigera*), and the spotted bollworm (*Earias vittella*). Bt cotton provides protection against bollworms and other minor Lepidopterans, such as semiloopers, hairy caterpillars, and leaf-eating caterpillars (Fand et al., 2019).

Table 1
Imagined futures – key terms, definitions and conceptual scales, as defined by J. Beckert (2018).

Term	Definition	Conceptual Scale
Imaginary	Mental representation of an envisaged (future) state of the world; this representation motivates actors in their decisions and provides them with guidelines for reaching this state	Discursive level
Narrative	Socially shared and empirically accessible stories, theories or forecasts regarding how the present will be transformed into some imagined (future) state	Middle ground between societal discourses and individual expectations
Fictional expectation	Mental representation of imaginaries; this representation is anchored in economic actors and takes a narrative form, such as a story, theory, or forecast	Actor-oriented level

Table 2
Diverse bioeconomic cases of Germany and India.

	A case from Germany (Section 4.1)	A case from India (Section 4.2)
Topic	The manure surplus, biodiversity loss issues, and manure-based bioeconomic innovations	Agricultural biotechnology, technological failure, and political regulation
Bioeconomy vision (Bugge et al., 2016)	"bio-resource vision"	"bio-technology vision"
Geography, socioeconomics, culture	Global North, industrialized agriculture, productive economy, and discourses on ecological sustainability and energy transitions (Beck et al., 2021; Friedrich et al., 2021b)	Global South, high share of subsistence agriculture, discourses on food security, population growth, and poverty reduction (Choudhary et al., 2014; Kathage and Qaim, 2012; Najork et al., 2021)
Bioeconomic policy strategies	Guiding principles: (1) the development of innovations by using biological knowledge and (2) the design of a circular economy (CE) based on natural resources; the aim is to help meet the SDGs (BMEL and BMBF, 2020)	Focus on "efficiency, productivity, safety and cost-effectiveness of agriculture, food and nutritional security; affordable health and wellness, environmental safety; clean energy and biofuel; and bio-manufacturing" (Departement of Biotechnology 2021, p. 7)

ratives that exist around innovations helping to solve the manure issue in Germany (Friedrich et al., 2021a) and Lepidopteran infestations in Indian cotton fields (Najork et al., 2021). Our aim is to reconstruct the irritations and subsequent dynamics that these narratives are subject to and to understand how these narratives are stabilized and adjusted by the involved actors. Based on our findings, we aim to obtain a deeper understanding of the nature of the very imagined future in which the bioeconomic model is rooted.

3. Methods and research design

To identify the narratives of bioeconomic innovation actors, we chose to compare two contrasting case studies (see Table 2 for a brief overview of the differences) – one investigating manure-based bioeconomic innovations in Germany (see Section 4.1) and the other examining biotechnological innovations involving genetically engineered organisms (GEOs) in India (see Section 4.2). This comparison follows the logic of "diverse cases" according to Seawright and Gerring (2008); i.e., both cases originate from the same background (i.e., the idea of a bioeconomy) but are based on very different visions (i.e., the "bio-resource vision" and the "bio-technology vision" of the bioeconomy) (Bugge et al., 2016). We would like to mention that diverse cases cannot represent the entire population but can serve to explore or confirm certain aspects of it (Seawright and Gerring, 2008). Our aim was to seek for similar dynamics of narratives among the two case studies that both share despite their content-related differences between these cases (see Section 4.3).

3.1. Data acquisition

We conducted 26 qualitative, semistructured interviews with actors in Germany and India; 10 of the interviews were chosen as the empirical base for this study. As this paper focuses on the narratives of economic actors, we limited the interview sample to actors who employed such narratives and excluded other actors. The perspectives of opposing interviewees were purposely excluded from the sample.

Table 3 describes the interviewed actors. In the German case, interviews were conducted to examine contrasting framings of the manure issue and imagined solutions thereto. The interviews included those with actors currently designing bioeconomic innovations and actors from civil society or representatives from farmers' associations who may have opposing perspectives on the issue. In this case, we speak of bioeconomic innovation actors, defined as people or institutions currently developing new innovations related to "substitute products," "new processes," "new products," or "new behavior" (cf. Bröring et al., 2020). A total of 12 problem-centered interviews were conducted, six of which were included in this study.

In the Indian case study, the interviews helped to map the present political landscape in regard to GEOs in India and disentangle the manifold networks that shape the ongoing negotiations involved in promoting, directing and constraining specific fictional expectations relating thereto. For this purpose, the stances and arguments of the main political actors (i.e., political parties; farmers' associations; and industrial, business, trade, and environmental associations) were documented. In sum, 14 expert interviews were conducted with entrepreneurs, politicians and activists, four of which were ultimately included in this study.

The interviews were conducted in German (for the German case study) and English (for the Indian case study). The German quotes have thus been translated into English. While the two interview guidelines (see supplementary information) are basically tailored to the specific contexts of each case study (see Sections 4.1 and 4.2), both guidelines share the common focus of bioeconomic innovation, prevalent political discourses on the subject matter, and actors' motivations and expectations in regard to the future of the technologies.

Table 3
Overview of interviewed actors in the two case studies.

IP (interviewed person)	Case study	Actor description
1	Germany	Economic innovation actor, recycling fertilizer
2	Germany	Economic innovation actor, recycling fertilizer
3	Germany	Scientific innovation actor, duckweed cultivation
4	Germany	Scientific innovation actor, recycling fertilizer
5	Germany	Economic innovation actor, recycling fertilizer
6	Germany	Economic innovation actor, transport of manure and fodder
7	India	South Asia Biotechnology center (SABC)
8	India	Farmer representing the Consortium of Indian Farmers Associations (CIFA)
9	India	Company representative from Metahelix Life Sciences under the auspices of the Association of Biotechnology Led Enterprises (ABLE)
10	India	Company representative from DuPont under the auspices of the Association of Biotechnology Led Enterprises (ABLE)

3.2. Data analysis

All interviews were recorded and fully transcribed. Data processing was performed by using MAXQDA software. The analysis and coding of interviews followed a combined deductive and inductive approach (Kuckartz, 2014). The first two authors of this article coded the material. We derived our deductive categories from theoretical considerations by Beckert (2018) Section 2, who stresses the relevance of uncertainty, fictional expectations, imaginaries, and narratives for economic decision-making that is directed toward the future (e.g., the design of innovations). We furthermore included the stage of the innovation design and diffusion (roughly guided by the multi-level perspective, cf. Geels and Schot, 2007), possible results of innovation (narrative irritation in Section 4)[3], and actors' innovation distribution networks. Through our analysis, we further added inductively gained categories and examined our data for irritations in technological development, diffusion and adoption processes and, finally, discarded the category of distribution networks. We then used open coding to identify, cluster, and structure different narratives (see RQ 1) about how the interview partners present their technologies to the wider public and which societal issues these narratives are semantically linked to. Furthermore, our empirical material allowed us to identify different dynamics of how these narratives were rejected, stabilized or altered in the face of irritations (see RQ 2 and Fig. 1).

4. Results

The following two case studies on the surplus of manure in Germany (Section 4.1) and on genetically engineered cotton in India (Section 4.2) show how bioeconomy actors use certain narratives to generate support for their respective innovations. The main emphases of the following sections are both the inductively discovered dynamics of the narratives deployed in the face of irritations and the strategies of the involved actors to stabilize, adapt or reject these narratives (Section 4.3).

4.1. Case study 1: manure surplus, biodiversity loss, and bioeconomic innovations

In various regions in Germany, nitrate concentrations in surface water bodies and groundwater exceed the maximum permissible values set by the European Union (50 mg/l; (BMEL, BMU 2020)). These high figures are largely attributed to manure surpluses resulting from intensive livestock production. In particular, the infiltration of manure-based nitrate from fields into water bodies raises concerns about the eutrophication of water bodies, the loss of biodiversity and the increase in drinking water costs (Umweltbundesamt (UBA) 2019). Approximately 17% of all groundwater assessment sites in Germany register nitrate values above 50 mg/l, while 27% of assessment sites characterized by surrounding agricultural land use register nitrate values that exceed 50 mg/l (BMEL, BMU 2020). Accordingly, Germany is facing lawsuits from the European Union, and fines of 850,000€ per day for exceeding the specified thresholds are currently discussed (Sundermann et al., 2020).

Against this backdrop, new bioeconomic products for manure management are currently being developed (Friedrich et al., 2021a). These innovations include the cultivation of insects on manure (this innovation could provide a protein-based fodder substitute in livestock production (e.g., Čičková et al., 2015)), the cultivation of duckweed on manure (this innovation could be used as a substitute for soy in livestock production (e.g., Stadtlander et al., 2019)), and the recycling of manure by using manure as a mineral fertilizer substitute (this innovation could help compensate for the finiteness of rock phosphate (e.g., Pintucci et al., 2017) and strengthen the already existing reciprocal transport of manure and fodder between different livestock-intensive and arable regions in Germany (e.g., Asai et al., 2018)). All these innovations fall within the "bio-resource vision" of the bioeconomy (Bugge et al., 2016), as these innovations relate to the conversion of matter. The German government supports the development of the abovementioned innovations through its bioeconomic strategy (BMEL and BMBF, 2020).

4.1.1. Key narratives and the technological fix imaginary

Based on our interviews, we identified five different narratives that are used by involved actors to legitimize their innovations to the public (see Table 4). All of these narratives rest on the imaginary of a technological fix for the underlying issues attributed to the surplus of manure. These narratives relate to two major fields: ecological sustainability and economic potential. Specifically, these narratives include i) "closing the loop" in a circular economy, ii) spatially decoupling agrifood systems, iii) substituting conventional mineral fertilizer, iv) protecting soils and higher yields, and v) unleashing economic potential through the widespread diffusion of innovation (see Table 4). i) The circular economy narrative relates to using technology to close (currently open) regional cycles of matter: "It would be much easier to significantly increase the degree of self-sufficiency [...] and then, ideally through a circular economy. [...] I imagine that I will be able to spread the liquid manure on the field or bring the liquid manure [...] to the duckweed.

[3] We refer to narrative irritations as events or processes that challenge the previously outlined narrative; these events or processes include public discourses, consumer preferences and new scientific results. An exemplary irritation relating to our case studies is the re-occurrence of the target pest (pink bollworm) of the biotechnological innovation (Bt cotton) in our second case. While the new (bio)technology originally promised to defang pests of the bollworm species (Lepidopterans), this narrative is irritated by the pest's renewed occurrence.

Table 4
Overview of the imaginaries and narratives of innovation actors relevant to manure-based bioeconomic technologies in Germany.

	IP 1	IP 2	IP 3	IP 4	IP 5	IP 6
Type of actor	Company, recycling background	Company, agricultural background	Science	Science	Company, agricultural background	Company, agricultural background
Type of innovation	Recycling fertilizer	Recycling fertilizer	Duckweed cultivation	Recycling fertilizer	Recycling fertilizer	Transporting manure
State of innovation	Development	Development	Development	Finished development	Market entry	Used in market
Imaginaries	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability and economic potential	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability
Narratives	i) closing loops, ii) spatial decoupling	iii) substitution of conventional fertilizer, iv) soil protection and higher yields	i) closing loops	i) closing loops, v) economic potential	i) closing loops, ii) spatial decoupling, iii) substitution of conventional fertilizer	Problem is solved by transporting manure

There are also other ways in which I can increase this circular effect" (IP 3). ii) The narrative of spatially decoupling agrifood systems relates to the end of the area-bound application of manure in livestock-producing regions. Supporters argue that this decoupling will not lead to an intensification of livestock farming: "This means that our concept is a decoupling of areas. This will not lead to an expansion of factory farming because this is no longer possible under current construction laws. [...] This means that we can support small and medium-sized farms. We can maintain the basic agricultural structure. [...] Yes, let me put it this way: we are back to where we were 150 years ago" (IP 5). iii) The narrative of substituting conventional mineral fertilizer relates to the finiteness of rock phosphate, which can be overcome by using recycled manure instead: "Phosphate is a finite raw material, which we are already seeing today or have seen in recent years, and we are having increasing difficulties processing this raw material because of the many, many impurities. So, the question is, where else can I obtain this raw material?" (IP 1). Relatedly, manure-based fertilizer would also render the energy-intensive Haber-Bosch[4] process unnecessary: "Especially now, from the point of view of CO_2 reduction, we have, for example, been able to recycle nitrogen instead of spending three liters of heating oil per kilogram on transposing nitrogen from the air by using the Haber-Bosch process [...] or to completely prevent methanization on agricultural land, including of nitrous oxide" (IP 5). iv) The narrative of protecting soils is related to the use of recycled fertilizer as a carbon carrier that will lead to improved soil health and higher yields: "At the end of the day, we have highly enriched nutrients and carbon carriers. This is one of the issues that is currently being completely overlooked in fertilizer policy, in my view. [...] There is actually the issue that they completely neglect the carbon cycle that such soil needs. But it's always just about nutrients and stuff like that. [...] You can see that quite clearly in our region. [...] The soil structure is gradually changing. [...] You can really see this in the yields" (IP 2). v) The narrative of unleashing economic potential through the widespread diffusion of innovations distantly relates to unburdening farmers from the need to pay to dispose of their manure surpluses due to existing legal standards: "So of course it's economically driven" (IP 4).

We categorize all five narratives as relating to a technological fix for the aforementioned manure issue. However, we do so with varying foci based on the different conceptualizations of what is regarded as the actual problem. The first and second narratives address technological fixes for environmental issues, particularly in regard to disturbed biochemical cycles of nutrients; these issues ought to be solved through technological progress. The third narrative also involves the imaginary of a technological fix for environmental issues; however, in this narrative, the environmental issues are specifically related to the energy-intensive production of mineral fertilizer. The fourth narrative concerns a technological fix for environmental and economic issues by arguing for both protecting soil by recycling fertilizer and generating higher yields through more productive agriculture. The fifth narrative ultimately relates to a technological fix for the economic standstill in agriculture; this standstill can be overcome by unleashing the economic potential of manure conversion.

4.1.2. Narrative dynamics

As outlined above (see Table 4), all of these manure-based innovations are in different stages of development. Since the innovations from IPs 5 and 6 are already available in the market, these innovations can be used to show the narrative dynamics involved (for more types of narrative dynamics, see Sections 4.2 and 4.3). We found that both actors use different mechanisms to reproduce and stabilize their narratives over time to be competitive in the market.

IP 5 provides us with two mechanisms that reproduce the narrative (prior to potential irritations), namely, telling economic success stories and building rhetoric coalitions; both mechanisms help the actor address the superiority of the innovation. The success story unfolds as follows: "One of the secrets of our incredible success that we have now [is to] always calculate the quality of the products and whether these can be immediately implemented in the market because we reproduce industrial products one to one as recycled products. That is the crucial difference, and with it, we have completely captured the entire market because all the others have always gone down this traditional path, typically engineering, but just never released any products of value and then just never achieved sufficient profitability" (IP 5). Building rhetoric coalitions is similarly straightforward: "According to experts from universities and chambers of agriculture/ministries with whom we work very closely, we are now highly recommended. They also highly recommend us because they say, 'This is the best solution that is currently available in the market and it truly works.' That is the decisive point" (IP 5).

IP 6 provides us with a stabilizing mechanism. The actor argues that the reciprocal transport of manure and fodder between regions characterized by intensive livestock production and arable re-

[4] Haber-Bosch process refers to the synthetization of ammonia out of the atmosphere.

gions allows the manure issue to be solved regionally while meeting the standards of the German nitrate directive. The actor (who developed the innovation of reciprocal transport of manure and fodder) builds on past experiences of success following the nitrate directive to legitimize his or her own innovation and regards the appearance of new innovations as an irritation of his or her own narrative of having solved the manure issue (for more information on irritation, see Section 4.3); IP 6 indicates this view of new innovations as an irritation by devaluing the company's competitors. In response to the question, "So, you are saying that these big industrial manure processing plants [the competitors] are not doing what they should be doing, and they are solving a problem that does not even exist in the end?" (Interviewer) IP 6 said the following: "Right. Which now no longer exists. That would have been a sensible thing to do 15 years ago because the whole logistics chain had not yet been set up. Now it has been built up; now many other biogas plants have been built up and constructed with it, and then you take the basis away from them again, just to operate a large system. That is quite wrong" (IP 6). We see this answer as a way of stabilizing IP 6′s own narrative. As such, the planned building of biogas plants translates into an irritation for IP 6 by undermining the favored narrative and elaborated innovation (Fig. 1).

4.2. Case study 2: agricultural biotechnology, technological failure, and political regulation

Biotechnology is meant to contribute to a "knowledge and innovation driven Bioeconomy," and its significance as a "tool for national development and well-being of society" is enshrined in the future vision of India's National Biotechnology Development Strategy (Department of Biotechnology, 2021, p. 1). According to the Department of Biotechnology's recently published strategy documents, efforts are being made to "create a strong enabling environment to promote the growth of the [biotechnology] sector" (Department of Biotechnology, 2021, p. 1); this is a perspective that corresponds to the "bio-technology vision" of bioeconomy (Bugge et al., 2016).

Among the multitude of GE crops researched and developed in India[5], Bacillus Thuringiensis (Bt) cotton is particularly relevant for our study. Bt crops produce Bt bacterium endotoxins that are lethal to key insects, such as Lepidopterans, which are considered a crucial limiting factor in both cotton and eggplant production (Choudhary et al., 2014; Kathage and Qaim, 2012; Kaviraju et al., 2018). As the first and still only authorized GE crop in the country, Bt cotton (Bollgard I) was introduced to India in 2002, while Bollgard I's successor (Bollgard II) followed in 2006 and is currently used on 94% of the Indian cotton area (Choudhary and Gaur, 2015; International Service for the Acquisition of Agri-Biotech Applications, 2017). While never fully accepted, Bt cotton technology was considered by many to be a silver bullet in the fight against bollworms (Choudhary et al., 2014; Kathage and Qaim, 2012). However, the pink bollworm (PBW), the major cotton pest that Bt cotton technology was intended to control, has recently developed resistance to the crop in several Indian states, thus causing plummeting yields and negative socioeconomic effects for farming households (Fand et al., 2019; Mohan Komarlingam, 2020; Naik et al., 2018; Najork et al., 2021; Tabashnik and Carrière, 2019; Tabashnik et al., 2021). The recently developed resistance of PBWs to Bt cotton has been perceived as a major irritation among related innovation actors and has substantially affected the corresponding narratives.

4.2.1. Key narratives and the technological fix imaginary

Broadly speaking, all interviewed actors and representatives considered the application of biotechnology in Indian agricultural production to be necessary. Expressed by all four interviewed actors, the superordinate imaginary related to the agricultural biotechnology sector construed biotechnology as a technological fix (IPs 7–10). This imaginary was expressed in the form of various narratives that can be categorized as social benefits, economic potential, and ecological sustainability (IPs 7–10). Specifically, we identified narratives related to i) increased farmer income, ii) workload reduction, and iii) food security in the social benefits dimension; iv) increased yields and v) international competitiveness in the economic potential dimension; and vi) pesticide reduction, and vii) adaptation to climate change in the ecological sustainability dimension (see Table 5).

In regard to the social benefits dimension of the involved narratives, all interviewees emphasized the importance of biotechnological innovations for farmers. This emphasis was exemplified by IP 7, who described his interest in research as follows: "As an agricultural scientist, I strongly believe that the technology and seed is very crucial for my farmers in India" (IP 7). In this context, the narrative of i) increased farmer income was particularly relevant: "And there, technology has a huge role, particularly in increasing incomes" (IP 9; see also IP 10). One interviewee even voiced this expectation aloud, stating that the goal was "doubling farmer income" (IP 7). Moreover, the narrative of ii) workload reduction was mentioned in regard to farmer well-being: "In the villages, it is very, very difficult for them, too. Physical work is [difficult]" (IP 8). Another important aspect related to the social benefits dimension of the technological fix was that of iii) food security (IPs 7–8). The interviewees expected food security to be jeopardized if the use of biotechnology in agriculture was reduced: "Can we stop 10% of cultivation every year? [...] What will happen to national food security?" (IP 8); another interviewee stressed the significance of biotechnology for food security against the background of India's population size: "Sooner or later, the government has to look at technology. There's no way that we can run away from development. [...] With the kind of population that we have, I think food security is much [more] critical for my country than any other country in the world" (IP 7).

These social benefits depend on narratives related to the economic potential of biotechnology regarding iv) increased yields, as noted by one interviewee: "Our cotton production at the national level actually increased by a factor of three. [...] So, I need to look at yield parameters" (IP 7). Another respondent underlined the economic role of biotechnology in India's v) international competitiveness; the respondent argued that productivity had improved in "every parameter" and hence "India was the largest importer of cotton, [and is] today [...] the largest exporter of cotton" (IP 9; see also IP 7; IP 10).

Furthermore, a technological fix regarding ecological sustainability was expected (IPs 7–9). Here, the main point was vi) pesticide reduction, which is of particular interest to actors working with food crops, such as Bt brinjal[6], as voiced by one respondent: "But in India we have half a million brinjal farmers. [...] They're still spraying four or five dozen pesticides to get the brinjal crop out to the market; [this] would be about a barrel pesticide residue inside [the crop], which no one wants" (IP 7). Another respondent even specified the potential future trajectory of possible pesticide reductions: "I would consider probably in the next, maybe, 50 years, if genetic technology is adopted, probably the use of pesticides, insecticides and weedicides will come down, maybe 70, 80%" (IP 8). In addition to the expected reduction in pesticide use, positive contributions regarding vii) adaptation to climate change were mentioned: "Water shortages, climate change. All this is going to

[5] For an overview, see Choudhary et al. (2014).

[6] Bt brinjal was developed in India from 2005 onward. However, this crop was put on hold after a moratorium was imposed on the commercialization of the crop by the then environment minister in 2010.

Table 5
Overview of the imaginaries and narratives of innovation actors relevant to GEOs in India.

	IP 7	IP 8	IP 9	IP 10
Type of actor	SABC South Asia Biotechnology center	CIFA Consortium of Indian Farmers Associations	ABLE (Metahelix Life Sciences) Association of Biotechnology Led Enterprises	ABLE (Du Pont) Association of Biotechnology Led Enterprises
Type of innovation	GE crops (Bt cotton, Bt brinjal)			
State of innovation	Bt cotton: widely used in the market; adoption rate of 94% (International Service for the Acquisition of Agri-Biotech Applications 2019, p. 2) Bt brinjal: moratorium since 2010			
Imaginaries	Technological fix related to social benefits, economic potential and environmental sustainability	Technological fix related to social benefits, economic potential and environmental sustainability	Technological fix related to economic potential and environmental sustainability	Technological fix related to social benefits and economic potential
Narratives	i) increased farmer income, ii) food security, iv) increased yields, v) international competitive-ness, vi) pesticide reduction	ii) workload reduction, iii) food security, vi) pesticide reduction	i) increased farmer income, iv) increased yields, v) international competitive-ness, vii) adaptation to climate change	i) increased farmer income, v) international competitive-ness

come in, so you have to modify the crops to suit these conditions" (IP 8). The potential of agricultural biotechnology as one of several solutions was thus emphasized: "Yes, GM crops are not a silver bullet; it is one [...] of the potent options for addressing the issues that the agrarian scenario in the country faces. Whether it be challenges from climate change [... or the] equitable distribution of development in our country" (IP 9).

4.2.2. Narrative dynamics

The aforementioned narratives have encountered irritations, which were found to play a central role in the narrative dynamics, as these irritations ultimately initiated the rejection, stabilization or adaptation of the original narratives. In the Indian case, technological and political irritations were relevant.

Our results show that the sector recently faced technological irritations caused by the failure of Bt technology and the reoccurrence of pest infestations. The PBW's evolving resistance to Bt cotton's built-in pest resistance – originally the crop's raison d'être – forced the actors involved to adapt their narratives. We found that this adaptation involved a rejection and the subsequent adjustment of the original narratives. As an empirical example, PBW infestation has been belittled and reframed as a mere management problem, and the relation of the problem to Bt technology is negated: "We believe that scientifically, it is very easy to manage pink bollworm [...] But I don't think pink bollworm per se would have to do anything with Bt technology. [...] I think it's a management practice, and I'm sure that by next season we should be able to contain this pink bollworm problem" (IP 7). While the severe damage caused by PBW infestation was originally the main argument for implementing the technology, this narrative is now rejected due to the pest's evolved resistance. Instead, technology failure is reinterpreted as a narrative of technology application failure.

Another rejected and then adapted narrative concerning this technological irritation is that the technology is said to be advanced, and new technological improvements need to be continually authorized for the technology's benefits to be fully realized: "You don't have to use [pink bollworm resistance] to beat down the technology. Technology development is a continuous process. From the very advent of agriculture, things have been moving. Resistant varieties develop, they succumb, then you have a new wave of varieties, [...] so it is a continuous process" (IP 9). While the first generation of Bt cotton was originally presented as a silver bullet in the fight against the target pest, now, after the crop's failure, this narrative is being rejected and adapted to a narrative of constant technological development. This narrative adaptation not only explains the failure of the first Bt generation, thereby stabilizing the narrative of its successful implementation, but simultaneously justifies its successors being repeatedly authorized and implemented. Similarly, one interviewee argued that the yield increase, which he had earlier attributed to the introduction of Bt technology, recently stabilized only because new technologies have not been authorized: "The yields have stabilized because Bt is not a yield technology. [...] Bt does not increase the yield per se. [...] The yield is stabilized only because then new genetics have to come on top of it" (IP 10).

Our results also revealed the possibility of a stabilization of narratives following irritations. For this stabilization, the interview partners referred to past technological innovation successes before the irritation to further consolidate the technological fix imaginary. As Bt technology has now been used in India for almost 20 years, the respondents could draw on their past experiences related to implementing and diffusing biotechnological innovations. Here, the respondents notably referred to past narratives of success while neglecting those of apparent failures: "Why are [the farmers] cultivating this? Obviously, they see the benefit in this, and the downsides, there are relatively fewer" (IP 9). In this regard, the high diffusion and implementation rate of Bt cotton (94%) throughout cotton-growing areas in India (International Service for the Acquisition of Agri-Biotech Applications 2019, p. 2) was of particular relevance, as it was argued that this high rate had been achieved because of farmers' preference for the technology: “And today, it is 12 million hectares. And seven million farmers. And who am I to tell my farmers what to do, what not to do? They do it because they like it. They found it to be useful. So, why would I convince my farmers not to use it? [...] But I would ask Vandana [Shiva] only one question: Why are there seven million farmers [using it]?” (IP 8). Finally, it was stated that if farmers were unsatisfied, the rates of adoption would have already declined: “they can always discontinue [using it] if it is not working” (IP 7).

Apart from the return of the PBW, political irritations were also mentioned; these included mainly the moratorium imposed on the commercialization of the first GE food crop, named Bt brinjal by the then environment minister, Jairam Ramesh, in 2010 (IP 7; IPs 9–10). One interviewee described the impact of the resulting uncertainties for the biotechnology sector as follows: “In India, I can tell you, until today, we have not been able to do anything because of the moratorium on Bt brinjal. [The] scientific community [is] completely demoralized. Nothing is moving. There is no investment, big investment in this technology. And all that you see today is actually the result of the moratorium” (IP 7; see also IP 9). Thus, “the industry investment in biotechnology [has taken a hit]” (IP 10) due to the moratorium, as was stressed repeatedly (see also IPs 7–9). This description of the demoralization of the entire industry and the lack of investment following the incident shows that the sector's fictional expectations were shaken, and hence no reliable mental representation of the future remained to direct action or investments toward.

All respondents mentioned path dependencies arising from such political decisions (IPs 7–10), as exemplified by the following statements: “I would say that this was the beginning of the slide of the biotech industry in India. Had Bt brinjal [been] commercialized, things would have been much, much better” (IP 10), and “had he [the former Environment Minister] approved Bt brinjal [...] you would have seen very different advancement in technology today in India than what we have now. [...] You see, since the moratorium began, [...] most of the companies withdrew or downsized their R&D facilities in India” (IP 7).

Another political irritation that emerged was the planned governmental price control of Bt cotton seeds: “So, those decisions [about Bt cotton price control] have had further effects. [...] Until [the] end of 2015, the industry was suffering because of the unpredictable scenario” (IP 10). As emphasized by all interviewees, these politically induced planning uncertainties had far-reaching effects on research and development (R&D) investments, as these investments, of course, would have to be made before the given innovation could be introduced (IPs 7–10): “For technology development, it's not like you can just come out with a white paper with some point and say that ‘here is the technology.’ [...] It takes time, it takes resources, it takes manpower, it takes intelligence. You need to hire people, [...] you need to fill laboratories. And you are liable to the legal structure that you have in the country” (IP 7; see also IPs 8–10). This quote underlines the severity of the irritation after investments have been made.

Ultimately, neither technological nor political irritations prompted a readjustment of the technological fix imaginary. In fact, rather than causing the reevaluation of stakeholders' elementary imaginaries, the irritations were found to have produced narrative dynamics, as they led to the rejection, adaptation or stabilization of the original narratives (see Fig. 1). The stability of the prevailing technological fix imaginary is emphasized by the interviewees' indication of the lack of alternatives to biotechnological solutions in agriculture (IPs 7–10): “Yeah, so I'm one-hundred percent sure that, you know, except for technology, there's no other alternative” (IP 7). In this context, one respondent was hopeful that GE technology “may get delayed, but it will not get denied, because people need it” (IP 9). Thus, in contrast to the dynamic narratives, the original technological fix imaginary remained intact as irritations arose; the imaginary even outlasted the resulting uncertainties.

4.3. Synthesizing the case studies: a model of narrative dynamics

Based on our empirical material from the two case studies that present different visions of the bioeconomy (cf. Bugge et al., 2016) in different local contexts, we now develop a generalizable model, depicted in Fig. 1, that describes the co-constitution of imaginaries, fictional expectations, narratives, and innovation dynamics (this builds up on Section 2; see also Beckert, 2018; Geels, 2020; Jasanoff and Kim, 2009). This model illustrates the contrast of fixed superordinate imaginaries and dynamic narratives by showing how narratives are stabilized, rejected or adapted in response to irritations (Fig. 1[4]). In the following, we outline this contrast on the basis of our case studies. An overview of the narratives and imaginaries presented by the two cases is described in Tables 4 and 5.

As our studies show, the narratives enable economic actors to legitimize their technological innovations vis-à-vis the wider public. In this regard, we discovered different dynamics of change in these narratives throughout the innovation design and diffusion.[7] We found that the narrative dynamics were triggered by irritations produced by internal and external incidents or developments that called respective innovations into question. In the German case, the appearance of new technologies that threaten the success of already existing technologies is one such irritation. In the Indian case study, the technological failure of Bt cotton associated with the return of PBWs and the political moratorium on Bt brinjal epitomized these irritative events. We identified three modes of narrative dynamics that actors implement to cope with such irritations: rejection of narratives, stabilization of narratives, and adaptation of narratives (Fig. 1[4]). These dynamics can occur in combined or consecutive forms and are not mutually exclusive. In the following, these dynamics are mapped out in detail. We further found that before irritations, actors use similar strategies which we interpret as a reproduction of their narratives serving to support the same (Fig. 1[3a]).

An example of the reproduction process (Fig. 1[3a]) is the building of rhetoric coalitions, i.e., referring to experts to provide narratives with an additional degree of credibility. In the German case (see Section 4.1), interviewees referred to scientific experts to amplify their narrative of the success of a specific technology.

The stabilization of narratives (Fig. 1[4]) occurs if economic actors underpin their own narratives with additional information or try to discredit other narratives to make their own more reliable and persuasive. For example, interviewees argue that the high implementation rate of Bt cotton in India (see Section 4.2) can be seen as proof of the technology's success despite the irritation caused by the return of PBWs.

A rejection of narratives (Fig. 1[4]) takes place if economic actors discard a specific narrative that they had formerly used to legitimize their technological innovation. In this case, these actors turned to adapted or completely different narratives, which may have existed before the irritation or may be created anew. For example, the failure of Bt cotton and the evolving resistance of the target pest forced the relevant actors to drop their original narrative of the first generation of Bt cotton technology being a cure for

[7] It is beyond the scope of this article to deeply interrogate the different processes involved in the design and diffusion of innovations across time and space. We point to the substantial body of literature in sociotechnical transition studies that covers these dynamics. In particular, we highlight the research on the multi-level perspective and subsequent related research, such as that on different transition pathways by Geels and Schot (2007), who describe different pathways of sociotechnical change.

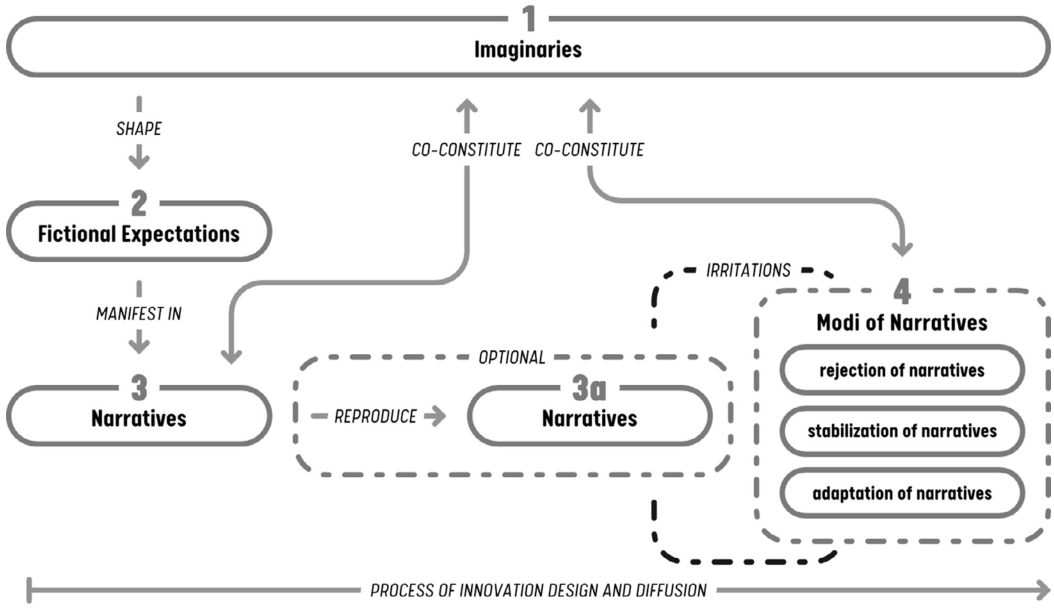

Fig. 1. Bioeconomic innovations and involved narrative dynamics.

the PBW problem and instead reinterpret the situation as one of continuous technological development (see Section 4.2).

The adaptation of narratives (Fig. 1[4]) means that involved actors add or remove specific aspects of the story and change the way they legitimize their technological innovation. This dynamic is found in the Indian case (see Section 4.2), where the failure of the Bt cotton technology forced involved actors to argue that the return of the pest was a mere management problem not attributable to the technology as such.

In addition to revealing these narrative dynamics, the two case studies bring to the fore a single superordinate imaginary that stays unchanged over time, and that is one of a technological fix (for further discussion on this aspect, see Section 5.2). Notably, this imaginary is not shaken, even in situations marked by severe internal (e.g., technological) or external (e.g., political or economic) irritations (see Section 4.2.2). Rather than revising their entire imaginary and thereby questioning their internalized logics, the interviewees adapted or rejected isolated narratives and adjusted them to avoid criticism to ultimately maintain their belief in technology.

5. Discussion

In this article, we investigated different narratives that bioeconomy actors used to legitimize certain technologies and examined how these narratives relate to changing conditions and discourses. We applied the economic sociology of (Beckert, 2013, 2018) to bioeconomies and showed that interview partners in both case studies followed the imaginary of a “technological fix” to solve social, environmental or economic challenges (see also Birch et al., 2010; Birch, 2019). The “technological fix” imaginary itself remained static over time as a prevailing idea of progress and development (cf. Harvey, 2003, 2007; Markusson et al., 2017) despite the occurrence of manifold irritations. Our results therefore reveal a sharp contrast to the more dynamic narratives used by bioeconomic innovation actors to legitimize their technologies (see Fig. 1). These narrative dynamics allow the relevant actors to avoid the dismissal of their single superordinate imaginary. Our inductively received model of narrative dynamics (Fig. 1) contributes to the existing theory of imagined futures in that the model describes these futures (in the form of empirically accessible narratives) on the micro level, thereby contributing to the overarching topic of normative dimensions of sustainability transformations (e.g., Schlaile et al., 2017). In the following, we first discuss these results in relation to the duality of the fixed imaginary of a technological fix and the dynamic narratives, and we come up with a plea for escaping fixed imaginaries in an attempt to “decolonize” the future through integrated systems thinking.

5.1. Narrative dynamics and a fixed imaginary

The results of our case studies show that the narratives of bioeconomic actors are related to the specific problems and societal discourses in each country. Thus, the technological fix imaginary is realized in different forms and manifestations (see Section 4.1 and Section 4.2). In the German case, technology was meant to solve environmental issues and create economic potential. This was described by using narratives of closing loops, decoupling, using substitutes for the energy-intensive production of fertilizer, increasing yields, and promoting the economic potential of cost avoidance for those willing to adopt the innovation. Socioeconomic narratives appeared to be less relevant than in the Indian case. In fact, in the latter, socioeconomic narratives were found to rather co-constitute the technological fix imaginary, e.g., in narratives of food security, increased yields and income, and the reduction of farmers’ workload, while in Germany, public discourses are centered on questions of ecologic sustainability, especially in relation to energy transitions (Beck et al., 2021; Friedrich et al., 2021b); in India, emphasis is placed on how to erase food insecurity and end poverty (Beck et al., 2021; Choudhary et al., 2014; Kathage and Qaim, 2012).

However, although the focus of the narratives differs, our results show that the imaginary of a technological fix underlies all mentioned narratives. While this imaginary stays unchallenged over time, the narratives are dynamically used to defend the idea of a technological fix against all odds (see Section 4.3 and Fig. 1). As the imaginary of a technological fix forms the basic roots of neoliberalism (Harvey, 2003, 2005, 2007; Markusson et al., 2017; McLaren and Markusson, 2020), its fixation has historically grown and is meanwhile deeply inscribed in society (e.g., Nightingale et al., 2020). It is therefore little wonder that this imaginary is highly resilient, thus posing ever more difficulties for any attempt to change it. The narrative dynamics discussed here both constitute and are constituted by the technological fix imaginaries, as these dynamics continually feed the imaginaries with new ideas and argumentations regarding how to effectively legitimize the respective technological innovation. Likewise, the fixed imaginary continually yields new adapted narratives and relativizes failing innovations caused by external factors.

5.2. Overcoming the imaginary of a technological fix: toward integrated systems thinking

In the neoliberal order, problems of public concern are often recast as nonpolitical issues to be solved by technological solutions instead of through changes in socioeconomic relations or culture (Roy, 2011; Scott, 2011); this has been described as technological fetishism (cf. Harvey, 2003). Morozov (2013) extends this by adding "solutionism," which refers to technological design and innovation that aims to solve problems whose complexity is not fully understood. We argue that similar tendencies apply to our case studies, as bioeconomic technologies attempt to solve highly complex social and environmental problems reductionistically by excluding societal aspects, such as human decision making, thereby possibly overlooking unintended side effects, which are difficult to solve once a certain development path has been taken (see also Friedrich et al., 2021a).

Escaping the imaginary of technological fixes is thus difficult, as it is rooted deeply in neoliberal ideas of growth and development and helps reproduce the neoliberal order (Birch et al., 2010; Birch, 2019). However, what can then be done to potentially overcome this imaginary? In our view, we first need to acknowledge the role of imaginaries in principle, as without them, society would be unable to make new social or technological developments (Ziegler, 2019). Castoriadis (1990) argues that imaginaries, specifically social imaginaries, constitute society as such through shared understandings and meanings; therefore, without social imaginaries, social life would simply be impossible. Thus, imaginaries that materialize in new technologies should not be viewed as negative per se. However, what is needed is an imaginary that is characterized by its own limitations. We can think of a technological fix of a technological issue; but as shown in our study, it is reductionist and may even be risky to rely entirely on a technological fix of societal issues by neglecting the underlying social, cultural and ecological aspects that produce these issues. Against this background, what is needed to grasp the complexity of socioecological problems is to develop an imaginary of a socioecological fix, meaning an imaginary that reintertwines the aforementioned idea of a technological fix with its underlying societal, cultural, and ecological factors. This also means attending to the complexity of wicked problems (in contrast to the "simple" narrative of neoliberalism; cf. Waddock, 2021). We therefore want to stress scientific concepts that indicate possible ways for future thinking. These approaches include, among others, philosophical debates on the ethics of invention (e.g., Jasanoff, 2016), responsible research and innovation (e.g., Owen et al., 2012), dedicated innovation systems (e.g., Schlaile et al., 2017), and adaptive governance methods (e.g., Cleaver and Whaley, 2018; Kovacic and Di Felice, 2019; Bohle et al., 2009). These concepts can help develop short-term strategies for adaptive and dynamic sociotechnological development. We therefore see the necessity of developing these approaches further in exchange with and for society.

As a long-term solution, we argue that societies need open discursive spaces that allow for societal exchange and debate, thereby building the ground for developing new imaginaries that can materialize in or produce new social and/or technological innovations. In our view, transdisciplinary science projects (e.g., Zscheischler and Rogga, 2015) that acknowledge the complexity of problems and the uncertainty of the future and include a broad range of stakeholders, thus coproducing knowledge and being able to influence the imaginaries of society and science, can provide such discursive spaces. Therefore, these projects provide opportunities to discuss wishes, expectations, and, thus, imaginaries of desirable futures (see, e.g., Pereira et al., 2018). In the words of Beck et al., p. 149), this would also mean "attend[ing] better to diversities of visions, actors and commitments that are present when one looks beyond dominant reductive and linear framings. Doing this reduces the risk that visions of transformative change close down, rather than expand, the range of pathways and the diversity of actors and their visions contributing to them." A practical example of how such discursive spaces in society could look like, very close to the transformation toward a bioeconomy, has been demonstrated by Kimpeler et al. (2018), who discussed different bioeconomic scenarios (imagined futures) during participatory workshops with interested societal actors. The results of the workshops show the importance of engaging with society in discussing (desirable) imagined futures, as this acknowledges the diversity of perspectives and knowledge in creating a sustainable bioeconomy. However, in our view, this could even be extended toward open imaginative and discursive spaces (following the idea of transdisciplinary science) that would not just discuss existing ideas (and scenarios) but rather would aim toward creating entirely new imaginaries with society and for society.

5.3. Limitations of the research: reflections on methods and research design

We chose an exploratory research design to examine the diverse (cf. Seawright and Gerring, 2008) and contrasting bioeconomic cases of Germany and India; this design allowed us to inductively develop a model of how bioeconomic actors legitimize their technologies by means of narratives that are adjusted over time. We contributed to the study of imagined futures (Beckert, 2018) by showing that the content of narratives is context related (see Table 2; see Section 5.1 for a brief discussion on this aspect), while actors apply a similar set of strategies to stabilize, reject or adapt their narratives (see Section 4.3). Particularly, the discrepancies resulting from the different backgrounds of the two cases (one case is in the Global North, and the other is in the Global South) and their contrasting visions of the bioeconomy (cf. Bugge et al., 2016) allowed for conferrable findings that we consider transferable to other regions.

While we presented two contrasting cases to allow us to identify commonalities among the broad range of bioeconomies, we see further need to prove our resultant model of narrative dynamics through complementary research, such as through an analysis of cases from other regions and other bioeconomic contexts and visions (cf. Bugge et al., 2016). Moreover, a comparison of different national bioeconomic strategies promises fruitful insights at the international level. Additionally, the manifold kinds of uncertainty (i.e., risk, ambiguity, uncertainty, and ignorance) can be addressed in more detail in further research (cf. Stirling, 2010).

Altogether, our approach should be seen as a starting point of how to empirically access bioeconomic futures among the interviewed actors. Thus, the above-stated limitations also relate to the very nature of exploratory, inductive, qualitative research approaches that are focused on in-depth descriptions of new phenomena or on applying theory to practical examples. We encourage scholars to place much more emphasis on the role of imagined futures and fictional expectations relevant to sustainability science to uncover how prevalent uncertainties are managed and to see how and what futures are imagined to overcome these uncertainties. In our view, this is very relevant knowledge that can inform the management of not only bioeconomic but also sustainability transitions more broadly.

6. Conclusion

The aim of this article was to shed light on the imaginaries that shape bioeconomic innovation design and the co-constituted narratives employed by actors to legitimize technological innovations in the public. We found that these narratives inform different dynamics that can be triggered by irritations on discursive or political levels. Based on empirical material from two case studies on the bioeconomy in Germany and India, our research reveals a duality of both the highly resilient and mostly context-independent imaginary of a technological fix and highly dynamic, context-specific narratives. Against this background, we inductively developed a model that combines the notions of imaginaries, fictional expectations and narrative dynamics to serve as a guideline for future research.

We have argued that the imaginary of a technological fix is rooted in the logic of neoliberalism and is therefore deeply inscribed in society. As a result of this inscription, path dependencies may arise, provoked by mental lock-ins that culminate in a "colonization" of the future and that deem societal issues to be solved by technical solutions. We criticize such a reductionist perspective and propose the elaboration of a socioecological imaginary that limits technology to solving technical problems while accounting for societal and ecological issues to be solved by societal and ecological means. We therefore end by encouraging sustainability scholars to create open spaces for debate in transdisciplinary research projects that serve to jointly imagine futures and to develop solutions that can be dynamically adapted to ever-changing circumstances.

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgements

We are grateful to the anonymous reviewers whose comments and suggestions significantly improved both clarity and precision of the paper. This study was supported by grants from the German Federal Ministry of Education and Research (BMBF) (031B0751) and the German Research Foundation (DFG) (KE1983/3-1).

Author contribution

Jonathan Friedrich and Katharina Najork contributed equally to writing this article, and thus, both function as first authors for this article. The same holds true for Jana Zscheischler und Markus Keck in their role as senior authors.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2021.12.026.

References

Asai, M., Moraine, M., Ryschawy, J., Wit, J.de, Hoshide, A.K., Martin, G., 2018. Critical factors for crop-livestock integration beyond the farm level: a cross-analysis of worldwide case studies. Land use policy 73, 184–194.
Beck, S., Jasanoff, S., Stirling, A., Polzin, C., 2021. The governance of sociotechnical transformations to sustainability. Curr. Opin. Environ. Sustain. 49, 143–152.
Beckert, J., 2013. Imagined futures: fictional expectations in the economy. Theor Soc 42, 219–240.
Beckert, J., 2018. Imaginierte Zukunft: fiktionale Erwartungen und die Dynamik des Kapitalismus. Suhrkamp 568.
Beckert, J., Bronk, R., 2019. Uncertain Futures. Imaginaries. Narratives, and Calculative Technologies.
Birch, K., 2019. Neoliberal Bio-Economies?: The Co-Construction of Markets and Natures. Springer International Publishing, Cham, p. 208.
Birch, K., Levidow, L., Papaioannou, T., 2010. Sustainable capital? The neoliberalization of nature and knowledge in the european "knowledge-based bio-economy. Sustainability 2, 2898–2918.
BMEL, BMBF, 2020. Nationale Bioökonomiestrategie: kabinettversion, 15.01.2020. https://www.bmbf.de/files/bio%c3%b6konomiestrategie%20kabinett.pdf. Accessed 19 June 2020.
BMEL, BMU, 2020. Nitratbericht 2020: Gemeinsamer Bericht Der Bundesministerien für Umwelt. Naturschutz und nukleare Sicherheit sowie für Ernährung und Landwirtschaft https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Binnengewaesser/nitratbericht_2020_bf.pdf.
Bohle, H.-.G., Etzold, B., Keck, M., Sakdapolrak, P., 2009. Adaptive food governance. IHDP-Update 3/2009: 53–58.
Bröring, S., Laibach, N., Wustmans, M., 2020. Innovation types in the bioeconomy. J. Clean. Prod. 266, 121939.
Bugge, M., Hansen, T., Klitkou, A., 2016. What is the bioeconomy? A review of the literature. Sustainability 8, 22 pages.
Castoriadis, C., 1990. Gesellschaft Als Imaginäre Institution: Entwurf einer Politischen Philosophie. Frankfurt am Main, p. 612 Suhrkamp.
Choudhary, B., Gaur, K., 2015. Biotech cotton in India, 2002 to 2004: ISAAA series of biotech crop profiles, Ithaca, NY. https://www.isaaa.org/resources/publications/biotech_crop_profiles/bt_cotton_in_india-a_country_profile/download/Bt_Cotton_in_India-2002-2014.pdf. Accessed 7 June 2021.
Choudhary, B., Gheysen, G., Buysse, J., van der Meer, P., Burssens, S., 2014. Regulatory options for genetically modified crops in India. Plant Biotechnol. J. 12, 135–146.
Čičková, H., Newton, G.L., Lacy, R.C., Kozánek, M., 2015. The use of fly larvae for organic waste treatment. Waste Manage. 35, 68–80.
Cleaver, F., Whaley, L., 2018. Understanding process, power, and meaning in adaptive governance: a critical institutional reading. E&S 23.
Departement of Biotechnology, 2021. National biotechnology development strategy [2021-2025]. Knowledge and Innovation Driven Bio-economy. http://dbtindia.gov.in/sites/default/files/NATIONAL%20BIOTECHNOLOGY%20DEVELOPMENT%20STRATEGY_01.04.pdf. Accessed 8 June 2021.
de Witt, A., Osseweijer, P., Pierce, R., 2017. Understanding public perceptions of biotechnology through the integrative worldview framework. Public Understanding of Science 26 (1), 70–88. doi:10.1177/0963662515592364.
Esposito, E., 2007. Die Fiktion der wahrscheinlichen Realität. Suhrkamp, Frankfurt am Main 127.
Fand, B.B., Nagrare, V.S., Gawande, S.P., Nagrale, D.T., Naikwadi, B.V., Deshmukh, V., Gokte-Narkhedkar, N., Waghmare, V.N., 2019. Widespread infestation of pink bollworm, Pectinophora gossypiella (Saunders) (Lepidoptera: gelechidae) on Bt cotton in Central India: a new threat and concerns for cotton production. Phytoparasitica 47, 313–325.
Feola, G., 2020. Capitalism in sustainability transitions research: time for a critical turn? Environ. Innov. Societal Transitions 35, 241–250.
Folke, C., Polasky, S., Rockström, J., Galaz, V., Westley, F., Lamont, M., Scheffer, M., Österblom, H., Carpenter, S.R., Chapin, F.S., Seto, K.C., Weber, E.U., Crona, B.I., Daily, G.C., Dasgupta, P., Gaffney, O., Gordon, L.J., Hoff, H., Levin, S.A., Lubchenco, J., Steffen, W., Walker, B.H., 2021. Our future in the Anthropocene biosphere. Ambio. https://doi.org/10.1007/s13280-021-01544-8.
Friedrich, J., Bunker, I., Uthes, S., Zscheischler, J., 2021a. The potential of bioeconomic innovations to contribute to a social-ecological transformation – A case study in the livestock system. J. Agric. Environ.Ethics doi:10.1007/s10806-021-09866-z.
Friedrich, J., Zscheischler, J., Faust, H., 2021b. Social-ecological transformation and COVID-19: the need to revisit working-class environmentalism. GAIA - Ecological Perspectives for. Sci. Soc. 30, 18–22.
Geels, F.W., 2020. Micro-foundations of the multi-level perspective on socio-technical transitions: developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory. Technol. Forecast Soc. Change 152, 119894.
Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Pol. 36, 399–417.
Giampietro, M., 2019. On the circular bioeconomy and decoupling: implications for sustainable growth. Ecol. Econ. 162, 143–156.
Giampietro, M., Funtowicz, S.O., 2020. From elite folk science to the policy legend of the circular economy. Environ. Sci. Pol. 109, 64–72. doi:10.1016/J.ENVSCI.2020.04.012.
Graupe, S., 2020. Change is always as a last resort change in habits of thought: for a new biodiversity of cognition in the face of today's crisis. Int. J. Pluralism Econ. Eductaion 11 (3), 243–254 https://dx.doi.org/10.1504/IJPEE.2020.116219.
Harvey, D., 2003. The Fetish of Technology: causes and Consequences. Macalester International 13.
Harvey, D., 2005. The New Imperialism. Oxford Univ. Press, Oxford, p. 275.
Harvey, D., 2007. A Brief History of Neoliberalism. Oxford Univ. Press, Oxford, p. 247.
Hausknost, D., Schriefl, E., Lauk, C., Kalt, G., 2017. A transition to which bioeconomy? An exploration of diverging techno-political choices. Sustainability 9, 669.
International Service for the Acquisition of Agri-Biotech Applications, 2017. Global Status of Commercialized Biotech/GM Crops in 2017: Biotech Crop Adoption Surges As Economic Benefits Accumulate in 22 Years. ISAAA Brief No. 53, Ithaca, NY.
International Service for the Acquisition of Agri-Biotech Applications, 2019. Biotech crops drive socio-economic development and sustainable environment in the new frontier. ISAAA Brief No. 55. International Service for the Acquisition of Agri-Biotech Applications.
Jasanoff, S., 2015. Dreamscapes of modernity: Sociotechnical imaginaries and the Fabrication of Power, Ed. University of Chicago Press 354 S.

Jasanoff, S., 2016. The Ethics of invention: Technology and the Human Future. W.W. Norton & Company, New York, London, p. 306.
Jasanoff, S., Kim, S.-H., 2009. Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. Minerva 47, 119–146.
Jasanoff, S., Kim, S.-.H., 2013. Sociotechnical Imaginaries and National Energy Policies. Sci Cult (Lond) 22, 189–196.
Kathage, J., Qaim, M., 2012. Economic impacts and impact dynamics of Bt (Bacillus thuringiensis) cotton in India. Proc. Natl. Acad. Sci. U.S.A. 109, 11652–11656.
Kaviraju, S., Kumar, D., Singh, N., Kumar, S., 2018. A comparative study on socio economic impact of bt cotton and non-bt cotton farm households in Warangal district of Telangana state. Int. J. Curr. Microbiol. App. Sci. 7, 1561–1567.
Kimpeler, S., Schirrmeister, E., Hüsing, B., Voglhuber-Slavinsky, A., 2018. Zukunftsbilder aus dem Leben in einer Bioökonomie – Kurzfassung. Fraunhofer ISI. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccv/2018/Zukunftsbilder_BioKompass_Kurzfassung.pdf. Accessed 20 November 2021.
Knappe, H., Holfelder, A.-.K., Löw Beer, D., Nanz, P., 2019. The politics of making and unmaking (sustainable) futures: introduction to the special feature. Sustain Sci 14, 891–898.
Kovacic, Z., Di Felice, L.J., 2019. Complexity, uncertainty and ambiguity: implications for European Union energy governance. Energy Res. Social Sci. 53, 159–169.
Kuckartz, U., 2014. Qualitative Text analysis: A guide to methods, Practice & Using Software. SAGE, Los Angeles, London, New Delhi, Singapore, Washington, DC, p. 173.
Longhurst, N., Chilvers, J., 2019. Mapping diverse visions of energy transitions: co-producing sociotechnical imaginaries. Sustain Sci 14, 973–990.
Markusson, N., Dahl Gjefsen, M., Stephens, J.C., Tyfield, D., 2017. The political economy of technical fixes: the (mis)alignment of clean fossil and political regimes. Energy Res. Social Sci. 23, 1–10.
McLaren, D., Markusson, N., 2020. The co-evolution of technological promises, modelling, policies and climate change targets. Nat. Clim. Chang. 10, 392–397.
Mohan Komarlingam, S., 2020. SWOT analysis of refuge-in-bag for Bt-cotton in India. Curr. Sci. 119, 1746.
Morozov, E., 2013. Smarte Neue Welt: Digitale Technik Und Die Freiheit des Menschen. Karl Blessing Verlag, München, p. 654.
Naik, V.C., Kumbhare, S., Kranthi, S., Satija, U., Kranthi, K.R., 2018. Field-evolved resistance of pink bollworm, Pectinophora gossypiella (Saunders) (Lepidoptera: gelechiidae), to transgenic Bacillus thuringiensis (Bt) cotton expressing crystal 1Ac (Cry1Ac) and Cry2Ab in India. Pest Manag. Sci. 74, 2544–2554.
Najork, K., Gadela, S., Nadiminti, P., Gosikonda, S., Reddy, R., Haribabu, E., Keck, M., 2021. The return of pink bollworm in india's bt cotton fields: livelihood vulnerabilities of farming households in karimnagar district. Progress in Development Studies 21, 68–85.
Nightingale, A.J., Eriksen, S., Taylor, M., Forsyth, T., Pelling, M., Newsham, A., Boyd, E., Brown, K., Harvey, B., Jones, L., Bezner Kerr, R., Mehta, L., Naess, L.O., Ockwell, D., Scoones, I., Tanner, T., Whitfield, S., 2020. Beyond technical fixes: climate solutions and the great derangement. Climate and Development 12, 343–352.
Owen, R., Macnaghten, P., Stilgoe, J., 2012. Responsible research and innovation: from science in society to science for society, with society. Sci. Public Pol. 39, 751–760.
Pereira, L.M., Hichert, T., Hamann, M., Preiser, R., Biggs, R., 2018. Using futures methods to create transformative spaces: visions of a good Anthropocene in southern Africa. E&S 23.
Pintucci, C., Carballa, M., Varga, S., Sarli, J., Peng, L., Bousek, J., Pedizzi, C., Ruscalleda, M., Tarragó, E., Prat, D., Colica, G., Picavet, M., Colsen, J., Benito, O., Balaguer, M., Puig, S., Lema, J.M., Colprim, J., Fuchs, W., Vlaeminck, S.E., 2017. The ManureEcoMine pilot installation: advanced integration of technologies for the management of organics and nutrients in livestock waste. Water Sci. Technol. 75, 1281–1293.
Roy, A., 2011. Urbanisms, worlding practices and the theory of planning. Planning Theory 10, 6–15.
Seawright, J., Gerring, J., 2008. Case selection techniques in case study research. Political Res. Quartelery 61 (2), 294–308. doi:10.1177/1065912907313077.
Schlaile, M.P., Urmetzer, S., Blok, V., Andersen, A.D., Timmermans, J., Mueller, M., Fagerberg, J., Pyka, A., 2017. Innovation systems for transformations towards sustainability? Taking the normative dimension seriously. Sustainability 9 (12), 2253. doi:10.3390/su9122253.
Schlaile, M.P., Kask, J., Brewer, J., Bogner, K., Urmetzer, S., de Witt, A., 2021. Proposing a cultural evolutionary perspective for dedicated innovation systems: bioeconomy transitions and beyond. J. Innov. Econ. Manage., prepublication doi:10.3917/jie.pr1.0108.
Scott, D., 2011. The technological fix criticisms and the agricultural biotechnology debate. J. Agric. Environ. Ethics 24, 207–226.
Stirling, A., 2010. Keep it complex. Nature 468, 1029–1031. https://www.nature.com/articles/4681029a.pdf.
Stadtlander, T., Förster, S., Rosskothen, D., Leiber, F., 2019. Slurry-grown duckweed (Spirodela polyrhiza) as a means to recycle nitrogen into feed for rainbow trout fry. J. Clean. Prod. 228, 86–93.
Sundermann, G., Wägner, N., Cullmann, A., Hirschhausen, C.von, Kemfert, C., 2020. Nitrate Pollution of Groundwater Long Exceeding Trigger Value. Fertilization Practices Require More Transparency and Oversight.
Tabashnik, B.E., Carrière, Y., 2019. Global Patterns of Resistance to Bt Crops Highlighting Pink Bollworm in the United States, China, and India. J. Econ. Entomol. 112, 2513–2523.
Tabashnik, B.E., Liesner, L.R., Ellsworth, P.C., Unnithan, G.C., Fabrick, J.A., Naranjo, S.E., Li, X., Dennehy, T.J., Antilla, L., Staten, R.T., Carrière, Y., 2021. Transgenic cotton and sterile insect releases synergize eradication of pink bollworm a century after it invaded the United States. Proc. Natl. Acad. Sci. U.S.A. 118.
Trencher, G., Rinscheid, A., Duygan, M., Truong, N., Asuka, J., 2020. Revisiting carbon lock-in in energy systems: explaining the perpetuation of coal power in Japan. Energy Research & Social Science 69, 101770.
Umweltbundesamt (UBA), 2019. Nährstoffeinträge aus der Landwirtschaft und Stickstoffüberschuss. https://www.umweltbundesamt.de/daten/land-forstwirtschaft/naehrstoffeintraege-aus-der-landwirtschaft" \l "stickstoffuberschuss-der-landwirtschaft. Accessed 29 June 2020.
van den Bergh, J., Folke, C., Polasky, S., Scheffer, M., Steffen, W., 2015. What if solar energy becomes really cheap? A thought experiment on environmental problem shifting. Curr. Opin. Environ. Sustain. 14, 170–179.
Vivien, F.-.D., Nieddu, M., Befort, N., Debref, R., Giampietro, M., 2019. The hijacking of the bioeconomy. Ecological Econ. 159, 189–197. doi:10.1016/j.ecolecon.2019.01.027.
Waddock, S., 2021. Wellbeing economics narratives for a sustainable future. Humanistic Manage. J. 6, 151–167. doi:10.1007/s41463-021-00107-z.
Ziegler, R., 2019. The times of social innovation – fictional expectation, precautionary expectation and social imaginary. In: Bruin, A.de, Teasdale, S. (Eds.), A Research Agenda For Social Entrepreneurship. Edward Elgar Publishing, Cheltenham, pp. 164–176.
Zscheischler, J., Rogga, S., 2015. Transdisciplinarity in land use science – A review of concepts, empirical findings and current practices. Futures 65, 28–44.