NARRATIVES AND MODELS IN THE ASSESSMENT OF UNPROVEN TECHNOLOGY

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Zusammenfassung

Imaginäre Zukünfte gelten als treibende Kraft der Gegenwart. Politiker, Wissenschaftler, Ingenieure und Ökonomen sind gleichermaßen auf nützliche Spekulationen angewiesen, wenn sie ihre gegenwärtigen Entscheidungen und Handlungen in vielversprechenden, sich entfaltenden Zukunftsvorstellungen umreißen und begründen. Zwar kann man die Zukunft nicht vorhersagen (Immanenz der Gegenwart), jedoch lässt sich empirisch beobachten, wie das Imaginieren und Streiten über Zukunftsvorstellungen an verschiedenen Orten, in verschiedenen Kontexten und zu verschiedenen Zeiten stattfindet. An diesen Orten der Hyperprojektivität entstehen und manifestieren sich die Grenzen plausibler Vorstellung unbewiesener Technologien in Modellen und Narrativen. Techniknarrative offenbaren die verheißungsvolle oder katastrophale Überschreitung einer vorhergehenden Normalität. Modelle untermauern die darin hervorgehobenen Aspekte mit ontischer Kraft und einer gewissen Objektivität. Inwiefern Akteure jedoch die narrativen Drehbücher und Modelle als Requisiten nutzen können, um in der Durchsetzung ihrer Visionen ihre relationale Positionierung zu verbessern, entscheidet letztlich die soziotechnische Praxis. Deshalb stehen Modelle und Narrative in dieser Thesis im Zentrum der Analyse und Unterscheidung imaginierter Zukünfte sowie der Diskussion von Implikationen für die Technikfolgenabschätzung.

Der konzeptionelle Ansatz begründet sich in zwei eher voneinander losgelösten Debatten im Umfeld der TA, nämlich in den Sociologies of Expectation und der Philosophie der Imagination und Modellierung. Während die soziologische Debatte die Reichweite und Bedeutung antizipierender Praktiken für neue und aufkommende Technologien aufzeigt, diskutiert die Philosophie Voraussetzungen, um in der Fiktion neue Überzeugungen und Motivation zu erlangen. Die Debatten treffen sich im Verständnis von Modellen und Narrativen als sozial autorisierte Anweisungen für die Imagination. Während Narrative die zeitliche Kohärenz heterogener Elemente in hypothetischen Handlungspfaden herstellen (von A nach B via C), bilden Modelle der Wechselbeziehungen berücksichtigter Faktoren die Grundlage sozio-epistemischer Anfechtung. Da beides für die Gestaltung der Zukunft von zentraler Bedeutung ist, gilt es die gegenseitige Beeinflussung herauszuarbeiten. Dazu richtete sich diese analytische Perspektive auf die integrierte Begleitforschung zu “Visionen der Ernährung mit Mikroalgen”. Anhand der empirischen Beobachtungen zeigt die Doktorarbeit, wie verschiedene Zukunftsnarrative den Machbarkeitsfragen Relevanz geben und Expertisen unterschiedlich arrangieren. Die Arbeit postuliert, dass der Wandel imaginierter Zukünfte durch drei dynamische Faktoren bedingt ist, nämlich durch die aktuelle Datenlage und Modellierung, verfügbare narrative Framings und die Kontingenz ihrer sozialen Praxis. Die Arbeit kommt zu dem Schluss, dass die zentrale Rolle von Modellen und Narrativen als Boundary Objects und Requisiten der Technikfolgenabschätzung mehr Aufmerksamkeit verdient, um die Zusammenhänge ihrer wissenschaftlichen, politischen und wirtschaftlichen Einbettung besser zu verstehen.

Die Artikel der kumulativen Arbeit ergänzen sich in ihrer Frage nach der Rolle von Modellen und Erzählungen in der Bewertung unbewiesener Zukunftstechnologien. Der erste Artikel erörtert aus systemtheoretischer Sicht die Rolle von Narrativen für die Erzeugung von Handlungsfähigkeit sowie für die perspektivische Bewertung von Wissen. Der zweite Artikel zeigt, wie gesellschaftliche Zukünfte mit Delphi-Methoden empirisch erforscht werden und generalisierte Schlüsselnarrative es ermöglichen, diese zu unterscheiden und in transdisziplinären Kontexten zu kommunizieren. Der dritte Artikel überträgt Kendall Waltons Theorie des “make-believe” aus den Debatten repräsentierender Kunst und wissenschaftlicher Modellierung auf die empirische Untersuchung von Visionen, um am Beispiel eines Stakeholder-Workshops die Ambiguität imaginierter Grenzen in der Abschätzung einer Zukunftstechnologie offenzulegen. Der vierte Artikel diskutiert Möglichkeiten, politische und wirtschaftliche Perspektiven der Ökobilanz (LCA) bereits im Studiendesign zu antizipieren unter den Prämissen von Vergleichbarkeit und methodischer Standardisierung. Der fünfte Artikel fasst die systemanalytischen Erkenntnisse des Fallbeispiels in einem TA Opinion Paper über Zukünfte der Mikroalgenernährung zusammen. Zusammengefasst gibt die Arbeit dem Zusammenspiel von Modellen und Narrativen innovativer Technologien eine neue Relevanz in den gegenwärtigen Debatten der TA und ihres wissenschaftlichen Umfelds.

Abstract

Imagined futures are said to be the driving force of the present. Politicians, scientists, engineers, and economists alike rely on speculations to reason and outline their present decisions in an unfolding and promising future. Although we cannot predict the future (immanence of the present), we can empirically observe how imagining and fighting about future imaginaries takes place at different sites, contexts, and times. At these sites of hyperprojectivity, boundaries for the imagination of unproven technologies emerge and manifest in narratives and models. Technology narratives reveal the promissory or catastrophic transgression of preceding normality. Models underpin the highlighted aspects of future narratives with ontic power and a certain kind of objectivity. However, the suitability of these scripts and props for asserting a vision and improving the relational positioning of actors, in the end, only becomes apparent in the sociotechnical practice. This thesis focuses on narratives and models to analyze and distinguish between imagined futures and gauge their implications for Technology Assessment (TA).

The dissertation's conceptual approach builds on two rather detached debates in the field of TA, namely the Sociology of Expectation and the Philosophies of Modeling and Imagination. While the sociological debate highlights the scope and significance of anticipatory practices for novel and emerging technologies, the philosophical debate addresses the prerequisites of achieving new beliefs and motivation in fiction. The two debates overlap in their understanding of narratives and models as socially authorized instructions for the imagination of futures. While narratives generate the temporal coherence of heterogeneous elements in hypothesized pathways for actions (from A to B via C), models are the basis for socio-epistemic contestation. Since they are both pivotal for shaping the future, the dissertation aims to identify their mutual influence, using the accompanying research on visions of microalgae nutrition as an empirical example. Based on the empirical observations, the thesis demonstrates how different future narratives provide relevance to feasibility questions and align expert assessments. Furthermore, the thesis postulates that imagined futures are pined on three types of nonfixeties, namely the data situation and models, available narrative framings, and the contingency of their social practice. Finally, the thesis concludes that more attention should be paid to the central role of narratives and models as the boundary objects and props of Technology Assessment to understand better the interrelations of its scientific, political, and economic embedding.

The articles of the cumulative work cohere in their question about the role of narratives and models in the assessment of unproven emerging technologies. The first article explores the role of narratives for agency and the ambiguous assessment of knowledge from a systems theory perspective. The second article discusses and exemplifies how to study societal futures through Delphi methods empirically and how generalized key-narratives allow us to distinguish and communicate them across transdisciplinary contexts. The third article applies Kendall Walton's theory of "make-believe" in the empirical study of visions to reveal the ambiguous sociotechnical boundaries of imagined future technology, using the example of a stakeholder workshop. The fourth article discusses ways of anticipating political and economic perspectives on life cycle assessment (LCA) in the study design under the premise of comparability and methodical standardization. The fifth article merges the system analytical findings in a TA opinion paper on futures of microalgae nutrition. In summary, the thesis gives the interplay of narratives and models of unproven and emerging technologies a new relevance in present debates of TA and its scientific surroundings.

List of Individual Articles Included in the Dissertation

Article 1: *Roßmann, M. (2018). Narrative Self-Reference and the Assessment of Knowledge. Journal of Sociocybernetics, 15(2), 38–51. https://doi.org/10.26754/ojs_jos/jos.201822630*

Article 2: *Roßmann, M., & Rösch, C. (2019). Key-narratives of microalgae nutrition: Exploring futures with a public policy Delphi in Germany. Science and Public Policy. Advance online publication. https://doi.org/10.1093/scipol/scz053*

Article 3: *Roßmann, M. (2020). Visions as Make-Believe: How Narratives and Models Represent Socio-technical Futures. Journal of Responsible Innovation, 8(1), 70–93. https://doi.org/10.1080/23299460.2020.1853395*

Article 4: *Roßmann, M.; Stratmann, M.; Rötzer, N.; Schäfer, P.; Schmidt, M. (2020): Comparability of LCAs — Review and Discussion of the Application Purpose. In Stefan Albrecht, Matthias Fischer, Leistner, Philip, Schebeck, Liselotte (Eds.): Progress in Life Cycle Assessment 2019. Cham: Springer International Publishing (Sustainable Production, Life Cycle Engineering and Management), pp. 213–225. https://doi.org/10.1007/978-3-030-50519-6_15*

Article 5: *Rösch, C., Roßmann, M., & Weickert, S. (2018). Microalgae for integrated food and fuel production. GCB Bioenergy, 30(6), 1344. https://doi.org/10.1111/gcbb.12579*

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"Computers are good at consuming, producing and processing data. Humans, on the other hand, process the world through narratives. Thus, in order for data, and the computations that process and visualize that data, to be useful for humans, they must be embedded into a narrative – a computational narrative – that tells a story for a particular audience and context. "

Fernando Perez & Brian E. Granger (2015). Project Jupyter: Computational Narratives as the Engine of Collaborative Data Science

"I can only answer the question 'What am I to do?' if I can answer the prior question 'Of what story or stories do I find myself a part?'"

MacIntyre, A. (2007). After Virtue: A Study in Moral Theory, Third Edition. Notre Dame, Ind. (p. 216)

Section I: Introduction

It is April 2020 and due to the Corona pandemic now in the home office, the author of this thesis finally finds time to finish the framework chapters of the cumulative thesis. Five individual publications for different audiences already summarized the findings of 3.5 years at the Institute of Technology Assessment and Systems Analysis (ITAS) along with the doctoral program on energy and resource efficiency (ENRES). Now they are to be reassembled into one coherent story that bridges temporal distances, emphasizes particularities, puts them in a context, and makes them significant. One could tell about an ongoing journey and exciting debates while presenting results and preliminary findings relevant to academics, project partners, and bioeconomy stakeholders. But since this would miss the required genre of a philosophical dissertation and the author lacks the talent to write a stirring drama, this work must begin differently. Preferably with an exposition of an actual event, a grand (societal) challenge, or an ignored problem in a scientific debate that, without giving too much away, foreshadows how the compilation contributes to its solution. With the prospect of a solution, moreover, it would then be foreseeable that the story will also have an end auguring in the spanned space in between an insight worth telling that goes beyond it. Just as important choices on a life path are only recognized, selected, and put into a meaningful context in a continuous retrospect, this work must now present the reader with a theme or challenge that now makes sense of the emerged assemblage.

Academic works, technology projects, and Technology Assessment (TA) studies must increasingly generate their relevance by promising to exceed the ordinary using stories of, for example, a better or disastrous future due to digitalization, rising resource and energy demands, and inequality – and this is precisely what is to be problematized in this work. However, not as a demand to do without; rather, to hone how the interplay of distinct narratives and models at different levels shapes the development and assessment of unproven technology. This thesis seeks to answer the question of how TA studies can ground their subject, design, and boundaries in public discourse so that model-based estimates and impact assessments respond to public narratives in a way that contests or makes plausible the hypothesized action for the future. Therefore, the role of imagined futures is first presented against the background of scientific discourse, followed by a definition and overview of models and narratives as instruction for imagination and a discussion of their role in the assessment of unproven

technologies. After summarizing the individual papers in terms of their contribution to the overall question, the discussion and outlook will examine cultural boundaries for defining the relevance of technology issues and the potential role of TA studies at the science-policy interface either as deliberative maps or as swords in the battle for political authority.

1. Covid-19, climate change, and the pretense games of fictional futures

"Is this [pandemic] a dress rehearsal [for climate change]?" (Latour, 2020)

Imagined futures are the driving force of the present. One cannot predict the future, but politicians, scientists, engineers, and economists are encouraged to reason and outline their present decisions and action to unfold in promising futures using props such as scenarios, models, and narratives. Practically, our knowledge restrains to the present ("immanence of the present," Grunwald, 2013b, p. 25), but still, what is considered useful speculation is no coincidence. Instead, we can empirically observe how the "hypothesization of experience" and fighting about future imaginaries take place at different sites, contexts, times, within different boundaries, and in recourse to memories and beliefs (Emirbayer & Mische, 1998, p. 984). Niklas Luhmann, therefore, distinguished the present future from the always future present as it would manifest itself in the future (Luhmann, 1976). Under this paradigm that the present future is still a contingent future projection, the social sciences analyze how imagined prospects emerge and evolve in contextual practices. The generation and contestation of futures are ongoing practices that induce actors in the past and the present to choose a party or policy measure, to invest their money in a company or financial asset, to conduct a specific research experiment, or to further develop a particular technology for the sake of societal value. This central significance of imagined futures for contemporary developments gives reason to examine their embedding in the assessment of unproven technology.

The conceptual interest of this work is the assessment of unproven technologies with an eye to future narratives and models as the interface for technology development, Technology Assessment (TA), and its political embedding. Therefore, I take up the two rather detached debates concerning TA, namely the sociologies of expectation and the philosophy of imagination. The sociological perspective begins with the assumption that it is no coincidence that the future visions, research objectives, and career plans resemble within cultural contexts and social networks without an explicit agreement. Central to this perspective is that the production,

negotiation, and contestation of imagined futures takes place simultaneously to their influence on the present. However, this debate neglects, as I will argue, the attitude of actors regarding feasibility and credibility and the role of narratives and models to distinguish futures and structure the discourse. To fill this gap, I take up insights from philosophical and narratological debates and examine the power of imagined futures to motivate action. I find narratives to be in an intermediate role between individual motivation, social coordination, and the discourse on sociotechnical futures. Models serve to represent modifiable or deemed true constraints for imagined pathways into the future. Both modeling and narration are socio-epistemic practices on which social collectives ground their reflection of the past and anticipation of the future.

The dissertation focuses on the interrelated role of models, narratives, and agency in the Technology Assessment of unproven technology. Imagined futures are not just a set of statements about the future. Instead, imagining futures is a practice that connects heterogeneous elements and social networks in fiction, draws boundaries of collective understandings, and frames the valuation and assessment of unproven technology. People often use objects like models, texts, laboratory instruments, and prototypes as a common reference point to instruct and constrain the imagination accordingly. Just as historical sources qualify narrated history for the discourse on reality (H. White, 1980), there are data and models with a "veto right" for reasonable future narratives (3rd article in this thesis). Their actualization or modification, on the other hand, can also irritate present futures when their imagination is based on sources that turn out to be fake, stock prices and positive case numbers that change, or experiments that fail to longer permit the hegemonic story to be told further. The dissemination of future narratives thereby determines whether such changes are meaningful. They provide the context and public attention to what is known and unknown as well as feasible and negotiable according to authorized representations. Designing and deliberately engaging in objectual practices using texts, models, and prototypes to represent potential action in the light of the future, therefore, implies responsibility and potential for collective actions.

Empirically, this thesis builds on the TA study about future visions of microalgae nutrition and integrative research. The different papers show how narratives and models play a role at different levels of TA: In the negotiation and communication of popular visions and their expert

assessment, in the scenario development at a stakeholder workshop, and the systematic modeling of environmental impacts. A great deal of the study not only aimed to meet the requirements of disciplinary discourses but also provide benefit to the scholarship colloquium on resource and energy efficiency as well as to the research colloquium on Bioeconomy. The benchmark of this dissertation project was to contribute to the responsible deliberation and assessment of unproven technology. This interdisciplinary collaboration distinguished the work from disciplinary work and resulted in the orientation of the empiricism and addressees of the papers. The thesis aims to provide an interface between disciplinary debates and the application of findings to practices at the science-policy interface. This framing paper (Section I: Introduction and Section II: Discussion) aims to place the doctoral thesis within philosophical, narratological, and sociological debates, to highlight conceptual findings, and reflect them in TA practice.

1.1. The Temporal Differentiation of Sociotechnical Futures

Analyzing present futures is preconditional. In everyday life, we only occasionally notice how present decisions and actions build on uncertain and contested future expectations. Instead, it is routine to save or invest money, to plan trips to and organize conferences, to spend ages at university, and to consider others or engage ourselves in politics for a better and livable future. The ongoing corona crisis is an example of how much our everyday life is affected by shared expectations of the near and distant future, thereby making visible how narratives about the return to an old or different normality and models on the virus transmission and vaccine availability stabilize uncertain and contested future projections.

In pre-modern times the motives, goals, and possibilities were fixed in hierarchical, recurrent, and historically or God-given structures. Expectations of the future were limited to the continuation and repetition of the past; events and novelties were interpreted according to this order. However, with functional differentiation and the fading authority of historiography in favor of statistics and forecasting, the orientation turned towards the future (e.g. Koschorke, 2013, p. 233). In the progressive dissolution of traditional structures, the novel fixed points of reference ranged from “romantic poetry” as some kind of individual consolation to the governance by the “politics of understanding” (Luhmann, 2002, p. 133). Reinhart Koselleck and Keith Tribe date the conscious orientation towards uncertain imagined futures at the beginning of foresighted politics in Italy in the 15th 16th century and later during the establishment

of statistics and insurance at the beginning of the 18th century (Koselleck & Tribe, 2004, p. 18). Since then, social and sociotechnical imaginaries, stories, and legends have remained the key ingredient of "an organized field of social practices" for establishing social order (Jasanoff & Kim, 2013, p. 122; MacIntyre, 2007; Taylor, 2007).

This thesis focuses on the development of novel technology. Under the paradigm of the "social shaping of technology" and the "social construction of facts and artifacts" (MacKenzie & Wajcman, 2010; Pinch & Bijker, 1984), the thesis rejects a linear understanding of innovation in which the shape and social benefits of technologies follow deterministically from basic research discoveries. At the same time, this view follows Armin Grunwald's extension of the consequentialist model of TA, as it aims not at "facts about the future consequences of science and technology", but also at expectations, debunking stories, and dealing with future communication, which also includes a critical view of one's own role in the discourse about the future (Grunwald, 2013a). Innovation follows neither the sheer scientific rationality of a hypothesis test nor natural determination but is shaped by publicly shared visions of the future, emerging collaborations, profit and funding expectations, and political promises already in the early phases of development. The Science and Technology Studies (STS) examine the co-production of knowledge and technology and reveal the blind spot of the norm-loaded nature of technology development. On the side of actively "shaping the future" and "managing action-oriented policy-making," the future studies cover a whole range of methods for mobilizing, aggregating, and evaluating versatile future knowledge (European Commission, 2014). Nevertheless, no matter how rational these practices may appear to us, all "prophecy transgressed[s] the bounds of calculable experience," and must, therefore, be considered central to "the political situation" (Koselleck & Tribe, 2004, p. 19). This thesis studies how the negotiation of imagined futures in the political situation is based on the mutual influence of narratives and models and derives conclusions for Technology Assessment. The simultaneity of the generation of futures and their intended and unintended influence on the present is central to the sociological debate on imagined futures.

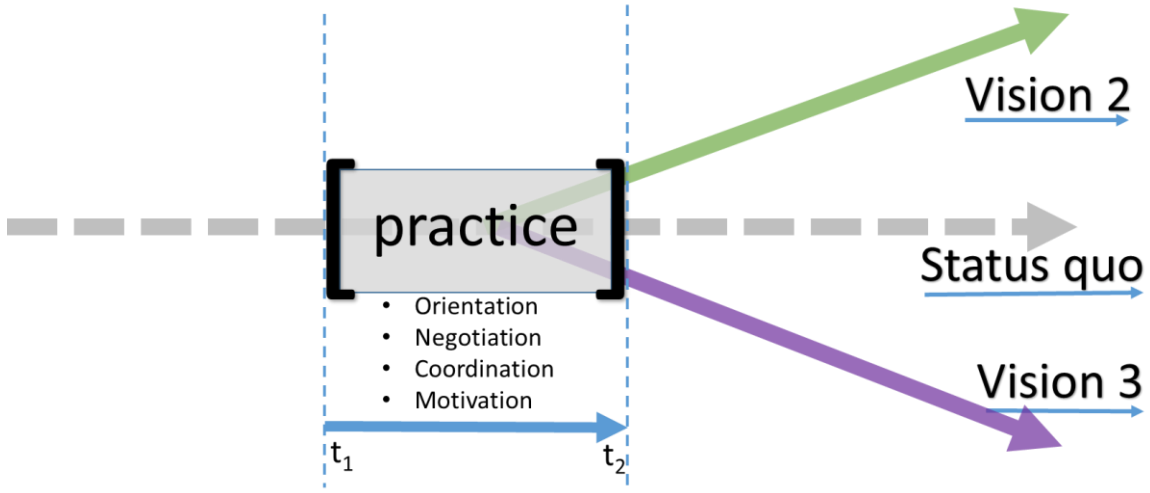

Figure 1: Temporal structures of future practices. A study observes practices in a set timeframe (t_1, t_2) to analyze the immediate effect of one or more contested futures.

The sociological and epistemological analysis constitutes present futures[1] in a procedural and social, and culturally embedded practice of generation, discussion, and dissemination. Thereby, the messy feedback and pull mechanism of different imagined futures, at different sites with varying actors, is considered (van Lente, 2016). The conception of a temporal process of multiple presences reveals how the production and contestation of current practices influence current action. One must envision anticipation *as a process,* or respectively as embedded in a temporal sequence so that both the factual imagination practices and the imagined future stories have duration (Figure 1). The social imagination of contested futures influences the orientation, coordination, communication, and motivation of actors (Lösch, Heil, & Schneider, 2017). Imagining the future, anticipation, and the social "*hypothesization* of experience" are considered a fundamental part of human agency (Emirbayer & Mische, 1998, p. 984). In this process, actors attempt to reconfigure received schemas by generating possible alternative responses to the problematic situations they confront. Their experiences are generalized and materialized, meanings negotiated in different societal contexts, alternatives considered, and decisions made or missed – in so far as opportunities arise. In this respect, imagined futures themselves have an inner and external temporal dimension. On the one hand, different imagined futures count as suitable points and pathways of orientation, while, on the

[1] Augustine (1994) has stated, futures are to be seen as part of the present in the form of expectations. In the same way, Luhmann (1976) highlights the present meaning of 'present futures' compared to the impossible prognosis of a 'future present'. Brown (2016) distinguishes the social science interest to look 'at contested futures' from looking 'into the future'.

other hand, imagined futures of other actors already influence present conditions and practices as some kind of "self-fulfilling prophecy" (Merton, 1948). Moreover, because you may strive to follow a vision, shadows may become visible, or other events may lead you to reassess the past guiding future.

Both, hope and historical consciousness – reflection on one's significance in a temporal context – inform action and actualize their bases. The simultaneity of the generation of futures and their impact on the present can be seen as a feedback loop that hinders the present imagined future to resemble the future present. There are approaches to model such dynamics with trajectors, akin to the "cob-web model" or the Leutka-Volterra equations. Nevertheless, the openness of the systems, the polycontexturality of actions, and epistemic boundaries practically seem to prevent a model-based prognosis which, moreover, itself takes place again in the system that models it. However, the simulated temporality of historical data extrapolations into the future or iterations gives a valuable template for telling "realistic" stories about the future, since their core is negotiated in a discourse about reality, while narrative meaning follows a desire for coherent and relatable events that is culturally predefined in fictional and non-fictional discourses. The examination of these present futures thus oscillates between an immersion to trace the meaning of the modeling along with existing beliefs about one's temporal context and an external tracing of forms and references to regarding discourses. This dual relationship to present futures, one that imagines narratives of one's self-positioning and actions, and one that shapes, changes, and authorizes representations of the future, creates the dynamics in discourse about the future, actor networks, and actor attitudes – central factors of present policies, investments, and the design of technologies. However, the temporal arrangement and social contextualization also mean that opportunities to change something in time can be missed or hindered because the generation of visions to be shared in a wide audience is a highly competitive political process.

1.2. The Strategic Use of Imagined Futures to Achieve Political Power and Economic Values

The generation, contestation, and motivation of present futures is a practical and societal process that is also observed by other actors in the present. The social sciences are a distinct but not the only notable instance of societal reflection within society. Also, beyond academia, actors reflect on their sociotechnical context and find valid conclusions that manifest as social facts. At a certain point in planning processes, for example, those affected become fully aware

that the present generation of power, energy, food, and waste management strategies will also significantly influence their near and far future. On both sides, the winners and losers, people are aware that it is now the time to express concerns, to withhold information, or to establish promissory and strategic alliances. The garbage can model, for example, vividly describes how actors with limited attention can be distracted from relevant decisions (see Cohen, March, & Olsen, 1972). Especially in politics and economy, it is obvious that not the best prognosis but the conscious management of sentiments and imagined futures is decisive for the success of an investment or an election (e.g. Beckert, 2016; Desrosières, 2005; Esposito, 2007; McCloskey, 2010; Soros, 2007). The analysis of mission statements, or respectively guiding images ("Leitbilder"), highlights in particular how performative action coordinates heterogeneous actors in an ongoing project (Dierkes, Hoffmann, & Marz, 1996; Schneider & Lösch, 2018). The future-oriented behavior of people counts as so predictable that the deliberate dissemination of imagined futures allows strategic coordination and motivation of actors. Historical studies about the gold rush or the so-called "Berggeschrey" suggest that, in the early days of capitalism, promissory rumors had the function to supplement the central management of labor and resources at its limits (Asmussen, 2020; Lingg, 2021). In their influence on stakeholder motivation, imagined futures are of political interest, so Jens Beckert (2016) calls the preset-oriented dimension the "politics of expectation." People narrate promissory stories when deemed appropriate to achieve immediate goals, and in particular, to obtain money or political power. Imagined futures are not formed in a powerless discourse to deliberate the best argument, but in strategic negotiations for the sake of the present due to the awareness of their formative power.

The formative power of imagined futures applies to both objects and actions and explains how assets emerge, and values are contested. On the one hand, deliberate assertions make certain actions and omitted actions more promising in the light of an imagined future. The projected reason for present efforts can, for example, motivate employees to work for a lower salary, direct students to show interest in certain fields. On the other hand, imagined futures also ascribe an essential value to objects and lead to the re-evaluation of salary, expertise, and ownership. Empirical studies show that a variety of stakeholders from mass media, business, politics, and science are involved in the valuation of objects (Birch, 2019). Specialist scientific journals with buzzword names give a good example for the co-production of ascribed value due to their promise to the patrons and subscribers of valuable knowledge in a subfield of

gaining relevance and due to the promise to the authors of being in the right place for publishing. To a limit, the imagined construct is self-sustaining, regardless of how concretely or miscellaneous one imagines the benefits of this future technology (see Merton, 1948). Particularly in the field of political economy and STS, scholars empirically study and critique the "technoscience capitalism" in research and innovation more in detail (Birch, 2019). The possibility of attributing imagined future value to both actions and material and immaterial objects makes them tradable assets and props that enhance the realm of power.

1.3. Why the Debate Needs a More Detailed Concept of Future Representation

The social sciences have revealed the scope and importance of imagined futures in innovation practice. The linear innovation model that considers the prior generation of stock knowledge and its subsequent application in the economy and society is not sufficient to explain and critique innovation practice, especially in the fields of new and emerging technologies. As a result, social sciences study the generation of imagined futures by the different stakeholders, the organizational force of imagined futures, and the extent they give present objects and actions societal meaning as well as political and economic value. Therefore, social science concepts define imaginaries and visions as follows:

- Charles Taylor defines "Social imaginaries [to be] the way ordinary people imagine their 'social' surroundings, [… and to be] carried in images, stories, legends, etc. [, and to make] possible common practices" (Taylor, 2007, pp. 171–172). Jasanoff and Kim extend the concept to sociotechnical imaginaries, including the technical surroundings (Jasanoff & Kim, 2013).
- The Sociology of Expectation defines "imaginings, expectations and visions" as "'constitutive' or 'performative' "future-oriented abstractions" (Borup, Brown, Konrad, & van Lente, 2006). They "provide structure," "mediate across different boundaries," "change over time," "have a temporal patterning over time," and "refer to images of the future" (ibid.). The sociology of expectation finds expectations in the "national policy through regulation and research patronage," in "sectors and innovation networks," and "within engineering and research groups and in the work of the single scientist or engineer" (Borup et al., 2006, p. 286).

- The Vision Assessment defines visions as socio-epistemic practices in present innovation and transformation processes having „the twofold effect [… to] enable the production of knowledge and visionary practices [… as well as to] newly order sociotechnical arrangements“ (Grunwald, 2019b; Lösch et al., 2017, p. 139).
- Emirbayer and Mische (1998) find a concept of agency that centers on collaboratively elaborated “imagined pathways and possible end-states” at “sites of hyper-projectivity.” These imaginaries exist “in our heads,” and as “externalizations in text, talk, and material objects” (Mische, 2014).
- Jens Beckert defines imagined futures as anticipatory practices that include objects akin to literary fiction but socially considered serious, and similar to non-fictional texts but including nonreal events (Beckert, 2016). Thereby he joins the concepts of John Searl, Kendal Walton, and Jasanoff in a promising relationship. This fusion of philosophical aesthetics and sociology, in particular, is further developed in this work.

What the sociological approaches have in common is that they place the meaning and motivation of sociotechnical futures in discursive or relational contexts. In this regard, they distinguish from analytical traditions that ascribe meaning to propositional attitudes. The confrontation with philosophical aesthetics indicates that the sociological discourse on imagined futures buys in two kinds of vagueness in dealing with the practice and content of imagined futures, namely the uncertain attitude of actors towards the future (do actors believe or pretend statements about the future?) and the distinction of imagined futures (How can technology visions be distinguished regarding their content, dissemination, and impact?). The vagueness becomes, in particular, visible when prominent experiments, simulations, and prototypes fail, and sociotechnical futures become contested.

Firstly, the deliberate use of imagined futures for a purpose in the present leaves open whether stakeholders believe or pretend their expectations. The sociological approaches share the view that imagined futures are a kind of background medium that allows epistemic and normative statements to be formulated (see the discursive function of visions in Lösch et al., 2017). Jens Beckert extends this perspective by the social attribution of credible and implausible fictions (Beckert, 2016). He raises the central question about the generation of credibility. It follows from this distinction that credible futures influence actors in a different way than untrustworthy futures. Since non-credible science fiction novels or scenario games also

seem to influence practices, many approaches did not make this distinction. These approaches correctly acknowledge that cognitive framings and cultural notions of normality delimit the freedom for deliberately shaping. However, I maintain that they systematically overestimate the influence of imaginaries and underestimate the role of materiality and institutions when it comes to aligning beliefs and actions with the future. I argue that the belief of actors is a relevant and neglected factor in determining whether the motivation of imagined futures lasts across societal contexts and over some time. Therefore, a theory must explain how imaginaries and the material situation together instruct imagined futures and influence motivation and cooperation in practice.

For Technology Assessment, the considered credibility determines whether the critique addresses the performative action (in case of mere pretense) or factual propositions. The response to strategic assertions, for example, to attract attention or distract, must be shaped differently than the response to incorrect assumptions in future projections. In addition, one must distinguish whether these false assumptions are only academically interesting or also relevant for present policy options. Instead of pointing out inaccuracies of an estimating model, for example, one can see that the improved calculation would not increase the acceptance or the success of a project. In case of a psychical trauma or an unresolved conflict, it may even sometimes be wise to refrain from a "rigorism of truth" (Blumenberg, 2015) and instead to remain silent for the sake of healing and political unity (see section 4.1). Therefore, at least two benchmarks are applied at the interface between science and politics, the scientific validity and coherence with viable policy options. And a third benchmark emerges in the form of their mediation. An imagined future does not have to be credible to have an impact on practice, but it has to be associated with beliefs to affect practice. Hence, one must distinguish what people believe and make-believe about the future, while keeping in mind that also make-believe can instruct learning. Therefore, in addition to clarity about the actor's attitude explaining the anticipatory practice, Technology Assessment must reflect whether to critique false beliefs and imagined prospects or malicious pretense practices.

Secondly, without distinction of representations, it is not possible to distinguish the fictional propositions of imagined futures and to study their dissemination and impact on practice. This difficulty concerns, in particular, the explanation by imaginaries, whose scope cannot be cap-

tured and distinguished (Hilgartner, 2015). Representations are between the discourse necessary to understand anticipatory communication and the concrete action derived in the discussion of the future. Without a sociological concept of representation, you can describe how actor-networks include material objects, embodiment, and imaginaries and correctly point that imagined futures do not linearly follow the imagination of individual actors. What is missing in given concepts, however, is an explanation of how the objects in social practice *and* the imaginaries constrain the imagined futures and therefore shape present practices. Such an explanation, as I suggest, includes factors for the success, manipulation, and distinction of imagined futures to be useful for TA practice. The concept of future representations that define the object in critique is crucial to explain the impact and intention of TA. For example, it should be possible to explain why and how one vision prevails over the other and suggests a different pathway for action. If not, the generation and impact of present futures is a fuzzy process. In such a case, Technology Assessment could not explain how its evaluation of desirability and feasibility of imagined futures should contribute to responsible, rational, or democratic research and innovation. Therefore, this thesis suggests understanding TA studies as representations that make plausible or challenge imagined policy options and viable pathways into the future.

To fill this gap, I draw on the philosophy of representative arts and the subsequent discussions in the philosophy of imagination and the fiction view on models. The approach follows the assumption that closer integration of recent developments in these fields provides additional valuable insights, especially regarding the analysis and distinction. The sociological challenge is to explain social imagination as a distinct and common reference point for further communication and their economic, political, and scientific embedding. Epistemically, the question at stake is not how to determine the quality of statements about the future, but, more generally, how TA can imagine to contribute and impact the collective imagination of sociotechnical futures, which therefore have to differ from daydreams in their political power and fictional truth[2]. For this reason, the following section focuses on the question of representation in narratives and models. Based on this, the articles then further discuss the rigor of truth (1st article) and the distinction of imagined futures (2nd article and 3rd article).

[2] Thus in the question of "objectivity" regarding the reception of objects, the analysis of socio-technical future is at a point that "social constructivism" attempted to avoid for a long time. If one is serious about the knowledge-

2. Narratives and Models as Representations of Sociotechnical Futures

An essential issue in the explanation of how imagined futures influence present technological development is the question of their representation. For an actor-centered perspective, representations are shared reference objects for propositional attitudes. From a discourse analytical perspective, they are structure-forming objects that make dynamics visible. Intervening concepts such as the Vision Assessment in Technology Assessment cannot be satisfied with by the presumption that dominant future imaginaries "just exist" if they want to explain their dynamics and impact. Explanation here does not mean to postulate natural causalities or laws of nature, but to justify formative and intervening action about invariant relationships (Woodward, 2005). I consider this explanation essential to explain why the Vision Assessment is useful for TA. For this purpose, the following literature review aims to sharpen the concept of social imagination. I start with the analysis of make-believe as a particular kind of imagination. The review of narratology places narrative structures as intermediaries between sentence and discourse. The evaluative element of narratives and the suitability of models as determinants of purpose and connecting point for social science. From there, I discuss the generation and role of agency and institutions for the assessment of unproven technology.

Following Jens Beckert, I consider imagining futures as a 'game of make-believe' (Beckert, 2016, p. 66). However, I maintain that the dynamic feedback of materiality and imagination in practices has so far been neglected and underestimated in the explanation of credibility and discourse dynamics. The following analytical characteristics of make-believe reveal the difference to other forms of imagination (see Salis & Frigg, 2020), and highlights what the uncertainty of imagined futures consists of:

- Imagined futures are propositional imaginations as they „usually have a temporal patterning over time" (Borup et al., 2006, p. 290). Instead of imagining a tree in the garden or the smell of fresh coffee (objectual imagination), imagining how the future unfolds means imagining propositions about the future (make-believe) (see Salis & Frigg,

based contribution of systems analysis and technology assessment to the debates on socio-technical issues, one cannot simply consider them the same status as daydreaming.

2020). Instead of imagining static symbols or mental images of the future, the game[3] is about following temporal propositions that make the course of the story.

- Imagined futures are "social imaginations" (See Salis & Frigg, 2020) since a group of people can share and discuss to a certain degree the feasibility of imagined technology as opposed to, for example, daydreaming. The details of a vision about microalgae nutrition, for example, are, to a certain extent, shared and discussed in the community. Robert Brandom's inferentialism clearly explains how statements about real and fictional objects go hand in hand with belief attributions *(Brandom, 2000, p. 161).* An utterance in the language game means two steps, namely "what is said, known, or expressed" and "what it is said *of* or true of." Speaking "*of* the representation" means a move in the language game (De dicto, "S believes that ϕ(t)") *and* it authorizes inferences to other (imagined) beliefs about the representations (De re, "S believes of t that ϕ(it)") (see Brandom, 2000, pp. 170–172). Brandon reveals the sociality of imagined futures in their representation, whose discursive content arises from the communicated attitudes between participating speakers (S) and their represented object (X). Therefore, social imaginations also allow inferences about fictional truths according to the representations given and found. Imagine for example a rocket to behave like the pen in the kid's hands (Rucinska, 2019). Alternatively, imagine the rocket acting according to an equation. If one follows the game, these instructions, texts, embodiment, uttered beliefs, and materialities constrain the ongoing social practice and allow uttering beliefs about the fictional rocket.
- Imagined futures can be conceived "voluntarily," in contrast to most dreams (see Walton, 1990, p. 16). People can choose to follow or not follow the instruction for an imagined scenario. Since narrating about the future and scientific scenarios follow an intention, one can also speak of a normative call to the imagination.
- Imagined futures "mirror" present beliefs (Salis & Frigg, 2020), since, natural objects are attributed similar characteristics to real objects unless explicitly stated otherwise. In the imagination, too, beliefs are represented, for instance, that the pencil rocket mentioned above is pointed at the front, starts vertically, and flies with the tip looking

[3] According to Suits (2005, p. 41), to play a game is to engage in "the voluntary attempt to overcome unnecessary obstacles" – you volutarily follow the (implicit) instructions for the game instead of simply moving towards a "target". Following and participating in a game is not a static thing.

forward. If there is a contextual purpose, one could, for example, throw the pen, measure the trajectories of the fictional rocket, and consider the model to a certain degree suitable or unsuitable for factual conclusions (3rd article).

- Imagined futures are in "quarantine" (Salis & Frigg, 2020), which means they do not have to coincide with other beliefs or imaginations and are initially without consequences. Even if you were a fan of specific science fiction novels, for example, by Stanisław Lem, that does not mean that they guide you in your actions. However, you could discuss imagined technologies according to the books with other appreciators. By mirroring beliefs, you might even find or ascribe new beliefs due to this game of make-believe that shape your expectations towards the development of novel technology and, thus, motivates further actions (Schellenberg, 2013).

To further analyze this process of fictive engagement, the concept of "make-believe" is briefly outlined below and discussed in greater detail for the study of visions in the paper on "visions as make-believe" (3rd article). The sociological peculiarity of make-believe is placing a social practice with actors and objects in a social context to define what is represented and modified by actions. The research on guiding images focuses on the relationship between actors and representation, while genealogical vision research analyses the historical and discursive relationship of present representations (e.g., Ferrari et al., 2018, pp. 45–49). Both research practices share the focus on objectual representations that gain meaning in social practice at a particular time. Genealogy focuses on the origin of the practice, to which the practice is blind by marking its beginning (e.g. Koschorke, 2015, pp. 102–131). An appropriate concept of representation, I suggest, should relate both the activities at the actor level and the discursive context to the representation to explain dynamics by mutual interference.

In philosophical aesthetics, Kendall Walton's concept of "games of make-believe" provides a widely acknowledged understanding of representation to explain the interplay between object, social practice, discourse, and acquired meaning (Walton, 1990). He compares the viewing of art and film to a children's game of make-believe. Children play and behave with objects by following rules of representation (principle of generation). With the rule "tree stumps are bears," they play in the forest. They derive inferences from the relations between themselves and the fictitious bears (due to embodiment and „imagine de se"), as well as between the fictional bears – for example, regarding their size, age, or group behavior. The crucial point is

that the principle of generation provides socially shared instructions for the imagination about representing objects and their relations. What counts as fictionally true, depends on the social practice and the relational constellation of objects in the world. The objects do not represent via similarity or isomorphism with the object represented. Instead, they constrain the propositional imagination at the basis of social norms, relational objects, and inferences from the social practice. Specific models, such as weather charts or the Corona contamination curve, are authorized representations. People understand the instruction for the imagination according to the data displayed in the model. The meaning for the current context remains undefined, and the model does not correspond to an image of the imagination. In the following sections, I will apply this principle to rumors, narratives, and history, to scenario games and models, and the self-referential generation of institutions and agency.

2.1. Future Narratives: Intermediaries of Assertion, Event, and Discourse

In the scientific debates of science and technology studies and Technology Assessment, the term narrative often refers to underlying patterns of interpretation that explain action and ambiguities to make utterances meaningful. Thereby the terms of narratives, visions, mental frames, ideologies, myths, and imaginaries are used interchangeably. Often, the criticism addresses the fact that a text fulfills a political function within a discourse, as it affirms, contests, or refrains from contesting gender, class, and racial ideologies. The term narrative serves as a reference to explain and criticize the cultural meaning of utterances by introducing distinctions, such as gender, sexuality, or class distinctions. From this perspective, one can criticize textual aspects that would never be visible or attributable to the text without the knowledge of the discourse in which it was placed by the analyst. This kind of narrative critique is often insightful and itself contributes to the discourse. From this perspective, however, no substantive statement is made about what the visionary story is about according to the text, what characters play a role, what is considered technically possible, and what moral, or respectively what policy or action option, the story suggests to its readers. Moreover, it remains unclear what is the specific function of narrative representations as compared to equations and facts. Therefore, I will outline how an understanding of the narrative as a representation of a story can empirically sharpen the discourse analysis and critique.

Narratology shows that the distinction and analysis of narrative structures provide valuable insights (Abbott, 2011; Culler, 2011; G. Currie, 2012; Koschorke, 2013). We find narratives as

linguistic structures in texts, films, images, speeches, and representational action. To differentiate the narrative concept more strongly and still to dispense with the finer distinctions of narratological schools, I refer to the narrative with Roland Barthes[4] as an intermediate level of discourse (Barthes & Heath, 1987, pp. 79–124). Homologically speaking, the sequence of sentences makes narratives a representation of a story, just as the structured sequence of words makes a sentence represent a proposition. The contextual meaning, however, is only found in the next higher level of language: a sentence makes sense as part of a narrative, and the narrative receives its meaning in discourse. An uttered proposition becomes meaningful in the move it makes in the narrative. Contentwise, a narrative thus seems suitable to represent the contingent discursive move of an utterance.

In simple terms, you define narrative as the representation of a story, or respectively a coherent sequence of events (Abbott, 2011). This raises the question of what makes the coherent unit. Aristotle describes the plot or mythos as a coherent unit of the beginning, middle part, and end that follow one another "by necessity or probability" (Aristoteles, 2005). This necessity follows from a kind of causal-temporal connection between events. On the one hand, one event naturally follows another ("causa efficiens"), and on the other hand, they follow a pathway towards a goal ("causa finalis"). So the beginning of the story determines the end, and the end determines the meaning of the opening. The unique feature of narratives, respectively, a high degree of narrativity, is to make the separate elements in the story a distinct and coherent whole (G. Currie, 2012). Narrating means to set "a beginning that which is not itself necessarily after anything else, but after which it is natural for another thing to be or come to be" (Aristoteles, 2005, p. 30). The beginnings and ends of narratives structure the discourse into elements of its own particularity. Therefore, the often subconscious choice of the beginning already implies a decision on how objects, technologies, and actors can become meaningful and hinder or contribute to a resolution.

Propositions associated with the nuclei of the story mean a move in the story, but propositions not only contribute to the story. Here Gregory Currie and Jon Jureidini (2004) also speak of

[4] Roland Barthes offers a suitable starting point for the social science analysis of narratives, since he attaches equal importance to the text and the reader. The emphasis on representation as object (narrative) and practice (narration) in a social and discoursive context for an evaluative purpose is a common thread in this thesis.

over-coherence because narrative representations inevitably address extra-narrative contexts that justify the purpose of the narration. In the words of William Labov, narratives have an evaluative element that ensures that the question “so what?” does not arise after a story has been told (Labov, 1972, p. 366). Dissemination beyond discursive spaces leads to the highlighting and modifying of different nuances that justify the narration for a particular context. Because we want to understand the key point of a story, we need to contrast what is told with shared normative ideas. Narratives are necessarily normative (Bruner, 1991, p. 15) and how people tell something thus says something about the social context of the narration.

The distinction between *how* one tells something and *what* one tells is found in the difference between story and narrative discourse. On the one hand, stories can be distinguished by their representations *of* a sequence of events from a beginning to an end via a middle part that is held together by a plot or theme – just like you would depict a flow chart *of* a certain process. Structuralist accounts further point out that there are certain character roles, such as the hero, villain, victim, and helpers, and events, such as "the hero is pursued and saved" that form the plot of a particular genre (Propp, 2013). Sequence analysts do not start with seeking specific characters but analyze the text for events, sequences, and their story-forming interrelation to then define the role of objects and actors in their contribution to the coherent story (Barthes & Heath, 1987). On the other hand, there are different discourses of a story, just as there are different layouts of a flowchart or a CV. They highlight or neglect particular aspects, give them different amounts of (textual) space, evaluate events to different degrees of explicitness and reliability, represent them chronologically, antichronologically, or thematically, let voices speak with different authorities, and thereby reveal the implicit perspectives of fictional narrators. In these representations, the contingent, and even intentional pragmatic effects on the present become visible, as later discussed in section 1.2 on “strategic use of imagined futures,” page 6.

The sociological significance of the story and narrative discourse becomes in particular clear at Albrecht Koschorke’s simplified and generalized concept of a hero narrative, following Vladimir Propp and Jurji Lotman (Table 1, Koschorke, 2013). At the center of the story are the crossing and restoration of a social norm which, as Jerome Bruner (1991) discussed, can only be recognized and analyzed at the background of cultural conceptions of norms. The narrative can either stigmatizes the hero for transgressing the ordinary so that the norm is restored with

the death or failure of the hero. Alternatively, the hero's actions can already be highlighted in the portrayal as honorable and courageous, so that, when the hero wins, a new norm overcomes the established. The narrative is thus interwoven with the audience for which it is told. The narratives of a sociocultural context represent the meaning of norms and morals of the cultural environment. And, as an act of their evaluative function, they suggest their reason or reason for their transgression. Once you are aware of this hero scheme, you can also imagine narratives that initially welcome the heroic transgression of the ordinary and then sanction the hero, for example, to effectively criticize a system that has no place for heroes (maybe Berthold Brecht's "*Der gute Mensch von Sezuan")*. And some narratives fascinate precisely with missing cultural standards in the representation and normative judgment of action and events (see Scholes, Phelan, & Kellogg, 2006, p. 265). In the end, the narratives have in common that the crossing of the ordinary makes them worth telling and suggests that the norm is known, shared, or neglected by the audience. This transgression of norms, therefore, later plays a crucial role in the definition of key narratives of a technology (2nd article).

Table 1: Narrative sequence in two basic versions based on Vladimir Propp and Jurji Lotman according to Albrecht Koschorke (2013, pp. 48–49)

1.	The hero crosses the border of the ordinary.
2.	a) He or she is stigmatized by this.
	b) He or she is awarded by this.
3.	He or she finds companions, helpers, admirers.
4.	An antagonist stands up to him or her.
5.	a) The hero is defeated. He or she must bow to the prevailing norms.
	b) The hero overcomes the adversary and changes the standards.

In the analysis of present futures, Ann Mische developed an analysis grid of projectivity dimensions (Table 2) to reveal the suggested common sense about the future of the narrator/listener relationship (Mische, 2009, 2014). Particularly noteworthy is the distinction between time frames, the openness and certainty of futures, and the attributions of agency to roles that can be filled by the addressees of the narrative. The narratological trained sociology of expectations gains a sharpened view for the discourse analysis. The study of narratives of future technology thus reveals the discursive classification and pragmatic function, according to which proposed technology futures are not merely neutral.

Table 2: Dimensions of Projectivity (Mische, 2009, 2014)

Cognitive contours	
Reach	Extension into short, medium, long term
Breadth	Range of possible alternatives considered
Clarity	Degree of elaboration and detail
Contingency	Pre-fixed vs. flexible, uncertain, dependent futures
Action orientations	
Expandability	Expanding vs. contracting futures
Volition	Relations of motion, influence, and control
Sociality	Consideration of future actors, relations, and interactions
Connectivity	Imagined logic of temporal connection
Mode of projectivity	
Genre	Recognizable narrative conventions or dramatic templates

The consideration of technology and scientific facts is characteristic of modern society. The design of future visions of unproven technology not only follows societal norms, but takes place at the interface of politics, economy, and science. The analytical grids can be applied not only to literary texts, but also to scientific, political, and economic communication. The interest of the literary-critical examination of non-fictional literature starts with Hayden White's critique of written history in the 19th century (H. White, 1980). Particularly noteworthy is the finding that history is more than a chronology since only a narrative structure makes and highlights the connections between the historical data. In this way, Hayden White reveals how narrative structures explain complex interrelations over a long period in a contingent and successful way, in picking up a small selection of very heterogeneous elements, such as dates, dreams, existing resources, or the physical condition of the actors. In distinguishing and contrasting narrative structures, he further illustrates how the same elements would provide a different morality. This contingency is crucial as the cultural and political self-understanding in the present is primarily based on historical memory and suggests plausible cooperations and actions to be derived from it. Willi Viehöver takes this perspective to develop the narrative discourse analysis, assuming that narratives count as stabilized reference points for social self-

organization (Viehöver, 2001). He finds the discursive field structured in narratives, which can be juxtaposed by a comparable structure, for example, in the form of a hero narrative. If the representations of different authors agree concerning story elements, i.e. if they label certain persons as heroes or villains or conclude the same moral from an actual event, Viehöver speaks of a discourse coalition. It is assumed that discourse coalitions would be more likely to collaborate due to the shared representation of reality. Technology narratives thus arrange discourse lines and actor coalitions.

By looking at scientific works as poetry, fiction, and narratives, Deirdre McCloskey (2010, p. 20) wanted to offer economists "a place to look in from the outside". In particular, the anthology "Narrative in culture" (Nash, 2010) took up the work of Hayden White and addressed the fields of economics, law, psychology, physics, and biology. Following in this tradition, Mary Morgan (Morgan, 2012, p. 243) states that narratives "provide the correspondence links between the demonstrations made with the model and the events, processes, and behavior of the world that the model represents." Narratives explain models and make the selection and interrelation of elements plausible and meaningful within a historical context. The more recent discourse on narratives in science developed a vibrant network of science criticism and proposal to apply narrative reflection in practices, for example, in Chemistry (Wise, 2017), Drug development (Stahl & Baier, 2015), paleology (A. Currie, 2019), and law (Blufarb, 2018). What connects recent these is the interest in the relevance and practical function of narratives that interrelate with models, facts, and data. Narratives guide the appreciators of models, data, and facts to make useful inferences within these assemblages. However, since the deconstruction of facts and values would not leave a standpoint of judgment and Technology Assessment, the following two subsections explore more in detail how the material world and our agency relate to the stories we tell and live by.

2.2. Scenario Methods: The Nonfixity of Data and Implications to Imagine Sociotechnical Systems

As outlined in the last section, the science and technology studies have so far focused on the influence of imaginaries, or respectively the socially sayable and the associated power relations in planning and development practices. The philosophy of science debate, on the other hand, reveals how imagined futures depend on the material and social situation. Imagined futures are represented in narratives and models. These objects have different roles in the generation of imagined futures, as the scenario method shows.

The early literature on the scenario methods clearly emphasizes the purpose of revealing interrelations of present knowledge with means of a creative game (Kosow, Gaßner, Erdmann, & Luber, 2008; Mißler-Behr, 1993). By definition, scenarios are stories to draw attention to present options for decision making: "[Scenarios] are hypothetical sequences of events constructed for the purpose of focussing attention on causal processes and decision points" (Kahn & Wiener, 1967). Scenarios are thus distinct from forecasts and explicitly do not claim to be true but to be useful for different purposes. One distinguishes the use of a scenario as the input and output for modeling. An input scenario represents input parameters with "the attitude to make-believe instead of the attitude to believe" (Poznic & Hillerbrand, 2019). Considered as an output scenario, the scenario represents the framework for making sense of the modeling results. Scenarios serve to provide the client with inquired knowledge for policy options, they serve to legitimize measures, and as boundary objects, they serve as a basis for societal discourse and internal organizational coordination (Dieckhoff, 2015; Kosow et al., 2008; also see the discussion in Section II:2). Scenarios are representations that include real and nonreal events for a socio-epistemic intent.

The role of models for future scenarios is to represent an imagined structure for transparent parameter manipulation reproducibly. Just as role-play rulebook, for example of "Dungeons and Dragons," suits to play different adventures, one model is suitable for different make-believe scenarios (see Roßmann, 2018; Silcox, 2012). The model responds to a set of questions with which the researcher or adventurer explores the behavior of the system and reveals contingencies and necessities for the narration of a particular audience (see Morgan, 2012). Just as the narrative structure constraints the imagined necessity of resolution in a plot, a model sets limits to the accordingly imagined. In contrast to the narrative, however, the model explicitly instructs the restrictions for imagination. The coupling of make-believe and the factual situation generates imagined constraints with the same resistance. The model, so to say, resembles the materiality and modifiability of the world in fiction (Figure 2). Within a story, the model represents the contingency of a turning point indicating possible alternatives. The model gives the reason why the chosen path is no different at this point. Depending on the story, different models are suitable to substantiate the sequel.

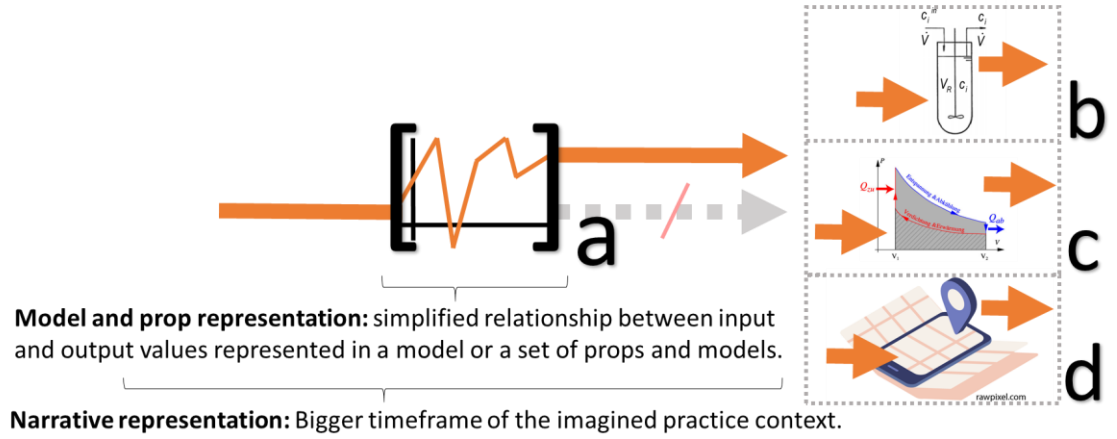

Figure 2: Different models as simplified relationships embedded in a narrative structure.

Modeling a scenario simulates providing "real" insights because it responds to the actual manipulation. When the defining parameters of the scenario are due to a model coupled with actual data, it responds to the further course of time and suggests, for example, how these variations translate into the future. Just as the situation of children and tree stumps in a forest according to Kendall Waltons (1990) game of make-believe indicates the position of bears and children, what is represented by the model is coupled with the situation. We consider the objects in our environment as meaningful constraints for imagining the past or future. The scientific generation of futures thus turns out to be equivalent to the generation of the past. David Weberman distinguished the skeleton of "historical past" and the flesh of narrated history (Weberman, 1997, p. 754). The skeleton is given ontological force to define what is narrated in history. Reinhart Kosellek (2007, p. 51) speaks of a "veto right of the sources." For if these data about the past change, for example, through new findings or the uncovering of fake evidence or documents, this affects not only the immediate environment but also the story that is held to be true. In other words, scientific narratives about the future or past are conditional. Making future narratives dependent on data makes them seem more reasonable. For example, the share price of a company or the results of an experiment can be used to paint and argue for entire visions of what life will be like in the future. However, merely imagining the future according to a contingent selection of present conditions, does not imply that one learns something reasonable. Still, according to the instructed imagination, these imagined futures remain true until the data they build on changes. However, it seems that data about the past are less uncertain than data used for future projections because the input data continues to change or be fought over, while the relevant data for the past tends to be archived.

Kendall Walton's make-believe theory found many followers in the philosophy of scientific representation (see Frigg & Nguyen, 2016b). Philosophers of science maintain that representational models, by definition, represent a target system (ibid.). Walton's direct account of make-believe describes the immersion in fiction and interaction with props. Props are both models and scenarios, or in the case of history, sources. According to Adam Toon, modelers imagine the target and themselves as props ("imagine de se") to explore fictional truths based on mirrored beliefs and prop interaction (Toon, 2014; Walton, 1990). New beliefs thus emerge as new inferences of mirrored beliefs. While anti-realists are satisfied with make-believe as a place for model-world comparisons (see Salis, 2016), realists argue for an exit of the "imaginative quarantine." Direct accounts claim that appreciators immerse in the practice of make-believe and indirect accounts claim for an imagined model system (Toon, 2014). Indirect accounts claim for fictional operators that, first generate fictional worlds that consist of denoted and explained fictional propositions, and then, serve as a key to transfer the fictional claim to the target system (Frigg & Nguyen, 2016a). In particular, the DEKI[5] account "explicitly associates the exemplified properties with properties to be imputed onto the target" (Frigg & Nguyen, 2016b, 2016a). When the sciences quasi keep control about the immersion and submersion in modeling, models become components of the social reality of science. However, according to Fiora Salis (2016, p. 254), deriving successful claims of validity about the target is still an unanswered and rather empirical question.

The make-believe approaches aim to explain how modelers find claims or new beliefs based on props and stories. Still, all one can learn from modeling and the hypothethization of experiences are inferences about parameters considered (immanence of the present). There is no truth in fiction but only truth according to this or that representation. Idealtypically spoken, the science-fiction author uses authorized models to paint the future plausibly, and the scientist learns about the limits of her or his representation in fictional model-world comparisons.

Regarding the proximity mentioned above of contesting futures to histography, I propose to "outsource" the evaluation of suitable conclusions to the social practice (3rd article). The situation and the social context determine useful conclusions. Both "what is a suitable principle

[5] According to Frigg and Nguyen (2016a, p. 230), "The account owes its name to the key ingredients: denotation, exemplification, keying up, and imputation."

of generation" and "what should conclude" are external to the model. The authorization of a model, for example, according to a particular discipline, and the "key" to valid claims are empirical questions. For the empirical study of imagined futures, make-believe thus draws attention to three uncertain variables of imagined futures, which are represented by horizontal arrows in Figure 3.

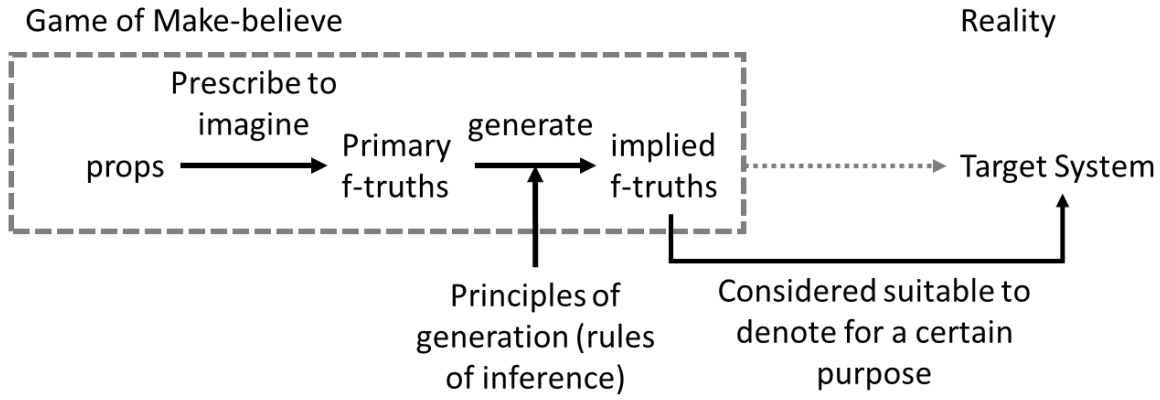

Figure 3: Primary and implied fictional truths that are considered suitable for a certain purpose (further developed, based on Salis, 2018).

The distinction of cultural contexts differentiates the distinction between "authorized" and "unofficial games" into reference systems (Walton, 1990). The possibility to also attend unofficial games leaves the last word to social practice. Mirrored on the make-believe approach, the "thin past" or "historical past" (Weberman, 1997) corresponds to the "primary f-truths" (Figure 3). Primary f-truths are assigned to the object or source. The "thick past" or narrated history corresponds to the "implied f-truths." The implicit truths, which promise new insights into the present through participation in the game, are conditioned by inference rules of the game. The handling of sources and models, for example, differs between disciplines. It follows that imagined futures are dependent on changes in: (I) props or sources at the material site, (II) on the sociocultural site, they depend on the authorized principles of generation, and (III) the considered suitability to denote for a certain purpose. While the latter (III) determines the present consideration of an imaginary, (I) and (II) determine the complementing parameters in the backgrounds of the cultural and material realm. A reference to authorized generators (II) allows, for example, to argue about different reasons for the same measure. (I) and (II) are conditioning to understand the future, and (III) determines what one practically or politically tries to use the fictional future for. That makes three uncertainties in the generation of imagined futures.

The distinction into a material, cultural, and social realm is analytical. Of course, the cultural and social domains influence the situation of the props. If prototypes, simulations, or experiments fail, the primary f-truths change, and the imagined futures become contested. If particular objects are not available, other props are used in practice and may, in the long-term, be authorized or de-authorized. In the context of disciplinary research, in the discourse on a certain theory, or a public social context, certain games of make-believe are authorized. In science, imagined futures are represented in a way to highlight what makes a move in scientific discourse. The authorization of imagined futures follows not only alongside the evaluative filter "worth telling in public," but alongside the filter "worth telling in science" (see Section 3.2). Imagined futures are, therefore, determined by their sociotechnical infrastructure, for example, laboratories and sociotechnical imaginaries (I and II). However, social practice has the final word about whether the imagined past or imagined future is meaningful, or not.

2.3. Narrative Identities: Representation of Self-reference in the Construction of Agency

The last two subsections highlighted the role of representations in the generation of imagined futures. In contrast to naïve social constructivist accounts, they no more denied the veto right of the sources and data than an interweaving of culture and materiality. Nevertheless, practice gets the last word. In particular, the "evaluative element of narratives" and the "suitability of a game" point to an area that is not accessible to the aforementioned epistemic models but only presumed. However, due to the interest in policy advice and the practical significance of imagined future issues, this thesis must pay special attention to this. The following section argues against the deliberate design of imagined futures and the epistemic critique according to material resistance. It highlights how the intertwining of practice and cultural identity and technology opposes the free shaping of the future by individual actors. This section emphasizes the occasional generation, the acknowledgment of significance, and the stabilization of imagined futures in discourse and social identities.

The observation of the persistence of imagined futures addresses an epistemic blind spot that goes against the assumption that plans and institutions can be changed by only criticizing their founding narratives or investigating contradictions or false beliefs. The attention thus shifts from the representational practices to their sociotechnical embedding and the generation of social facts. The evaluation of narratives and suitability of models practically count as quasi-decisions about whether make-believe makes a difference to the communicating system. I

equally consider social facts as institutions or expectation structures of double contingency. Whether you can factually or only metaphorically reduce these structures to psychological habits or "mental frames" (E.g. Lakoff, 2010) remains unanswered here. What counts is that an observer gives the object a meaning that shapes his or her future. In other words, the system does not attribute the inferences to the object of representation (external reference) but the system (self-reference). So to say, not the book or model but reading and understanding make the difference to a debate.

In Luhmann's communication model, the designation of understanding is a before-after distinction of the previous communication (Luhmann, 1987, p. 601). He distinguishes three types of self-reference, namely basic self-reference, reflexivity, and reflection. Basic self-reference is the inference in the continuation of the communication, or respectively, the distinction on how the utterance contributes to the semantic network of previous communication. Reflexivity is the "episodic reference" in the distinction before and after, and reflection is the reference differentiating system and environment. Luhmann finds the reflexive communication of the system by the system as the starting point of autopoiesis. It is the realization of the possibility of continuing communication later. Luhmann does not call reflexive communication a narrative. However, I find the reference to an object that represents a notable difference in a sequential structure to be in the form of a narrative (1st article). In reflexive self-reference, a social system represents the notable transgression of any social norm that makes the story worth telling. Reflection on the communication of relevance is a narrative act of communication that "brings to mind" a past process to continue communication about it. The narrative analysis of reflexivity sharpens the discourse-analytical view of systems theory to focus on the narrative generation of beginnings that decouple systems from their origin. It offers patterns to analyze underlying norms (see Table 1, p. 19) and the projective dimensions of reflexivity (see Table 2, p. 20).

Some scholars accuse the systems theory of being blind towards technology and practice. Therefore, I briefly discuss the compatibility with the former proposed features of make-believe. Although systems are operationally closed, that means that objects do not transfer truths into thoughts or communication, systems theory does not reject but presuppose material reality through structural coupling (e.g. Luhmann, 1992, p. 225). Thus, one must not un-

derstand the reference to a thought or a "real object in the world" ontologically but functionally (e.g. Luhmann, 1992, p. 76). In other words, systems theory does not propose a direct correspondence but an indirect relationship with the material environment through the structural coupling of the "sense systems," psyche, and social system, with the body and its physical environments. Besides, systems theory does not presuppose given rules for communication or mutual beliefs to constitute meaningful communication – instead, systems theory bases on the difference. The asymmetry of communication partners gives the occasion for the emergent self-dynamic of communication systems. Luhmann focuses on the development of inferential structures and the functional closing through communication practices (see Luhmann, 1992, p. 171).

However, the connection to narratology and make-believe supposes that systems achieved a distinction of the rule-constituted and objectual make-believe practice. Heinz von Förster compares this development of communication structures with the beautiful metaphor of a dance where patterns and self-references show up (Foerster, 2003, p. 296). The many references to children's games by Kendall Walton or Jerome Bruner support the argument that a make-believe attitude is learned at children's age (Bruner, 1990; Walton, 1990). One learns the distinction between make-believe and belief attitudes as one grows up. The professional application of make-believe in contexts of politics, business, and science presupposes the distinction of make-believe attitude and belief attitude towards facts. Therefore, I claim that systems theory can draw on this resource to study social practices of narrating and modeling in histography, futurology, and technology development.

Imagined futures and history reveal resistance as part of institutions and social identity. Arnold Gehlen uses this shift of perspective from the (imagined) motive to (social) purpose, or respectively to the "secondary, objective expediency (sekundäre objective Zweckmässigkeit)" to describe the emergence of institutions from social imagination (Gehlen & McMillan, 1988, p. 393). Gehlen finds totemism as the archetype of social institutions. According to him, a group of hunters imagines hunting an animal that represents the enemy or the food source, due to the hard everyday life of searching for food (Gehlen & McMillan, 1988, p. 391). In this "mimetical enactment" that goes beyond any emotional experience of "we" or a purely common behavior, the participants make common experiences that result in collective behavior that – in reflection – is attributed to the animal (Gehlen & McMillan, 1988, p. 392). Attributing

the factual difference to the animal as the representation of the imagined practice indicates the difference in the continuation of the social system. The attribution manifests itself in narratives about the experience (Gehlen & McMillan, 1988, p. 395). The formation of group identity and institutions that structure social life become social facts, while, semantically, the group attributes its identity to an actual animal. Therefore, the identification with the animal must be taken literally and means fictionally far more according to the culturally shared narratives. The cultural identity of the group sediments culturally in rites, relics, tales, imaginaries, and social structures that appear foreign to external observers.

Analytically, one can distinguish the two levels of the presently actualized narrative. At the practice level, a narrative told represents the social identity of a collective in practice, or respectively a detailed mission statement or future policy. At the discourse level, the practice narrative is entangled in further narratives, sociotechnical imaginaries, and whole cosmologies that make it meaningful. For example, the series of iconic inventors such as Thomas Edison, Henry Ford, and Steve Jobs, or the series of the Manhattan Project, the Apollo program, and the internet are familiar symbols (see Hilgartner, 2015, p. 36). As part of a culture, these symbols virtually generate placeholders in the practice narratives of the next genius innovator or national promissory program. Institution theory thus stresses that the purpose of follow-up structures in a social, material, and semantical realm detaches from the motive of the initial narratives. As a result, social and semantical institutions emerge. The local narratives about the visionaries in practice become a candidate for an institution on the semantic level. As follow-up structures based on imagined pasts and imagined futures, they become social facts themselves.

The detour into institutional and systems theory seems necessary since visions of technology in discourses show stability that is immune to the rational critique of motives. Even if “sources” of the past or imagined future change (see Weberman, 1997), which gives narratives their ontological power, this does not mean a change in the institution. The interweaving of the narrative with the social being instead leads, I maintain, to a compartmentalization of the scope of validity claims – something may be true but does not concern one's own case. The function of the totem or, respectively, the reflexivity of emerging systems explains how social imagination leads to the creation of institutions. You can purposefully imagine something. But you cannot easily institutionalize a future. Even claiming a lack of orientation in modern times

is just a starting point for a narrative. Instead, the imagined futures emerge on various occasions and then stabilize when more follow-up functions and semantical relations build on them. One can neither predict such an evolutionary process nor the realization of an imagined future. However, the assertion that an imagined future or evolution "will prevail" can become a self-fulfilling prophecy that operates "in the absence of deliberate institutional control" (Merton, 1948, p. 210). Imagined futures are co-produced at the material, social, and cultural levels. The sociotechnical and discursive situation, therefore, promotes the dissemination of imagined futures, the considered suitability of the future assessment, and the stabilizing evaluation of narrative value.

Imagined futures stabilize, even though the enlightened thought of an "immanence of the present" advises against deriving conclusions on uncertain grounds. I maintain that the social and temporal significances of imagined futures outweigh the factual dimension. In particular, the temporal dimension is the condition for intentional action, and the social dimension is a prerequisite for the generation of a collectivity. The argument of institutionalization emphasizes that the creation of individual consciousness and collective actors requires an imaginative process. For the Poiesis of its own agency, the system, respectively the spirit or collective, must reach beyond the scientifically assertable. Indeed, scientific models represent actors and bureaucracies as purpose-rational actors. But still, social systems, actors, and collectives depend on autopoietic self-enchantment. Protagonists of enlightenment also depend on the narrative self-enchantment promising adolescent autonomists the liberation from fictional spells (see Koschorke, 2013, pp. 388–395). Hans Blumenberg (2015), therefore, questions the "rigorism of the truth" when identity and foundation narratives encounter scientific facts. If one follows this ontological path, then the good can only be found in the narratives that constitute communal coherence and the unity of human life (see MacIntyre, 2007). Values and imagined futures, therefore, exist as social and semantical facts. They are performatively actualized and criticized in narratives, parables, ethical models, and scenario methods.

The joint analysis of narratives and models in the assessment of unproven technology opens up a novel perspective. As discussed earlier, the co-production of knowledge and sociotechnical imaginaries (Jasanoff, 2010; Jasanoff & Kim, 2013) or societal symbiosis (Robert E. Park, 1939) highlight the material conditions of the social. The narratological and make-believe perspectives, on the other hand, highlight semantical conditions of sociocultural reproduction.

Narratives and models quasi represent semantical building blocks for the formation of social actors and institutions – they are intermediaries between social practice and discourse. In other words, I see the possibility of successful claims to validity not pre-structured by rationality inherent in language, but by the narrative structures in discourse that make the existence and actions of participating actors meaningful. In the continuation and actualization of narratives, actors find their freedom in the distinction between maintaining, modifying, or abandoning narratives when their represented futures become contested. The narrative sets a beginning that governs what follows for the system without coinciding with the transcendental antecedents that another observer might find (Koschorke, 2015). Thus, reflexivity is not the control of the system, but another moment in the dynamics, which is of significant interest for the understanding of identity formation and future-oriented action.

Narratives and models form a basis for the hypothetization of actions and the potential relations and identities of actors (Emirbayer & Mische, 1998; H. C. White, 2012). However, the range and power of narratives depend on various further factors, such as the social position, institutional relations, technical possibilities, authorized models, and the cultural capital of the narrator. As narratives represent (potential) social networks and spheres of action, visionary narratives are particularly interesting for Technology Assessment. However, the veto right of the sources and the normativity of sociotechnical facts only come into play when actors succeed in making them shine through as props and narrative turning points.

3. Narratives and Models in the Assessment of Unproven Technology

Technology Assessment [TA] differs from disciplinary research in the discursive orientation of aspired research results. Instead of answering disciplinary questions, issues regarding technology in society are taken up in public discourse and addressed scientifically. In TA, one is aware that scientific communication about the issue is likely to have societal consequences. In doing so, TA draws on the knowledge, theories, and methods of disciplinary research, without attempting to break down complexity in the boundary of disciplinary conventions, but focussing on the systemic challenges of the specific case. In the purpose-oriented practice, Technology Assessment resembles engineering approaches relying on a vast toolbox that can, in their practice, hardly be reduced to grand theory. However, in contrast to industrial stakeholders, TA aims to represent and include neglected and public stakeholders and democratic

values when it comes to assessing trends, impacts, and possible alternatives to considered technological pathways. TA can, therefore, be considered as the science for revealing and managing the contingency and practice of necessary simplifications of sociotechnical systems in technology development (see Luhmann, 1992, p. 715).

However, given the constraints of necessary simplification, it is promising for the assessment of unproven technology to focus on the role and potential of representations as the boundary objects to manifest, intervene and improve the sociotechnical development processes. To estimate the potential of TA anticipating and impacting technology developments with representations, two deliberate methodological applications of narrative representations in technology development are briefly described, at the example of collaborative data science and agile software development.

3.1. Narratives and Models in the Development of Unproven Technology

The application of "user-stories" (Cohn, 2013) in agile software development (e.g., Scrum, Kanban[6]) and "computational narratives" for collaborative data-science (Perez & Granger, 2015) motivate to focus on narrative representations and boundary objects. The use of representations fulfills functions of internal and external communication as well as the visualization and testing of sociotechnical futures. Collaborative work in data analysis and software development requires context and stakeholders' demands to be made explicit. Explicit communication is necessary for organizations because formal decision-making structures cannot refer to informal communication. In organizations, decisions about an object constrain the conditions for follow-up decisions so that Luhmann (2011) characterizes them as decision-making structures. Therefore, the distinctive feature of organized technology development is, as the thesis maintains, that the institutional setting requires representational objects to instruct the imagination of technology. Organized technology development cannot build on definitions or require a step-by-step implementation according to a plan. Instead, the process steps follow updating ideas whose representation the organization can decide about. Therefore, I propose that, in technology development, distinct narratives serve as loose couplings within the fixed

[6] Many thanks to my carpooling ride Florian for this reference to "user-stories" as an applied method in his work when I explained my deep interest for narratives in science, engineering, innovation, and the generation of agency.

coupling of organized decision-making structures to stabilize the design of technical or material structures.

This loose coupling is essential in data science because it is unclear which data, tests, and visualizations become relevant. The analyst follows an imagined trail through the data like a detective equipped with repositories of libraries, methods, codes, and snippets from, for example, StackOverflow. The narrative representation of this trail thus allows collaboration in the process and transparency of findings. The data narratives in Data Science are texts in natural language that embed codes, data models, and analyses like clues in a detective game and highlight meaningful information (see Figure 4). For the survey on microalgae nutrition, I learned and discussed the statistical analysis with means of computational narratives (2nd article). Like a detective game, the data narrative gives meaning to why specific data models are applied, and conclusions derived. It places data in a narrative worth telling by highlighting the particularity as a deviation from normality that drives the plot forward.

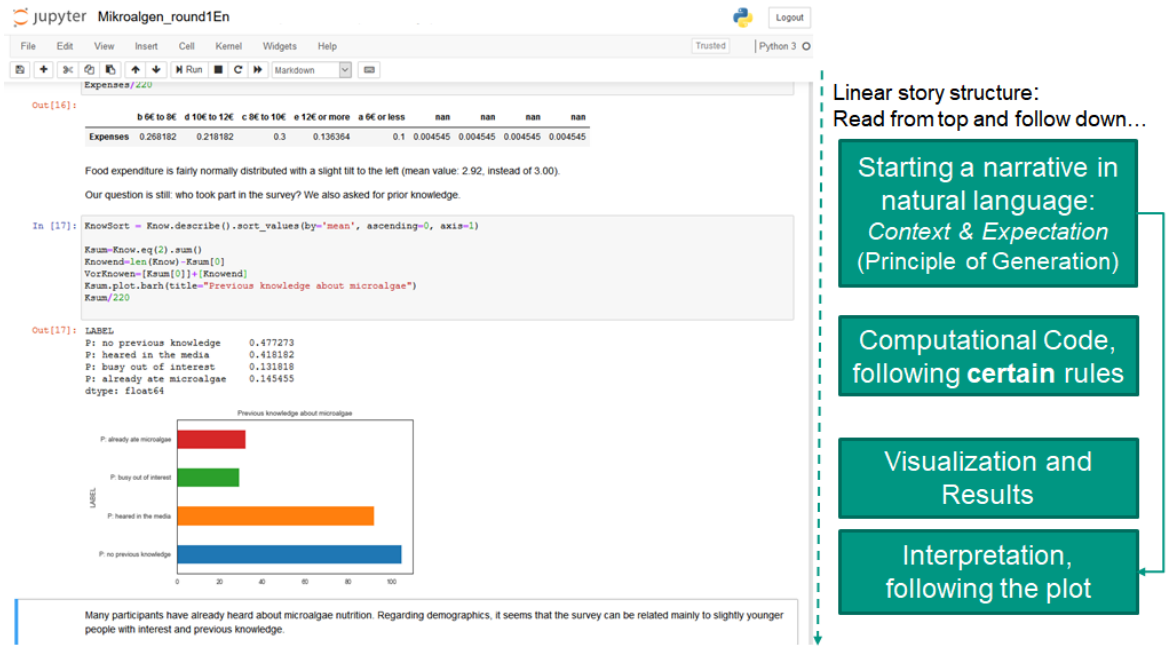

Figure 4: Computational Narrative in Jupyter Notebook (The code illustrates the survey evaluation for Roßmann & Rösch, 2019, see Roßmann, 2018).

In software development, to facilitate consultation with the client and to keep solutions open, the first step is not to define components of the solution to be developed, but rather the contextual application of the solution. Therefore, fictional user stories are intended to represent the practice context of the software application. User stories are short texts that follow the simplified scheme “As [Role] I want [Function] for [Use]” (Cohn, 2013). To understand this

schematic story as a technology narrative worth telling, I propose to understand the "function" as a necessary capacity of the technology to, like a hero, transcend the ordinary (see Table 1, p. 19). Technology developers quasi become the helpers of the hero. The Scrumboard connects different user stories about the unproven technology so that the design resembles the generation of a fictional map according to a set of novels. Where the map becomes inconsistent, the stakeholders discuss whether to change the story or the map accordingly (see 3rd article). Both, the user-stories at the Scrumboard and the data-narrative keep separate and heterogeneous elements, like models, texts, values, codes, users, and prototypes, together, and make them meaningful.

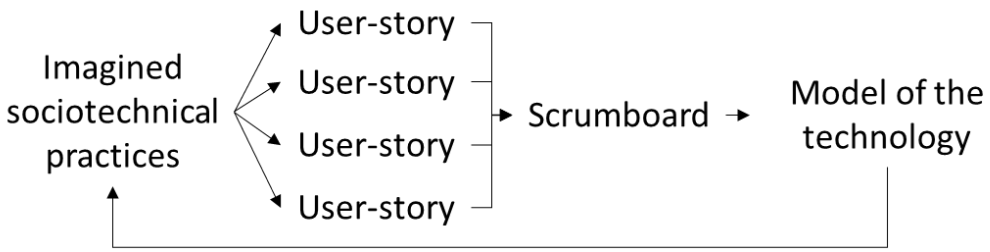

Figure 5: In organizations, user-stories at the Scrumboard organize the imagination of future technology

Considering the narratives in their application as a solution to a problem, I claim that creative and transdisciplinary collaboration in an organizational environment that is partly structured by formalized communication would not have been possible without these objects – leaving open the specific characteristics of narrative structures. Organized communication relies on representations that allow transparent structuring of the different worlds of participating actors without restricting their freedom like Fordist machines. As the representation of the imagined future offers an organizational structure and is itself flexible, the organized process can adapt to a changing and unknown organizational environment. However, there is little research about the translation of visionary narratives and sociotechnical imaginaries to institutionalized platforms. It might provide insights into the effectiveness of visions in sociotechnical and organizational practice and the role of the platform or medium (see Section II:2). By applying these narratives in technology development, there is a common interface for the joint analysis of narrative structures and underlying assumptions in the models. TA can use such objects as an interface to intervene as actors in the environment of technology development. In fact, TA could even learn from this practice for its own dealing with the challenge of uncertain outcomes and diverse backgrounds and stakeholders. The relationships to be revealed

between narratives and models proposes further to elaborate their use in Technology Assessment and integrated research (see Section II:2). Given that TA is the scientific analysis of the social consequences of sociotechnical simplifications, it becomes evident to focus on the generation and authorization of representations of imagined futures.

3.2. Everything Is Political: The Normative Dimension of Technology in Society

As stated above, TA finds its niche and purpose in contrast to disciplinary research in the orientation of the public discourse for democratic objectives (Grunwald, 2019c). In contrast to the aforementioned business-driven technology development, TA emphasizes its awareness of the practical uncertainty of facts in juxtaposition to a diverse set of values in the political dimension. This thesis, therefore, claims to historically understand the emergence of TA as the reflection of the science-policy interface as an emerging field between political demands and scientific boundaries.

The beginnings of TA in the 1960s count as the institutional response of government, industry, and science to a public sentiment of progress criticism (Grunwald, 2019c). One assumed a deficit model that explains the low acceptance of technology with a deficit of knowledge about the technology, just as some people still suppose today. Therefore, people are supposed to achieve acceptance for their imagined futures by providing more scientific facts that enlighten their opponents regarding their legitimate concerns, hopes, and values and determine rational goals and risks.

However, in the 1970s, TA reflected on the criticism of the early positivist and technocratic paradigms. The community took it up constructively and developed theory and practices, as participatory TA. The debate on Technology Assessment had emerged around Thomas Kuhn's critique in the "structure of scientific revolutions" and the questioned authority of science (Kuhn, 1976; Wynne, 1975). While on the one hand methodological criticism was received as an academic challenge to find new rationality through a higher analytical resolution, the critique of paradigms also further increased awareness for the political and economic embedding of scientific actors in the aftermath of the atomic bomb (Feyerabend, 1980; Lakatos & Musgrave, 1974). In response to Thomas Kuhn, Karl Popper (Popper, 1974; 1995), as a spokesperson for "Objective Knowledge," acknowledged the importance of this empirical criticism.

However, Popper interprets it as a lack of awareness of engineers about uncertainty and societal implications, and not as a structural problem of scientific perspectives (Popper, 1974, p. 53).

In Germany, the debate about the science-policy interface and the limits of scientific objectivity center at positivism dispute and protocol sentences ("Protokollsätze"). In particular, the Frankfurter Schule continued to criticize the limits of scientific practice in the societal embedding with regards to the scientific and lingual premisses, unquestioned research aims, and contextualization of findings. The insight to be gained for knowledge-based policy advice was that science could not retreat into the distanced position of a neutral observer. Or in the words of Roger Pielke, Jr.: "you can't swim without getting wet" – all science engagement is political, and there is no neutral science communicator (Pielke, 2015). This particular insight seems to be central to the reflection of Technology Assessment, which is about criticizing positivistic or technocratic attitudes and the disguise of political decisions with seemingly objective data and value definitions. I, therefore, consider these reflections of Technology Assessment about the science-policy interface to be the founding narrative of TA as it justifies the ambitions to systematically reflect on public technology issues and identify viable alternatives in line with sociotechnical constraints. At the science-policy interface, however, I propose that the role and potential of narratives and models for the assessment of unproven technology tend to be overlooked (see Section II:2. Discussion).

3.3. At the Science-Policy Interface: Participation, Construction, and Props of Technology Assessment

The criticism from academic discourses about the "non-neutrality" of scientific policy advice has not yet changed the political and institutional demand for TA. New concepts and metaphors are, therefore, being developed in reflection to reconcile science-based policy advice with its justified criticism within a globally networked community. That the normal application of methods is not sufficient "when facts are uncertain, stakes are high, and values in dispute" is central to the program of post-normal science. From this perspective, I view TA as post-normal science. I find TA to be the research and practice of managing the epistemic and normative challenges at the science-policy interface. For this reason, two variants, namely participatory and constructive TA, are briefly presented in their significance for the science-policy interface.

Participatory TA, therefore, involves stakeholders, affected parties, laypersons, and the general public in the assessment of technologies (Grunwald, 2019c). Such an "extended peer review" by an extended community involving a plurality of disciplines and interested actors (Funtowicz & Ravetz, 1990) aims to legitimate derived results and measures by the affected parties for them. Especially Jürgen Habermas gives a theoretical account for the epistemic dimension of deliberation, emphasizing how to introduce new arguments into a formative discourse from diverse people (Habermas, 2008). Scientific work is to be supervised by laypersons that, empirically speaking, at present lack the power to compete with engineers and scientists and significantly shape technological development (Feyerabend, 1980). Although the participation of citizens enriches technology development in the epistemic dimension, it cannot replace the democratic institutions and exchanges with parliamentarians, or justify the implementation of measures due to unavoidable power differences.

In contrast to Participative TA, the Constructive TA, which emerged in the 1990s, takes a pragmatic approach to current power relations shaping technology (see Schot & Rip, 1997). The argumentation of Constructive TA adopts the rejection of the linear innovation model and highlights the potential early decision in the social construction of technology as an organized project. Instead of basing the TA study on insights and arguments from single public participation, Constructive TA sees its role in mediating, modulating, niche management, and establishing an infrastructure between relevant actors that are involved in technology development (Grunwald, 2019c; Schot & Rip, 1997). In this understanding, it is clear that TA is politically one voice, among others. In political and economic environments, the scientific reason is not sufficient to stimulate debates. Instead, the contribution of TA thus manifests itself in its role as a mediator and establisher of an infrastructure that anticipates blindspots in technology development by institutionalizing a multi-perspective observation. In practice, representations are already used for this purpose, for example, by enforcing claims of validity with the help of methods, models, heuristics, white papers, and positions without anyone fully seeing through or believing it. Even if the network of scientific propositions is consistent, you cannot anticipate the emerging political meanings stakeholders give it. TA actors seek to have an eye on the emerging networks and the political and economic stakes according to the commitments of the discursively self-constituting stakeholders. From this perspective, the dissertation examines the question of how to represent and map issues and visions from public discourse to form the basis of TA infrastructure and create the coherence of knowledge elements to be

considered and shaped as props for more inclusive technology development and assessment. I assume that narratives and models play a central role in the assessment of unproven technology, particularly as boundary objects and for the managing of complexity. I further explored these questions in empirical and theoretical studies.

4. Overview of the Articles

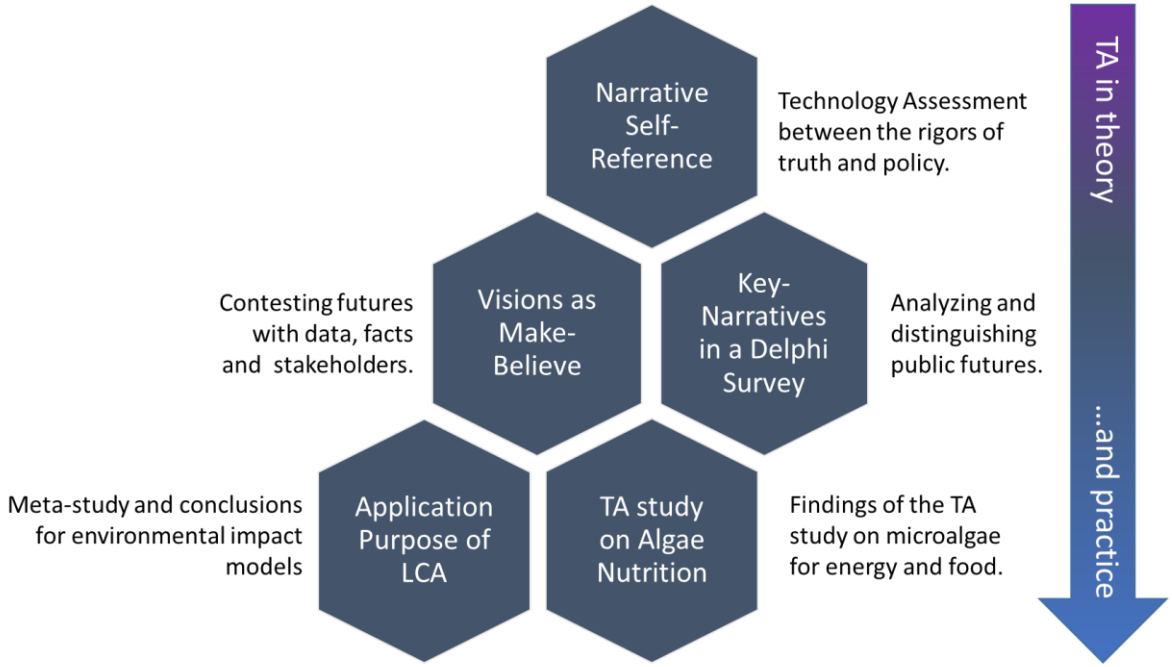

Figure 6: Overview of the papers to reflect on TA in theory and practice.

The articles included in this dissertation intend to reflect and discuss the conceptual developments in theory and their practical application (Figure 6). The ordering begins with the systems' theoretical reflection on Technology Assessment between the rigors of truth and policy (1st paper). It ends with the TA study about microalgae for energy and food (5th paper). Both papers were published in 2018. In this thesis, they provide the framework on which the subsequent papers follow and discuss TA between theory and practice. With the experience of TA practice, I further developed the theoretical approach of the first paper in three empirical studies about unproven technology. The empirical studies comprise a public Delphi survey (2nd paper), a stakeholder workshop (3rd paper), and an LCA study (4th paper). The papers on key-narratives (2nd paper) and make-believe (3rd paper) address the theoretical questions in the field of Science and Technology Studies and Technology Assessment. The article on the application purpose of LCAs shares findings with the LCA community (4th paper).

The cooperations and contexts also reflect the authorship of the papers. The idea for the LCA paper emerged in the fruitful discussion within my Graduate School on energy and resource efficiency (Kooperatives Promotionskolleg ENRES). While I wrote theory and the discussion in the LCA paper, my co-authors introduced me to the particularities of LCA in practice and focused more on the study review. I co-authored the papers on key-narratives and the opinion paper on microalgae with Christine Rösch, the head of bioeconomy research at ITAS (Institute of Technology Assessment). She kindly allowed me to try out theoretical considerations about narratives and make-believe in the empirical study design. In this way, we addressed our empirical findings to both the scientific communities of the bioeconomy and the science and policy studies. The many formats of stakeholder participation on microalgae, for example, at an adult education center, a future food congress, in a design workshop, and an open house day, provided further chances to develop considerations of transdisciplinary collaboration using future narratives and models. The scholarship finally provided the context for eclectic discussions and composing the articles and thesis.

4.1. Narrative Self-Reference and the Assessment of Knowledge

The thesis begins with the systems-theoretical question if the self-reference of social collectives constitutes narratives as temporarily fixed reference points for the assessment of knowledge. In “After Virtue,” Alasdair MacIntyre states that you can only find moral meaning and telos of life and action in communally shared narratives. Besides, he writes that you can answer the question’s on “what is he doing?” in various ways. You can answer with ‘Writing a sentence,’ ‘Finishing his book,’ ‘Contributing to the debate on the theory of action,’ or ‘Trying to get tenure’ (MacIntyre, 2007, p. 207). The *relevant* answer, however, is the proposition that gives life its coherence. I maintain that the same applies to the question about the function and value of technology and knowledge. Technology and knowledge are meaningful in the stories we tell, in the move that would not be possible without them. TA should assess knowledge about unproven technology and policy prospects not according to universal categories and fixed systems but based on the difference technology makes in the self-images of collectives affected.

However, according to MacIntyre, not individual authors or historians write these narratives, but the community co-authors them in stories about themselves. People find themselves in a web of stories whose narrative structures give the anchor point for the assessment of actions,

a successful life, and the possible purpose of knowledge: “The unity of human life is the unity of a narrative quest. […] I can only answer the question ‘What am I to do?’ if I can answer the prior question ‘Of what story or stories do I find myself a part?” (MacIntyre, 2007, pp. 216–218). I consider this the question about narrative self-reference. The question applies to the person who advises policy-makers as well as the client. It gives a form to the contingent whole that is at stake.

To discuss the central elements of MacIntyre’s concept of identity, namely narrative, and agency, I studied this position in literary and systems theory. The literary theory explains in particular how narrative structures make heterogeneous and unrelated elements cohere and meaningful. According to the theory of self-referential systems, systems themselves produce this coherence of preceding communications that stabilize networks and hypothesize action, as I proposed with MacIntyre, in the ongoing construction and revision of socially shared identity narratives. Niklas Luhmann vividly describes the generation and re-shaping of identity in his process theory of legitimation, at the example of a law case (Luhmann, 2013). The self-entanglement performed in role-playing about the present issue gives people a social past and future. The oral and mass medial distribution of the event stabilizes and shapes the narrative about the person within the network of further communication. The status of legal institutions, such as some law curt and official agencies, give narrators additional authority. The identity narratives thus constrain the freedom of actors as social actors, and narratological analysis reveals the specific role of knowledge or technology.

Narratives are the pivot of the social and the psychic system, and between collectivity and future-oriented action. The authorship of a collective narrative means power about the selection and context of claims to validity. Blumenberg (2015) highlights the meaning of founding myths for social identity and criticizes “the rigorism of truth,” as he believes Hannah Arendt displayed in the Adolf Eichman Case. I acknowledge his theoretical criticism without commenting on the attribution to Hannah Arendt. Instead, I contrast this position with a “rigorism of power.” This attitude subordinates all evidence to the purpose of shaping identity and policy narratives. I claim that these ideal types span the field in which Technology Assessment takes place. Technology Assessment negotiates the political possibility of retelling stories about un-

proven technologies and therein couples scientific enquires with societal relevance. In summary, this article reflects the negotiating power of narratives by creating system boundaries for collaboration and a common ground for the assessment of knowledge.

4.2. Key-narratives of Microalgae Nutrition: Exploring Futures with a Public Policy Delphi in Germany

This paper explores how narratives as boundary objects complement the Delphi method to survey and summarize public imaginings about the future so that both public stakeholders and technology developers can discuss their perspectives. In the context of the research cluster on bioeconomy and the potential of microalgae, the paper analyzed public visions of microalgae as a food source to explain the present innovation paths of a yet unproven scientific technology. The study involved a two-round online survey with 229 participants and open and closed questions. The particularity of a Delphi study is that the respondents obtain the aggregated results to orientate themselves in the second series of questions on the statements of the other participants. This feedback allows stakeholders to shape the representation of their opinions. However, in contrast to a classical Delphi method that only includes a little group of experts, public participants were surveyed because they are considered experts for the investigation and assessment of the public perception of the technology. Therefore, narratives served as a boundary object for people to understand the statistical findings of the first round and evaluate the popularity, desirability, and feasibility of emerging clusters.

In contrast to the classical Delphi method, the research on futures did not aim at evaluating the consensus regarding one most probable future, but at disaggregating different futures. Futures are distinguished in hero narratives, each highlighting different characteristics of the technology (see Table 1, p. 19). I applied statistical models to evaluate the closed questions. To obtain feedback from the participants in the second round, I summarized the numerical results in narratives. The particular question was, therefore, how to combine both the easy understanding of narratives *and* the objectivity or transparency of numbers – qualitative meaning *and* quantitative results. Regarding microalgae visions, the survey showed an interesting contradiction between the expected and the desired future imagination. Participants want microalgae to sustainably feed the world, while they also expect microalgae to be more likely a health product or an inconspicuous food substitute.

I conclude that Delphi methods are not only suitable to look into the future, but also for empirical research into perspectives on the future that help distinguish and hone the cognitive interest of politicians and researchers. The paper proposes that only a common representation allows questioning the attitude of actors towards an imagined future. The paper highlights the multi-perspectivity of contested futures, focusing on the role of generalized narratives as boundary objects. In this way, it also contributes to the methodology of transdisciplinary research and the debate on imagined futures by emphasizing the importance of representations for distinguishing and generalizing futures. Conceptually, the differentiation of key-narratives already proved to be useful in a subsequent TA project (Schneider, Roßmann, & Lösch, 2020).

4.3. Visions as Make-Believe: How Models and Narratives Represent Sociotechnical Futures

When prominent experiments, simulations, and prototypes fail, sociotechnical futures become contested. This paper discusses the negotiation of visions as make-believe in an attempt to give the considered feasibility of future narratives a greater account in innovation dynamics. Following Walton's theory of representational arts, I propose that imagined futures possess a certain kind of objectivity according to the considered data, models, and artifacts – just as certain pictures, films, or novels represent fictional details about lightsabers and the Death Star's vulnerability. In introducing and applying the make-believe concept onto the empirical analysis of uncertain futures, I study visions, not in terms of their epistemic or aesthetic value, but their social authorization and motivational power arising from their contested representations. In a game of make-believe, the data, models, and prototypes serve to tell stories that make them politically and economically significant as representations of promissory futures. However, if the authorization of the story declines or an experiment fails, the vision is contested. It arises the question of whether re-writing the promissory story or evicting the object from the game. The workshop on microalgae nutrition questioned exactly this vertex. I demonstrate how fictional narratives reveal ambiguous but meaningful sociotechnical boundaries for the imagination and the assessment of unproven technology. The perspective shows how barriers in fiction are considered insurmountable and how narratives change. In sum, I argue for a greater account of the self-dynamics of representations and the authorization of make-believe in innovation dynamics due to their sociotechnical embeddings.

4.4. Comparability of LCAs – Review, and Discussion of the Application Purpose

The life cycle assessment is considered a central element of the Technology Assessment of environmental impacts. Nevertheless, the method has been subject to criticism for some time, as the varying assumptions would have too great an influence on the results and prevent the comparability of studies. It is clear in the context of the thesis that strong assumptions and, in some cases, model extensions are necessary, especially for unproven technologies, if political decisions are to be supported or environmental efficiency gains from measures of an industrial plant are to be estimated. I find that the quality of the model depends on its usefulness for a purpose. However, therefore, this purpose must be represented in the study. While standards play a central role in an assessment according to legal norms or in a comparison between technologies, the “objective truth” is relatively irrelevant if the study only serves a limited target group to compare and estimate between options.

Therefore, this article discusses the comparability of Life Cycle Assessments (LCA) and the central role of the application purpose in a study review. According to ISO 14040, an LCA study design emerges in continuous reference to the “intended application.” Goal and scope, case-specific assumptions, as well as methodological freedoms, should be justified by their significance for the specific application purpose, for example, for process optimization or advice on a political issue. In contrast, our systematic review of 58 LCA studies shows that LCAs hardly name applications, and more generally, applications are difficult to reconstruct. This lack of transparency makes the LCA methodology attackable through meta-studies that ignore the problem-oriented and case-specific approach. LCA studies are valuated for different purposes by a diverse set of actors. They serve to promote assets, implement policies, explore scenarios, or try out and enjoy modeling games. Therefore, an LCA study should represent narratives about the application purpose to justify assumptions and provide transferable results for other studies. This paper draws initial conclusions for TA practices from my examination of the role of narratives and models of unproven technology.

4.5. Microalgae for Integrated Food and Fuel Production

This opinion paper represents the assessment of our study about the potential of microalgae for an integrated food and fuel production. It aims to serve as a common reference for the discourses about the present technology, options, and perspectives of microalgae research.

The study bases on a literature review, expert interviews, and the Delphi survey. We supplemented the compilation of approaches and perspectives in calculations of cost scenarios and environmental impacts. We point out, reveal, and comment on future pathways without rejecting any vision. In this way, the paper aims to provide an interface to which opponents and supporters, experts, and decision-makers alike can refer. Therefore, a co-design approach is used, considering public perception and the views, knowledge, and values of citizens and stakeholders already at an early stage in the research and innovation process.

Research assumes that Microalgae have great potential for the sustainable production of food and fuel for a growing world population with increasing demands and changing habits. People claim that they do not contribute to land-use competition, loss of biodiversity, and environmental pollution like other food and energy crops. These advantages result from the cultivation of microalgae in technical pipe systems. However, the technical effort means high costs, and the present technology provides very limited economies of scale. Therefore, experts consider the commercialization of algae technology still in the infant stage. Algae fuel production has so far failed due to low oil prices and a lack of economic viability. In particular, energy and labor costs for the permanent operation of a plant are at present an obstacle for the dissemination of the technology. However, integrated food and fuel production are promising because the food market is more diversified and open to new and innovative products than the energy market.

Ongoing research and public discourse point to variegated pathways of technology development. We represent future scenarios in the key-narratives of microalgae nutrition mentioned above. Besides, we responded to some of the hopes and concerns of the survey participants in this paper. Microalgae research is, in particular, associated with promises about health and sustainability benefits that are not feasible according to the current state of research. I, therefore, propose that without the imagined futures and the openness to explore and switch avenues pragmatically, existing projects would not stand their ground on the market at present. The visions give technology development and expertise a higher value by projecting their necessity to a more distant future. In sum, this paper demonstrates how the exploration and discussion of future narratives can become an integral part of a TA study.

Section II: Discussion

Findings in social sciences and Science and Technology Studies [STS] indicate that a linear innovation model is not adequate for understanding present-day technology development. Technology development does not base on neutrally derived stock knowledge. Instead, guiding visions already accompany engineering and science in schools and universities and influence the imagination of desirable and achievable technology. Under the paradigm of the "social shaping of technology" and "the social construction of technology" (MacKenzie & Wajcman, 2010; Pinch & Bijker, 1984), the STS study the co-production of knowledge and technology and reveal the blind spot of the norm-loaded nature of technology development. "Sociotechnical imaginaries" are a prominent framework to analyze boundaries for imagining, planning, and negotiating future technologies (Jasanoff & Kim, 2013). The sociology of expectations (Borup et al., 2006) frames the analysis of how imagined futures impact economic, technical, and political developments. However, they so far don't address the demarcation of imagined futures, and the dynamics of the feasibility considered by stakeholders. This thesis worked out the theoretical and practical relevance of representations in the assessment of unproven technology.

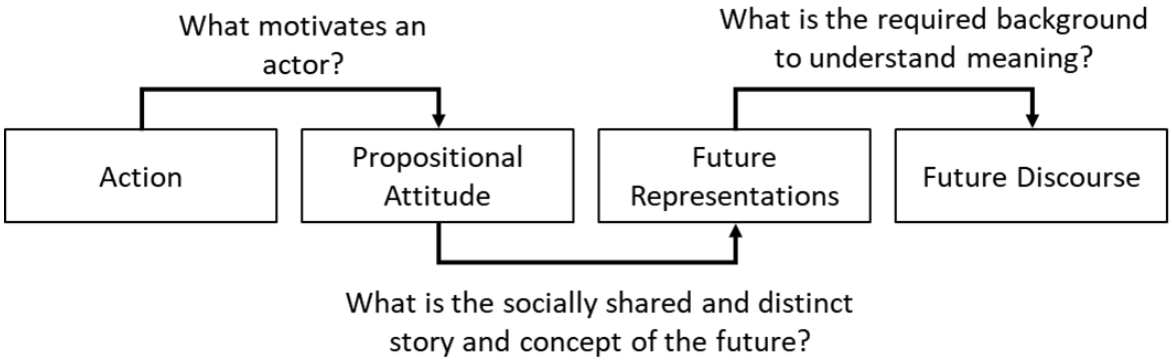

Figure 7: The central role of representations in the organization of future-oriented action and discourse.

The thesis approached the concept of representation from the direction of discourse and the direction of the actors (Figure 7). From the linguistic perspective, narratives are the structuring elements that give single propositions meaning in a discursive context. Just as single words reveal their contextual meaning only in a sentence, so utterances are meaningful if they mean a difference in the narrative discourse. Models, texts, action, images, and even silence are meaningful in the framework of narrative structures. From the perspective of attitudes and

actors, representations are the crucial reference to build up a memory of social communication and attitudes of persons that pave the pathway for collective action. Representations of imagined futures ensure that the actors coordinate their ideas about themselves and their environment to a certain extent. Given both perspectives, representations are concrete objects in the environment of actors and structuring elements of discourse that decide on the adequacy of statements. Regarding motivational power, the belief of propositions is distinct from imagining propositions in make-believe – a social practice in which actors gain novel and motivational beliefs, for example, due to the resistance of the objects involved (Salis & Frigg, 2020; Schellenberg, 2013). However, in contrast to a symbolic communicative theory, representation also includes the dynamic constraints of objects, situations, models, and protagonists. Imagined futures depend on and impact contexts that escape communicative observation.

To better understand these dynamics, I emphasized three uncertainties of make-believe, namely the uncertain prop situation ("veto right of the sources"), the socioculturally uncertain principle of generation, and the uncertain suitability to make a difference, respectively "the last word" of social practice. Hermetic systems manage to control the uncertainties by isolating the prop situation and defining the principle of generation. However, make-believe in society builds on, takes place, and can impact the actual material and sociocultural situation. To put this into concrete terms, I propose the example of visionary microalgae technologies. On the modeling side, there are observations of biology, physiology, and engineering. On the discursive side, there are historical templates about objects allowing a transgression of the norm. Make-believe reflections may condense and disseminate as narratives and motivate action and research. However, the vision-driven efforts in research and development of microalgae technology could finally discover that the energy demand is too high to realize, for example, the vision of sustainable nutrition. But the prop and discoursive situation allow make-believe about wellness applications. Without the prior vision and practice, the funds, laboratories, and materials, as well as the scientific studies and emerging expert groups, would not be in the present situation that fosters a re-evaluation of the old vision and the reorientation towards a new vision present constellation. However, this representation is highly simplified. Still, it defines decisive parameters for empirical studies and iterative technology development (Figure 7):

- The discourse analysis reveals key-narratives about what would make a story worth telling.
- Studying representations and anticipatory practice shows what data and sources games of make-believe base on, define feasibility, and irritate the imagined future.
- Studying the attitudes towards representation in practice shows the considered feasibility and motivational potential of actors to engage.

The discourses on the co-production of knowledge, imaginaries, and expectations examine the relationship of discourses, materialities, and innovation. However, they neglect how considered feasibility, the uncertainty and meaning of props, and sociocultural backgrounds constrain the deliberate hypothetization of action. Also in the theoretical discourse on transdisciplinary research and TA methodology, however, the interplay of narratives and models played hardly any role with a few exceptions, such as the enlightening discourse on boundary objects or the co-creation of innovation narratives, and the use of cards and maps to reflect stakeholder interaction[7] (Böschen, Kropp, & Soentgen, 2007; Felt, Fochler, & Sigl, 2018; Strand, Saltelli, Giampietro, Rommetveit, & Funtowicz, 2018). Therefore, this theoretical discussion claims for a new focus on the dynamics of models and narratives in the assessment of unproven technology.

The practice-oriented attitude of the STS and Technology Assessment motivated keeping contact with practitioners in the style of integrated research. Therefore, I postponed many further theoretical and disciplinary deliberations. In developing the thesis, the approach had to convince primarily in practice so that sociological and philosophical laypersons can make sense of it. In the peer group communication of empirical findings, theoretical reflections have repeatedly proven their worth. They eased distinguishing imaginary futures from one another and discussing the feasible and desirable with engineers, scientists, as well as laypeople and practitioners. The various sites of "hyperprojectivity" include scientific conferences, a public survey, a stakeholder workshop with transdisciplinary stakeholders, a design workshop for algae product development, an adult education course at the "Volkshochschule Karlsruhe," and several meetings in the research cluster on the bioeconomy. The approach worked in practice as

[7] The Kopernikus project, eNavi (https://www.kopernikus-projekte.de/projekte/gesellschaftliche_teilhabe) was very promising in this regard, but unfortunately did not generate the promissed boundary object for navigating the energy system transformation across different perspectives.

the audiences made references to the key-narratives to highlight and discuss different technological aspects. The narratives enabled citizens and scientists alike to consider options for action and to establish connections in a narrower discourse space, for example, to biotechnological possibilities and economic assessments.

I understand this academic work as a scientifically supported reflection of practices in the assessment of unproven technology. Disciplinary discourses enriched intellectual development just as much as practical observations, narratives, and conversations (see Section I:3.1). I conclude from practice and theory that the TA relates to representations in two ways. On the one hand, it seeks to represent structures *of the discourse*, to point out trends, gaps, and contradictions. On the other hand, TA seeks to position itself *in the discourse* as the "honest broker" for the negotiation of uncertain technology futures. The latter becomes all the more apparent in the self-reflection of TA at the science-policy interface (Section I:3.2). These two perspectives will be further analyzed below. This thesis aims to build bridges between disciplines and share their treasures for empirical research and Technology Assessment in practice.

1. Analysis and Critique of Sociotechnical Visions Across Sociocultural Contexts

The object of technology assessment is not the technology in itself or thoughts about technology, but rather representations of technology. Technology criticism must address representations to which it attributes vagueness and shortcomings in comparison with other and own representations. However, what is considered a relevant shortcoming and inconsistency is contextually and culturally different.

Representations of technology are mainly incomplete sketches with a purpose. Since TA so far hardly criticized the representation of technology in novels, I first focus on the organizational embedding of technology representations. To distinguish technology, Luhmann aptly describes observing technology as a form of functioning simplification in the medium of causality so that (1) processes can be controlled, (2) resources can be planned and (3) errors (including wear and tear) can be identified and attributed (Luhmann, 1991, p. 97). Organizations rely on representations to build decision-making structures about controlling, managing, and maintaining technology. In this way, they organize the representation of technology and the relevance of aspects. Section I:3.1 already mentioned the user stories in technology development, and checklists and standards fulfill a similar function. These representations provide engineers

and scientists with instructions on how to imagine future technology and organize consequences for non-compliance. Their specialized training provides for particular responsiveness through these representations. While it is unlikely that all possible things are said about a particular technology, organizations organize much attention and relevance of aspects represented.

The institutional function of TA becomes apparent in the fact that different actors attribute relevance differently so that representations and attitudes towards representations of technology differ. Technology is perceived differently outside of industry and technology research. In everyday life, technology mainly becomes visible when it does not work and therefore interrupts this established context or when it causes the solution or causation of another problem worth telling. Especially technology-critical literature gives relevance to aspects and contexts that play a subordinate role in developing technology. The contextual comparison of employed representations indicated different ideas and priorities regarding the feasibility and desirability of technology. Industrial companies and non-governmental organizations, as well as engineers and public stakeholders, have a different idea of what needs to be represented to ensure that the technology will be beneficial. Conflicts about future technologies, therefore, require that a future situation is represented differently.

In the democratic intention of enhancing reflexivity, TA aims to reveal respective blind spots and to make the technology issues subject in political discourse. TA can, therefore, be considered as the science for revealing and managing the contingency and practice of necessary simplifications of sociotechnical systems in technology development (see Luhmann, 1992, p. 715). However, only in the juxtaposition of representations of the contingent relations and purposeful contexts of the technological application, TA can study the unconsidered blind spots and, in the next step, assess viable pathways for actors. Therefore, I find the prerequisite and task for Technology Assessment is making explicit and juxtaposing simplified representations of imagined technology in public discourse and technology development.

In Section I:2.2, I outlined scenario methods as a means of revealing background premises. In this way, they also resemble literary technology criticism. Literary technology criticism aims to reveal the contingency of technological simplifications in their significance for exceeding the norm – regardless of whether these simplifications are considered fiction or fact (see

Culler, 2011, appendix). Replacing representations from their official context to another generates unofficial readings that might, nevertheless, reveal fictional truths, inspire novel hypotheses, or question established beliefs. In particular, Jonathan Culler's literature criticism expressed this critique of absolute positions in favor of an ongoing discursive movement:

> *"For anything that seemed to make sense, literature could make it nonsense, go beyond it, transform it in a way that raised the question of its legitimacy and adequacy." (Culler, 2011, p. 41)*

From a critical point of view, such unofficial readings are creative when they induce a shift in their official discourse. They raise the question of legitimacy and adequacy by revealing blind spots considered relevant in a story, therefore, worth telling. Jonathan Culler gives a brief comparison of various accounts that enable new and critical perspectives on literature based on specific distinctions such as the role of man/woman, class conflicts, colonization, sexual identities, etc. (Culler, 2011, appendix). These non-structuralist or deconstructivist perspectives of literature and literature studies systematically break with reading habits and critically ask for the linguistic and social preconditions of their stabilization. Technology Assessment resembles this approach when the scenario method uses fictitious stories to reveal significant blind spots in the conception of technology (see 3nd paper). In classical scenario games, participants involve themselves in a role-play whose narrative portrayal might have just as much potential worth telling as literary technology critique.

The juxtaposition of representations, as according to the scenario method, can either generate insights by their appreciators or formulate criticism with authority. The distinctions mentioned above of feminist, Marxist, or technology critique are controlled observers or respectively authorized focalization lenses to systematically re-contextualize narratives and work out contingencies. The same applies when Technology Assessment takes technology models or narratives and systematically criticizes a lack of, for example, environmental impacts, privacy, working conditions, or democratic values compared to other imagined applications of technology. Especially costs and life cycle assessments seem applicable to every fictitious and factual process (see 4th paper). TA finds the normative standpoint for assessing the relevance and evaluating findings with means of public narratives that make facts meaningful and thus justify the importance of criticism. Technology Assessment thus studies unproven technology implicitly following revealed user-stories (see Section I:3.1) that represent the political-normative relevance of factual contingencies.

Moreover, the reference to a peer community or tradition helps to acknowledge the legitimacy of criticism and also offers a kind of retreat to tolerate the risk of uncomfortable results. Section I:3.2 suggested the founding narrative of Technology Assessment as the recovery of contingency for political decision-making in technology development. In the genre of Technology Assessment, so to say, the meta-narrative of the critique is characterized not only characterized in turning points where the continuation of everyday life is interrupted by a malfunction or side effects of the technology according to scientific knowledge. Instead, the turning points of a TA story highlight political alternatives questioning values, power positions, or concealed political goals. To this end, simplifications of technology are examined for their potential to represent a turning point in political narratives.

In contrast to literary critique, Technology Assessment does not only address the representations about the socially proposed future practice of sociotechnical systems. Instead, TA also criticizes the relationship between the present data and these imagined practices. The criticism of visions not only confronts the imagined futures with alternative stories but also with scientific studies, models, and facts. When facts are communicated as a scientific claim to validity and not as a political negotiating mass, they are still widely acknowledged regardless of the story one tells with them. The unique feature of TA is, therefore, that it bases validity claims not only on public sympathy or common sense but also includes scientific authority. The reference to scientific authority seems to be justified by the anticipatory dimension requiring an assessment of knowledge to pragmatically build on (Grunwald, 2019a, p. 703). TA thus equally acts as a mediator and an advocate about what data and models must be recognized for the sake of the public negotiation of policy issues. To be aware of these roles, however, Technology Assessment must estimate whether stakeholders pretend claims to validity with political intent or factually belief them.

For better awareness of the political significance of the data and models used in a study, technology narratives can be analyzed and contrasted. In the case of unproven technology, it is a matter of the shared stories, whether people consider the transgression of norms to turn out positive or negative. These stories provide the occasion for Technology Assessment. Contrasting narratives reveal the factual contingency of technology representations with political and practical relevance embedding facts for functioning technology in the transgression of an

imagined social norm. Figure 8, therefore, proposes a multi-level concept to analyze technology issues of unproven technology. The model distinguishes the practice narratives considered by actors or policy-makers and the key-narratives structuring the discursive backgrounds for validity claims. The key-narratives illustrate the discursive meaning of values and facts. Practice narratives show pathways for stakeholder engagement and give meaning to future-projected actions – they express the actor's attitude about factual and fictional claims[8]. On the analytical level, however, one can still derive the technology issues in terms of what counts as facts, values, and actors, for example, to assess the scope in which successful claims of validity are expected. The recognition that a narrative highlights certain aspects stronger than others does not mean acknowledging the story. Instead, it calls for critical positioning. Therefore, I claim that the juxtaposition of narratives raises awareness about what aspects require particularly robust modeling and datasets due to their political relevance. Analyzing public technology narratives thus serves as a benchmark for assessing whether relevant aspects have been sufficiently considered.

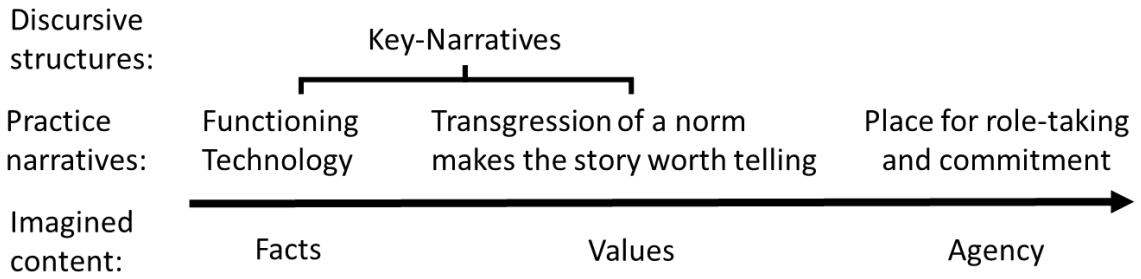

Figure 8: Narratives to manage the relation of facts, values, and agency at the levels of practice and discourse.

Organization relieves the narratively generated coherence of fact, values, and action to motivate actors and coordinate action through decision structures and hierarchy. Outside organizations, narratives still have a structuring function. In this regard, narratives are the semantic building blocks in which actors draft their imagined futures (p. 26ff). The approach of a global TA highlights particularly the different institutional and cultural frameworks in which global

[8] Practice narratives serve the reflexive or anticipatory attribution of agency by suggesting a plausible subjective perspective expressing truthfulness and appropriateness. In a similar way, Habermas (1987, p. 84) finds references to the subjective world besides the objective (facts) and normative (values) worlds. However, since practice narratives only instruct to imagine a person's subjective world, they do not have to correspond to his or her actual ideas but nevertheless constrain his or her socially considered role and scope of action. Moreover, the value implicit in narratives lies in the evaluation of the suggested norm transgression (see Table 1, Section I:2.1).

TA actors operate (see Grunwald, 2019a; Hahn, 2019). The analysis of global technology narratives connecting the imagined technology with socio-cultural backgrounds could supplement the deliberate exchange, understanding, and negotiation of technology policies at local, national, transnational, and international levels. Comparative studies could reveal the versatile considered norm transgressions, highlighted functions, and imagined details of future technology in some kind of extended socio-cultural user-stories across various societal, cultural, and even historical contexts. Both in TA and technology development, the appreciation of contrasting key-narratives could guide attention and benchmark modeling and expert assessments regarding relevant aspects. The recognition and work on global technology narratives seem particularly crucial for collaboration in the face of global challenges, as sources, data, and models are unequally authorized and mean different things in the respective identity and founding narratives. Although the science is a global endeavor, political negotiation must take into account and make sure that the stories of the actors involved can somehow continue.

2. TA in Transformatory Constellations: Maps and Swords at the Science-Policy Interface

At the science-policy interface, Roger Pieke distinguishes the roles of scientists in an "Honest Broker" and the "Issue Advocate" in anticipating the political use of scientific studies (Pielke, 2011). He points out that positioning in scientific policy advice is indispensable. If you shift the perspective from boundary people (narrators) to boundary objects (props) at the interface of politics and science, you reveal further meaning. I would like to emphasize the focus on objects, as the scientific studies, models, and analyses are suitable for different contexts and games with less epistemic and rather political ambition. As a basic distinction, I want to distinguish metaphorically between swords and maps – swords are suitable for fighting and maps to reveal pathways. The Honest Broker intents the generation of maps giving epistemic insights, whereas an Issue Advocate arms stakeholders with swords to only defend one political position. In both cases, the objects represent barriers for the imagination that resemble the anticipation of the Honest Broker or the Issue Advocate. However, the insurmountable pathways for action can, on the one hand, arise from deliberation based on a map. On the other hand, impossible pathways arise in the exclusion of considerations through the symbolic

power of scientific truth, or what you could call, the technocratic exclusion of irrational positions.

One could argue that the model is neutral in itself, although many models are authorized to represent a target system. Still, the objects only become models when they are used to represent a target system in practice. Therefore, I claim that models become political when their application purpose is the epistemic interest in a political battlefield. The authority about the application purpose is not due to private intention. Instead, the discursive embedding attributes the author of an utterance an attitude and an application purpose to the representation. The lack of anticipation on the science-policy interface does not make a scientist a neutral agent and the model a neutral prop (see Section I:3.2). In the paper on narrative self-reference, I describe the self-location of actors to only one field as rigorism of truth and rigorism of power (1st paper). The rigorous scientist may complain in the political arena about being misunderstood. Still, the consistency of scientific evidence is only one contingent stake in the political arena, which competes with the consistency of political ideologies, institutions, and narrative pathways for action. Similarly, the reference to the truth of a model does not make it politically neutral. However, if one considers the discourse to define the implications of the representation, one can anticipate application purposes in the design. Consequently, one can anticipate designs that make swords or maps.

LCAs compare sociotechnical systems and policies regarding their environmental impacts. They are, therefore, suitable examples of models used as swords or maps. A special feature of LCA is that the scientific discourse externalizes design decisions to the application purpose (see 4th paper). Assumptions, simplification, and evaluation of data should equally base on authorized standards and the intended application in practice (European Committee for Standardization (CEN), 2006). The debates of the scientific LCA community center on the methodology of generating and assessing studies and not the validity of the representation of particular target systems. For the application purpose, the scientific community mobilizes, so to say, science-external forces to authorize the representation of the target system (Figure 9). Depending on the intended application, standardized, legally normed, or measured data and structures are authorized to represent the target system. To point out environmental compliance, for example, the model must refer to reliable props, such as legal norms and proven

model structures. The “veto right” of the reliable sources (primary f-truth) and scientific authorization (secondary f-truth) facilitate claims for validity in scientific or legal discourses. However, if one aims to improve an industrial process or justify environmental measures for a limited audience, the stakeholder discourse authorizes the props. Then, model extensions, like economic allocation models, expert surveys, or technology trend assessment, are equally common data sources as there are inconsistent modularization levels of process steps. The different application purposes are different benchmarks and make studies differ in their findings about the same target. The represented environmental impacts of the system are not “universally” true but only true-according-to-the-model. The design of the model, thus, anticipates the addressed and authorizing discourse to serve either as a map or as a sword.

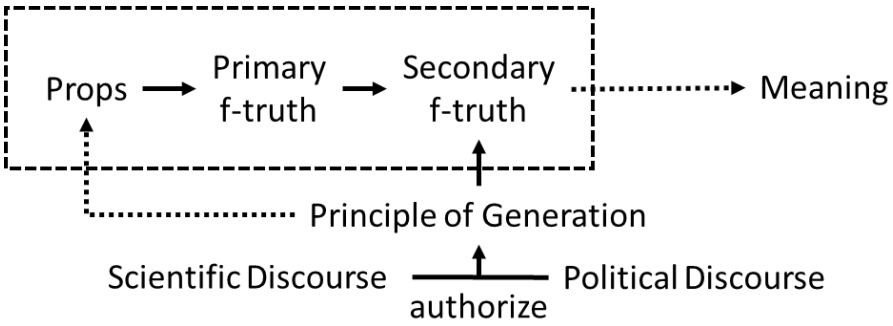

Figure 9: Model authorization at the Science-Policy Interface.

Modeling with authoritative intent builds on authorized instructions for the make-believe. However, modeling with rather inter-and transdisciplinary demands can dispense with specific and general truths and anticipate the design of a boundary object. The use of objects in trans- and interdisciplinary practices requires that people communicate without reference to disciplinary positions. Purely deductive understanding would have to trace a conclusion back to commonly given last premises. However, such common grounds cannot be found in *inter*disciplinary collaborations and especially not at the interface of observation- and evidence-based science and the identity- and action-oriented politics. If one were to build on a common ground only by definitions and reductionist dictionaries, one would have to do without the promises of interdisciplinary division of labor and transformative intentions. However, without advocating an anti-reductionism or a strong theory of emergence, I see a practical use for disciplinary and opaque languages, which engage in a discourse in natural language at the basis of boundary objects. I claim that pretense theory provides a viable understanding of

transdisciplinary and transformative collaboration, given the constructive pretend-as-if-attitude towards propositions about the representation.

The approaches of make-believe modeling emphasize that there are authorized games whose framework implies fictional truth leading to scientific hypotheses and conditional beliefs (Section I:2.2). Section I:2.1 explained the use of narrative representations to distinguish different perspectives in a story and highlight the peculiarity in a discourse. In the article about key-narratives of microalgae nutrition, the narratives serve to identify different views on an imagined technology for different audiences. Accordingly, one can translate the model introduced in the context of the games of make-believe (Figure 3,p. 25) to a model for transdisciplinary cooperation by mirroring at the boundary object from one to another principle of generation. Figure 10 shows how texts, shared variables, maps, data plots, or flow charts are the gateway for inferences in different peer groups and the emergence of a common practice. The result of the original games of make-believe based on the authorized principles of generation and suitability considerations in system A and system B lead to hypotheses in the subsystems and conditional beliefs about the fictional possibilities according to the shared representation. Through the self-reference in a joint group, the boundary object enables the emergence of a trans- or interdisciplinary debate about the possibilities and constraints of socially imagined futures.

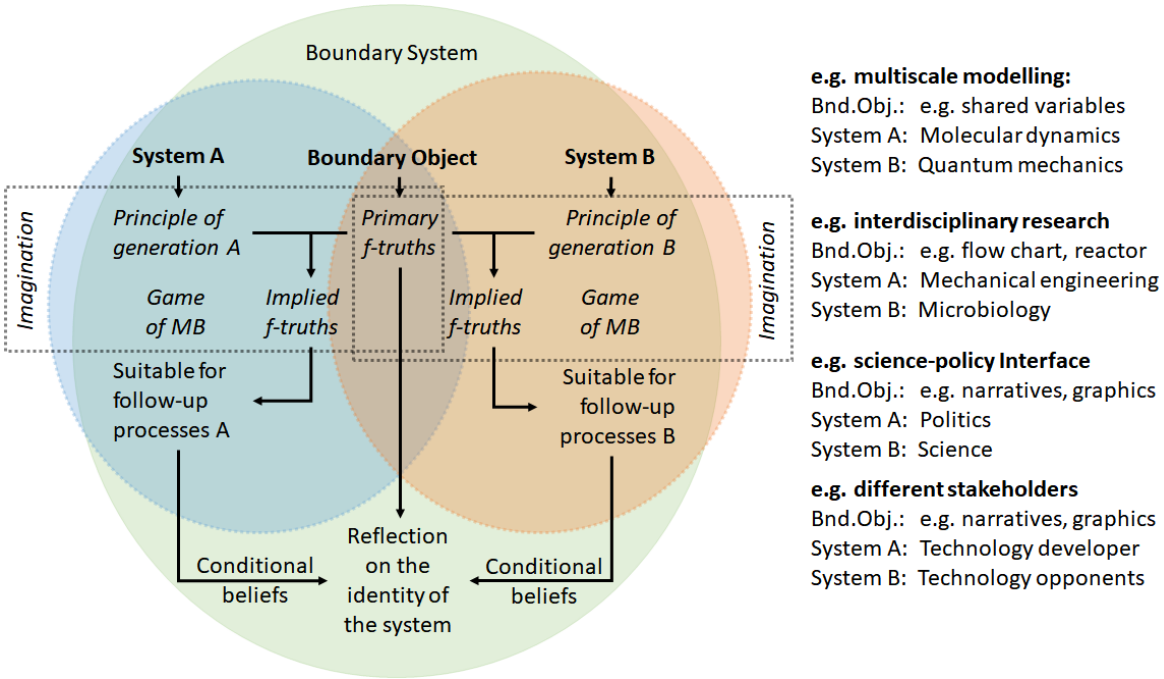

Figure 10: The Boundary System as the joint discourse on a boundary object with means of two or more distinct principles of generations.

The central point for transdisciplinary collaboration is not to assess the findings in disciplinary consistency but regarding their significance for cooperation in the boundary system. Instead of drawing out their weapons in a disciplinary fashion, for example, to "falsify" an opponent's view about the object, different experts cooperate in an open game[9] using a common map. The reference to the boundary object allows stakeholders to share and accumulate common knowledge (Figure 10,p. 56). These propositions about the boundary object are not necessarily commensurable with disciplinary or sub-disciplinary communities. One can, for example, combine theories of molecular dynamics with theories of quantum mechanics in one model. Similarly, one can play different games for politics and science with a narrative, model, or graphic as a boundary object. The diagrams with curves for the expected climate or pandemic Covid-19 scenarios, for example, offer different debating material for politicians, scientists, or the heads of producing companies. The representations come from science. However, one can nevertheless plot packages of political measures and imagined consequences in their timing and discuss feasibilities in sub-discourses at the basis of different premisses. However, the debates can fictionally meet at the boundary object. As such, the representation provides the potential for the autopoietic continuation of a transdisciplinary subfield – based on constructively omitted misunderstandings.

Narratives decouple the beginning of autopoietic continuation from the origin (Section I:2.3). The use of a boundary object illustrates the function of the narratives to mark a contingent beginning of the story in which the object is meaningful. Narratives represent the discursive background for statements and function to decouple the validity claims in the boundary system from the validity claims of the associated systems. Assertions are then, for example, not attributed to the truth-seeking in disciplinary discourse but, instead, to their problem-solving in the transdisciplinary or transformatory field. Cooperative actors, science-policy networks, and scientific subfields emerge from the reflexivity of their history. Compared to Arnold Gehlen's theory of institutions, it is not a totem animal, but the boundary object that gives rise to the reflexivity of the collective (see Section I:2.3). Theoretically, boundary objects can generate commonalities that are stabilized by narratives that dominate further communication over

[9] Suits (2005, p. 122) defines open games as games which have no inherent goal whose achievement ends the game.

the legacy[10]. In the function of generating a distinct whole of attention, narratives manage the complexity. Section I:2 discussed institutional and discursive capacities and resistances for new narratives to maintain. However, one would have to examine further in practice to what extent new narratives are capable of defying dogmatic ties to disciplines or even historically entrenched conflicts.

Maps clearly illustrate how one object merges cultural, economic, and geographical elements with considerable implications in particular debates. Such maps exist because there are stories about the map that make the elements cohere and meaningful. At the Science-Policy Interface, I maintain that one could equally use models as maps regarding this function. Moreover, one can even extend the original model with findings, and request, for example, disciplinary feedback. If one dispenses with the claim of objective truth about models, representations unite games without a central perspective that is capable of representing all moves in their considered constraints, strategies, and intentions. The use of factual maps as game boards illustrates how interaction with the model leads to new stories that entangle individual deliberations in a joint practice. As part of a participatory process, such a model could start and grow with the inter-and transdisciplinary actors to represent the decision-making process and entangle the statements of the actors. For example, a process flow diagram or management route in nuclear waste management, climate, or pandemic strategy means different things to different actors. As a boundary object, it can also represent the timing of cash-flows, organizational, and legal decisions, as well as the assembling or temporal behavior of materials. No participant in this game completely understands the disciplinary or practical backgrounds and restrictions of all associated actions that make the game. Still, the actors can use the model to understand what is relevant for them, or respectively necessary in their world. Such “living models” that change by the collaboration of different actors represent both the emerging findings and the story of their design. They do so, without a participant in the process being able to predetermine or fully comprehend the evolution based on known premises.

To sum up, the narratives and models at the science-policy interface are not only tools for disciplinary reflection. Instead, they also maintain attention to a set of elements across disci-

[10] A subsequent thought would be to discuss narratives as modal-logical operators for decoupling and re-organizing contingent fictional worlds. Metaphorically speaking, narratives are the lenses to distinguish small worlds from complex systems as the meaningful playgrounds for hypothetizised action.

plines for a period and purpose and reinforce the emergence of boundary systems. In approaches of co-design, representations serve epistemically for the exchange about imagined futures, and socially, for the self-reflection and formation of collective identity. Framed in a tale of modernity, they promise a new orientation, as the grand narratives lost authority and left people in an open and shapeable future. The perspective of the thesis explains the relevance of models and future narratives for institutionalization and generation of agency – the prerequisites not only to describe the world but to change it. However, a conclusive judgment about the validity, truth, and correct application of narratives and models, including those presented in this thesis, remains reserved.

The reflection on the narratives and models in the assessment of unproven technology reveals both how narratives make desirable futures and how the ontological power of props makes them seem feasible and uncertain. The study proposes perspectives to explore further the organizational embedding of future narratives and models and the role of platforms for make-believe – both because the objects play a crucial role in innovation, and also because TA may adopt this in practice (see Section I:3.1). Continuing the history of Participatory TA and Constructive TA, Technology Assessment should not only reflect its role as an honest broker (see Section I:3.3). Neither does TA have to become an issue advocate of selective evidence for biased policy support. Instead, TA should reflect about and aim at designing models that serve as maps, game-boards, and platforms to entangle and inspire stakeholders in the deliberation of alternatives at the science-policy interface.

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Section IV: Individual Articles

Attached on the following pages are the individual articles of this dissertation.

Article 1: *Roßmann, M. (2018). Narrative Self-Reference and the Assessment of Knowledge. Journal of Sociocybernetics, 15(2), 38–51. https://doi.org/10.26754/ojs_jos/jos.201822630*

Article 2: *Roßmann, M., & Rösch, C. (2019). Key-narratives of microalgae nutrition: Exploring futures with a public policy Delphi in Germany. Science and Public Policy. Advance online publication. https://doi.org/10.1093/scipol/scz053*

Article 3: *Roßmann, M. (2020). Visions as Make-Believe: How Narratives and Models Represent Socio-technical Futures. Journal of Responsible Innovation, 8(1), 70–93. https://doi.org/10.1080/23299460.2020.1853395*

Article 4: *Roßmann, M.; Stratmann, M.; Rötzer, N.; Schäfer, P.; Schmidt, M. (2020): Comparability of LCAs — Review and Discussion of the Application Purpose. In Stefan Albrecht, Matthias Fischer, Leistner, Philip, Schebeck, Liselotte (Eds.): Progress in Life Cycle Assessment 2019. Cham: Springer International Publishing (Sustainable Production, Life Cycle Engineering and Management), pp. 213–225. https://doi.org/10.1007/978-3-030-50519-6_15*

Article 5: *Rösch, C., Roßmann, M., & Weickert, S. (2018). Microalgae for integrated food and fuel production. GCB Bioenergy, 30(6), 1344. https://doi.org/10.1111/gcbb.12579*

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ORIGINAL ARTICLE

Narrative Self-Reference and the Assessment of Knowledge

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The concept of narrative self-reference incorporates selected aspects of literary theory into the theory of self-referential systems in order to sharpen its analytical and explanatory perspective on certain linguistic structures. Since cybernetics and systems theory focus mainly on computer-aided metaphors and information, the narrative approach provides a better insight into meaning. Narrative self-reference is the narrated sequence of events that constructs a simplified self-image in the referred system-environment relations (e.g. in history or future visions), and thereby stabilizes the system. In practice, these narratives become the pivot of the social and psychic system and sketch contingent collectivities and actions. Since narrative self-reference is not static but rewritten, continued and entangled in various present practices, it offers flexibility against new and disappointed expectations as well as stability for accountability and planning. In this context further theoretical concepts of legitimation theory, sociology of technology, and the philosophy of science and neuroscience are compared. In summary, this article formulates a systems-theoretical research interest in the negotiating power of narratives that create system boundaries for cooperation and a common basis for the evaluation of knowledge.

url:

1. Introduction.

The recent strengthening of populism was like the awakening of a monster of postmodernist dreams. Now it becomes clear what it means when scientific facts are contrasted with alternative facts or scientific explanations are labeled as an interest-guided projection of mere paradigms of a false elite with a false consciousness: Necessary political measures for climate change and peace lose their foundation and are blocked and reversed. Without a universal criterion as the guardian of the right truth, it seems that society lacks the common ground for its preservation and a future worth living. Where have objectivity and rationality disappeared?

The post-truth crisis is not a general loss of scientific authority or scientific accuracy, but a crisis and neglect of common grounds to evaluate knowledge-based policy programms since embedded facts have practical meaning (see Jasanoff & Simmet, 2017). To address this problem, I propose the perspective on narrative self-reference as the pivot of collective and individual meaning and action. In summary, this article argues for reflection of the function of narratives for orientation by providing system boundaries that support and cross stand to the unity of a scientific system (part 4). Because societies are based neither entirely on evidence nor on consent, a narrative negotiation makes alliances of power and truth meaningful (part 4.1). This concept shall give a system-

theoretical basis for further studies on narratives in policy and technology genesis research, assessment and modeling practice.

To provide this perspective, I interpret the function of narratives in terms of self-referential systems (part 3). In Niklas Luhmann's systems theory, the term narrative is not used, but other terms have a similar function, like e.g. "parallel poetry", "historicity", "episode formation", "reflection", "dramatization". I argue that the term narrative helps to explain and to give insight into the self-referentiality of individuals and collective actors. The concept of narrative self-references provides a distinction of only externally ascribed collectivity and self-referential systems with the capacities of autonomy, collective action, and accountability. In the following parts, four theoretical approaches are interpreted in this context. Each highlights another important aspects and procedures of complexity reduction in the formation of shared narratives that impact personal and cooperate identity, legitimation and the option of collective action:

3.1. The "entanglement in a role play" is based on institutional procedures like legal proceedings and political elections and mass media to produce legitimation (Luhmann, 2013, p. 87).
3.2. The internet provides new and contested technical infrastructures for emerging self-reference by means of controlled feedback Dolata & Schrape, 2018.
3.3. The make-believe theory takes narratives as props and distinguishes authorized imaginary model-world comparisons on basis of "public rules" (Frigg, 2010; Walton, 1990).
3.4. The "narrative self-constitution view" completes the "autobiographical narrative" with the pragmatically approving on "reality constraints" (Schechtman, 2015, p. 398).

All approaches are compared by reference to the above-mentioned function of self-referentiality and narratives. To point out the meaning of narratives, I shortly review some aspects of the narrative theory (part 2).

2. Narratives as the sequential organization of events

> "531. We speak of understanding a sentence in the sense in which it can be replaced by another which says the same; but also in the sense in which it cannot be replaced by any other [...], something that is expressed only by these words in these positions. (Understanding a poem.)"
> (Wittgenstein, 1984)

Narratives are traditionally the subject of literary studies, but recent cognitive science, sociology, cultural studies, political science and the philosophy are increasingly paying attention to them. Brown, 2017 gives an excellent overview of narrative approaches in these fields and their impact on environmental psychology research. Narrative analysis is about "meaning encoded in language" and "recipients' understanding" (Hermwille, 2016, p. 238). We make sense by following a linguistic sequential organization instead of looking side by side at propositions and arguments (see Wittgenstein, 1984, § 531). Aristotle describes the mimesis of a tragedy as "an imitation of an action that is serious and has a wholeness in its extent" (Aristoteles, 2006, 1449b.24), that is, "has a beginning, a middle, and an end," meaning that nothing is necessary before or afterwards in order to make it a whole (Aristoteles, 2006, 1450b.26). The sequentiality of events "create the order of time." (Abbott, 2011, p. 4). In order to clarify the term of the narrative, I mainly refer to the derivation, definition, and distinction in "Cambridge introduction to narrative":

> "narrative is the representation of events, consisting of a story and narrative discourse; a story is an event or sequence of events (the action); narrative discourse is those events as represented. [...] we never see a story directly, but instead always pick it up through the narrative discourse."
> (Abbott, 2011, pp. 19–20)

The following parts focus on the analysis of the rhetorical power by carrying us from A to B, guiding our perception on a selection of relevant aspects, as only a "lack of narrative continuity or coherence" causes hesitation (Abbott, 2011, p. 14).

2.1. Focalized mediation and language oriented analysis of a discursive-internal world

Stories are embellished and narrated in various ways. In practice, a "story is always mediated (constructed) by narrative discourse." (Abbott, 2011, p. 21). A story can only make a difference in practice, thus "you could say that history does not really happen in the past but must wait until someone narrativizes the past" (Abbott, 2011, p. 155). Two narrative discourses can frame the same story but evoke other feelings or conclusions. We could, for example, imagine how the planning process of a power plant is narrated from the planners' and an opponents' view or how the court case of Eichmann in the medial report of state Israel differs from Hannah Arendt's report (see part 4.1). For heuristic-analytical reason and in reference to literary theories, we compare narratives in forms of contingent whole referable sequential language structures that focalize a story – if we were stuck on different points of view or the authors' background, there was no benefit of the term narrative in contrast to, e.g. structure, discourse, schema or concept. In contrast to discourse analysis, "narrative analysts ask rather what language and speech does, than what it means or presupposes" (Hermwille, 2016, p. 238). In many cases, the narrator focalizes "the lens through which we see characters and events" (Abbott, 2011, p. 73). On one hand, we can analyze narratives with means of masterplots, typical genres, structures, and stereotypes (Abbott, 2011, p. 58; Jones & McBeth, 2010). On the other hand, we can analyze narratives in juxtaposition to their practice or history, and in traditions like Marxism, psychoanalysis, colonialism or feminism (Culler, 2011, pp. 135–146):

> "For anything that seemed to make sense, literature could make it nonsense, go beyond it, transform it in a way that raised the question of its legitimacy and adequacy."
> (Culler, 2011, p. 41)

Both, fiction and non-fiction cause powerful effects on their audience. The narrative discourse frames an internal world in its own rules and inherent-discursive meaning that is "indifferent to […] extralinguistic reality" (Bruner, 1990, p. 44). Thus, "literary fictions often contain statements that, when judged from a real-world perspective, are evaluated as false and that is about objects that do not exist concrete spatiotemporal entities" (Salis, 2016, p. 245). Being asked to imagine or to believe a story can make a difference for the demands of the internal world of a narrative. But it is neither necessary nor possible to distinguish whether a narrative is a fiction or non-fiction by the narrative reference to the story (John Searle discussed in Abbott, 2011, p. 148). Whether it is actually a non-fictive story is only apparent in the ascribed "referential function" to something real in the world of the recipient (Abbott, 2011, p. 153). Beyond a "true story" claim of extralinguistic reference, narratives are discussed in terms like "believability' and "coherence" since they are "less about facts and more about meanings" (Brown, 2017, p. 219).

2.2. Closure, suspense, and surprise as the driving force for continuity and coherence

A story must neither be told to its end nor the world described in every detail. When we follow a narrative from its beginning, we start to expect and look for closure that is the resolution of a problem or conflict, as "satisfaction to desire, relief to suspense, and clarity to confusion" – confirming a masterplot at the end of the narrative (Abbott, 2011, pp. 56–64). Mary Morgan describes the ordering of selected material, categories, and internal divisions that make the narrative into a coherent whole as a "detective or forensic casework, be it fictional or factual" (2017, p. 93). On every step in the narrative, we assume coherence in a "way of normalizing those events" (Abbott, 2011,

p. 44) – the "underlying" rules are not expressed by propositions but shown. We expect at minimum completeness and consistency (Crasnow 2017, p. 12), but as a representation of a whole external real world, a narrative would always be necessarily incomplete and thus meets contingent focalization. Driven by suspense and surprise, narratives can even transcend the boundaries of space and time as we confront the protagonists' dreams and thoughts to gain further impressions of their motivation, expectation, or belief.

Suspense drives us further into the story and keeps us on reading and imagining. With suspense, we continuously follow a sequence of events and experience the pleasure to be carried "from one point to another", while an "explanatory gap" does not necessarily matter and leaves "room for further narrative discourse to fill this gap" (Abbott, 2011, pp. 195, 211). Woken expectations let us notice and highlight turning-points and contingencies in a way that makes a story worth telling and listening (Crasnow, 2017, p. 12). If we would insist on "someone to a character type", we denied "her capacity to surprise us with behavior that exceeds the limits of the type" (Abbott, 2011, p. 136). Thus, the surprise may confront us with our own expectation of normality, types, genres, and masterplots. The narrative gains its spurned rhetorical power in immersion when we fail to notice that "the attraction of narrative coherence has overridden both reason and the evidence of the senses" (Abbott, 2011, p. 45). We continuously expect closure, but when a narrative ends before closure is reached, it causes the even more interesting effect: By not closing, many powerful narratives "don't tell us what to think but cause us to think" (Abbott, 2011, p. 63). Our imprisonment in "the masterplots we grow up with" (Abbott, 2011, p. 189) can be critically addressed in such reflection – are we the ones who imagine, follow, notice or cling to stereotypes and rigid ideology? This practical orientation on narratives, implied normality expectations and emerging perspectives, will be discussed in the following part.

3. Narrative self-reference

To provide theoretical connectivity, the first part focuses on self-reference in Luhmann's social systems theory and gives reasons for a partial interpretation of some theoretical terms as narratives. The later four subparts give theoretical examples of further institutional, technical, authorial, and pragmatic dependencies for the constitution of psychic and social systems with means of narrative self-reference.

Self-reference is the reference of the system to itself and thus the constitutional condition of self-referential systems (Luhmann, 1987, p. 31). Self-referential systems are non-trivial machines, since their actual output does not depend only on an objectively understood input, but accounts for it in a function found from previous operations (von Förster, 1972, p. 36). Non-trivial machines are characterized by structure but are practically unpredictable in their operation. Luhmann distinguishes between three forms of self-reference based on the grounding self-referential distinction:

1. "We want to speak of basal self-reference when the distinction between element and relation is at the bottom" (Luhmann, 1987, p. 600)

2. "We want to speak of reflexivity (processual self-reference) if the distinction between before and after elementary events is at the basis." (Luhmann, 1987, p. 601)

3. "We want to speak of reflection when it is based on the distinction between system and environment [...] in which case the self is the system to which the self-referential operation belongs" (Luhmann 1987, p. 601); "and in order to mark the difference to a mere creation of the unity of the system (as seen by an external observer), in the case of reflection we speak not of unity but of identity." (Luhmann, 1992, p. 482)

Basic self-reference generates models of element relations that recreate in the case of communication and thought. The processual self-reference refers to sequentiality of events in order to make sense. This already fits our definition of a narrative as lingual reference to a sequence of events. The reflexive observation tells a story; and as reflection, it tells a story that implies its distinction from its environment in this self-image. The basal operation in form of communication or thought then becomes an addressable self. The narrative concept is not namely intended in the theory of social systems for self-reference. However, Luhmann refers to historicity as the "basis of meaning" that has been built up in "a history of experiences and communication processes" (1971, p. 43). For systems, the experience is "structurally relevant information" and leads to the "restructuring of meaningful premises of the processing of experience" (Luhmann, 1971, p. 41). In the current experience processing, narrative self-reference becomes the form and relevant conglomeration of self-ascribed experiences that provide expectation. For this purpose, experiences must be assigned to the identity, "in the case of psychic systems [...] the immediately experienced consciousness, with which it knows to be one", and in the case of social systems "a context of coherent actions that stand out from an environment" (Luhmann, 1971, pp. 81–83). In the same way, as on the horizon of the past, self-reference can also be told on the horizon of a fictional future (Luhmann, 1971, pp. 59–60). Action is distinguished from behavior when the change of state of a system is assigned to it – by others and in self-reference (Luhmann, 1992, p. 141). In the case of reflection, the individual action is attributed to the system, and the identity becomes a latent phase in the form of a representation of the unity of the system in the system - as opposed to the pure constitutive principle of presence (Luhmann, 1987, p. 618).

In our observation of the narrative self-reference of systems we aim to follow the under-complex, but the contingent observable orientation of the system in written or spoken language. We make sense of our observations with means of our psychic ability of "episode formation" (Luhmann, 1987, p. 369). In the normal understanding, a system is described as driven by interests and dependencies towards the environments. In the narrative understanding, we make clear the reflected dependencies on the horizon of narrative closures. In scientific foresight, this shift was recently reflected as the "'Narrative Turn'" from "storytelling" to "story-listening" (Schwarz, 2015, p. 512). Bruner noticed a similar turn in cognitive-science from computational metaphors to narrative interpretation (Bruner, 1990, pp. 1–30). To sum up, Narrative self-references are simplified narrative self-images that reflect their system-environment relationship, provide orientation and thereby stabilize. Narratives are "intermediators between the individuals' internal structures and the social collective" (Hermwille, 2016, p. 240). The observation of narrative self-reference might give a better or additional understanding of what makes a difference for the system. Thus, it might be useful for mediation and policy and technology assessment.

3.1. Legitimation as entanglement in a role play

Technology Assessment analyzes the development and consequences of socio-technical systems, such as automation or renewable energies. The following part focuses on empirical acceptance and thus discusses the role of narratives for empirical legitimation through procedures. Empirical legitimacy is "a generalized willingness to accept undefined decisions within certain limits of tolerance" (Luhmann, 2013, p. 28). Luhmann does not justify the acceptance of undefined

consequences "as the result of a personal decision" or the rightness of normative arguments, but as based "on a social climate that institutionalizes the recognition of binding decisions as a matter of course" (Luhmann, 2013, p. 34). Thus, institutionalized participatory procedures and legal cases are carried out in order to "build a cooperative audience from case to case" (Luhmann, 2013, p. 209). Such institutionalized "entanglement[s] in a role play" take starters into account that provide context and suspense gradually integrating the interests, references, personality, arguments, and believable sub-histories of those involved in a collectively shared history of interaction (Luhmann, 2013, p. 87):

> "As the process evolves, the actors' opportunities for action converge. Everyone has to take account of what he has already said or omitted to say. Amendments bind. Missed opportunities do not return." (Luhmann, 2013, p. 45)

The uncertainty and the prospect of not everything being decided yet motivate for further participation and thus must be "maintained during the procedure with all due care and means of ceremonial." (Luhmann, 2013, p. 116). This uncertainty is suspense by the only certainty that closure will be reached at the end of the procedure in reference to the legal system or previous set public rules. The open opportunity to take on the perspective and to participate is more important than actual participation for preventing mistrust (Luhmann, 2013, p. 123). This opportunity is granted by a followable, and medially spread narrative about the particular case and a culturally shared meta-narrative of the generalized case. Legitimation is mainly achieved by the "social behavior" and "symbolically expressive action" (Luhmann, 2013, p. 224). The participants will be given a "new past" in the procedure (Luhmann, 2013, p. 43). A realistic drama is performed whose rules of intelligibility, truthfulness and appropriateness are sought and determined in the process so that a coherent, understandable reception is possible. Consensus on the outcome can only be assumed by the recurring presence combined with the public pressure to find and keep an agreement as a basis of further concerns. In the end the subsequent and shared reception of the proceedings decide over the legitimation:

> "The future is the future only as the future of a present-with-past; [...] My consensus is consensus only on your consensus, but my consensus is not your consensus" (Luhmann, 1987, p. 113)

To sum up, the legitimation through processes are based on institutionally provided role play entanglements following public rules whose spread and shared narratives force the participants to keep on their new given past. In our narrative perspective, empirical legitimation is the result of narrative self-references that positively frame the process of decision making.

3.2. The internet as technical infrastructure for emerging self-reference

The same way as by institutional procedures, self-organization can be stimulated by technical infrastructures. Dolata and Schrape (2018) describe new ways of the emergence of collective behavior based on internet infrastructures. According to them, the prerequisite is a technological infrastructure that enables the visibility of one's own action and allows feedback mechanisms – it provides social space of observable interaction. Taken the metaphorical "code is law", code and algorithms are not neutral but technically regulate these conditions for visibility and interaction (2006). Unorganized individuals may behave as an aggregate at comparable orientation and observable patterns emerge. The referring to these emerging patterns of basal self-reference of e.g. swarm consumption, likes or rating-feedback systems leads to a processual self-reference: The recognition of certain previous events becomes of present importance with implication for the future. For example, the mass sharing of a tweet or the establishment of a hashtag gives evidence of

the possibility of a partial normality to which one can reflexively refer. Further self-reference, such as the established hashtag in new contexts, promotes the reflection and negotiation of shared views, goals, competencies, and principles of communities or publics. In their study, Dolata and Schrape (2018) show that on one hand, the Internet becomes the primary base of communities and social movements; on the other hand, these collectives become dependent, platform owners are gaining power and open code alone does not make an open society. The authors emphasize that technical infrastructures have a major impact on the formation of collective actors, but in addition to digital features, social organization and structuring services are still indispensable.

With means of narrative theory, we attribute the condition of possibility of this processual pattern recognition to cultural meta-narratives and their narrative closure: The social system recognizes this peculiarity in the form of reflection, for example by communicating that "there are still a few missing for the first 1000 likes", "we're going viral" – which frames this observed event in a bigger and meaningful narrative. From now on, explanatory references follow the principle of narrative closure and shape the system boundaries. Appropriate behavior becomes recognizable, criticisable, expectable and plannable. Further communication practice leads to further elaboration, shaping, and distinctive generalizations. What we may perceive on the surface is, from this perspective, not personal opinions of individuals in a filter bubble, but the social self-references that contribute to the common narrative identity. Such an antecedent narrative identity offers viable conditions for the formulation of membership conditions and the establishment of an organizational decision-making structure, in order to further suppress contingencies in favor to the masterplot. In the end, such narratives in function as a founding myth may exceed scientific or historical appropriateness (see part 4).

In both cases, the entanglement in a role-play and the reference to patterning collective behavior, the narratives are formulated by reflection following culturally shared masterplots. Spread and remembered narratives make the merge of plan statements the legitimating basis of infrastructure projects or frame patterns of rejection on Twitter as part of a legitimate protest. Especially in times of continuous certainty of the existence of parallel practices and new formative collectives on the Internet, the perspective of narrative self-references offers a meaningful orientation with regard to personal and organizational accountabilities.

3.3. Authorized games of make-believe

In the perspective of pretense theory, many adult activities are best understood as continuations of children's make-believe (Walton, 1990). Following Walton, we can imagine fictional worlds as games to learn from with means of props like novels and literature. The above-mentioned narrative examples of participatory processes or the emergence of protest movements can already serve as an invitation, that is, as the "principle of the generation" of such a game (Walton, 1990, p. 69). For example, prior to a lawsuit, experienced lawyers can play a case according to the legal rules. In imagination, they can estimate whether it makes sense to actually start a lawsuit. Even before protest or terrorist groups occur in the public, patterns of collective behavior on the Internet are observed and evaluated by means of algorithmic pattern recognition. In games of make-believe, these data-models are "representations" that serve as props for generating "fictional truths by virtue of their features" (Walton, 1990, p. 138). These props distinguish such games from pure day-dreaming – if what is "to be imagined" under these props is authorized by public rules. The fiction view on models assumes that scientific and technical questions can be explored in an imagined context:

> "We explore and develop models in the imagination, from an internal or participatory perspective. And we originally compare models and targets from within an extended imagined

> context. In this case, we are fully immersed in the game and we assume an attitude of imagination towards the relevant propositions. However, we can also exit the game and assume an external and descriptive perspective…" (Salis, 2016, p. 256).

In games of make-believe, e.g. engineering students actually imagine to design a machine, reactor or circuit. As an immersed participant, one has the opportunity to imagine what each component does and question intermediate results for plausibility and completeness, such as size, design, and cost of the imaginary machine. Distanced computers do not participate in the game and question their results and intermediate results only on instruction. The users of the model learn about the transferability and plausibility of the results when dealing with the model within a game of make-believe. On the other hand, one can exit the game and analyze consistency and whether the game is authorized, i.e. is based on public rules:

> "Representations are things that possess the social function of serving as props in authorized games of make-believe [...] Games based on public rules are 'authorized'; games involving ad hoc rules are 'unauthorized'. By definition, a prop is a representation if it is a prop in an authorized game." (Frigg 2010, p. 259)

With means of public rules self-referencialy refer to the science system, you can argue for the validity of the representation and modeling results. Outside of a scientific community, model assumptions and rules are neither explicitly known nor considered to be set, but have practical meaning. If there is no insight and no common authorized reference, for example in practical, interdisciplinary and transdisciplinary projects, "narratives can show what experiences one must make in order to keep the use of certain general concepts for the right reaction to the world" (Hampe et al., 2016, p. 21). Such interaction makes sense of its system boundaries on practical constraints and the constraints of the self-referential science system in narrative self-reference. Thus, explicit narratives in science-based modeling improve collaboration and reproducibility by establishing, organizing and evolving the shared problem-solving perception with transparent references to established and considered scientific rules. They help to generate and guide through the authorized game of make-believe, highlight what is to experience in every followable step, and how additional assumptions and contingencies about practical concerns have been considered. On one hand, you can immerse, and follow the narrative in a fictional model-world-comparison and reflect affordable plausibility and completeness. On the other hand, you can exit, and analyze the logical consistency of authorization references and interpretation. The latter seems either carried out systematically to a certain depth in peer-review and by the expected perception or when something does not seem plausible. For example, in case of surprise, the better life-cycle assessment of aluminum foil compared to a reusable snack box (see Wellenreuther & Drescher, 2013) might pose questions that go beyond the application of ISO norms. The need for an authoritative narrative framework for modeling is already reflected and implemented in the concept of the open source project "Jupyter": the narrative form of "computational narratives" is designed to facilitate collaboration, interpretation, and reproducibility through an interplay of models and narratives (Perez & Granger, 2015). Such narratives can also be understood as hermeneutic chapters that interrupt continuous interrogation and keep a particular section of the world stable for a certain period of time. Although further analytical and empirical evaluation is still pending, this practical achievement seems to address some practical challenges in engineering, consulting, and forecast.

3.4. Pragmatic constraints on narrative identity

Narrative self-reference refers to system identity in the distinction of system and environment. In the context of the following theories, narrative self-reference for social systems is referred to as tradition

(MacIntyre, 2007), cultural community (Bruner, 1990) or "the natural third-person view of her history" (Schechtman, 2015, p. 398) and for persons as their narrative identity (Bruner, 1990; Schechtman, 2015). Narratives constitute the pragmatic "pivot between the realms of the social and the psychological" (Kirmayer, 2007, p. 363):

> *"In basic outline, then, the "Narrative Self-Constitution View says that we constitute our identities as persons by generating and operating with an autobiographical narrative that meets the articulation and reality constraints."* (Schechtman, 2015, p. 398)

This "implicit autobiographical narrative" serves "as the lens" through which persons "experience and act on the world" and cause effects that "constitute personhood" (Schechtman, 2015, p. 396). We neither need nor can assume continuous consciousness of our autobiographical narrative since we only refer to it stepwise. The implicitness of the narrative closure in practice allows inconsistency and gaps in our autobiographical narrative to a certain level since not every aspect is marked in the present narrative self-reference. There is no need for a narrative to tell every detail, as soon as we get an idea of the implicit closure, i.e. keep asking "what comes next?". Thus only gradually, we are forced to extend a story with additional assumptions that make it more coherent or believable in the present context.

In practice, we are only "co-authors" and depend on continuations and constraints of narratives that have already started, "each of us being the main character in his own drama plays subordinate parts in the dramas of others, and each drama constrains the others" (MacIntyre, 2007, p. 213). Bruner and MacIntyre, compare the embeddedness of our life in an ongoing history of traditions metaphorically with a stage, where "others on stage already have a sense of what the play is about, enough of a sense to make negotiation with a newcomer possible" (Bruner 1990, p. 34). Through this cultural embeddedness, we learn about "interpretive procedures for adjudicating the different construals of reality" (Bruner 1990, p. 95), become "the prisoners of the masterplots we grow up with" (Abbott, 2011, p. 189), and we are educated "into the virtues" (MacIntyre, 2007, p. 216). The "fruit of our experience enters into our judgment of narrative fictions" (Abbott, 2011, p. 157) so that our narrative identity is not determined by our social environment, but we can access and emancipate from certain dependencies in reflection. Thus, MacIntyre takes narrative self-reference as a basis for moral reflection:

> "I can only answer the question 'What am I to do?' if I can answer the prior question 'Of what story or stories do I find myself a part?'." (MacIntyre, 2007, p. 216)

The implicit reference to our tradition or cultural contexts allows assuming accountable subjects. Being subject of a narrative makes you practically "accountable for the actions and experiences which compose a narratable life", and to "be able to respond to the imputation of strict identity" (MacIntyre, 2007, p. 217). Because the narrative self-reference takes place in society, we can only listen and learn about our constraints and about our perspectives on criticism. Storylistening and storytelling as societal virtues provide the environmental conditions for orientation:

> "The ethics of storytelling has its necessary counterpart in the ethics of listening, of witnessing and taking part in the creation of community through compresence." (Kirmayer, 2007, p. 379)

In most cases, we implicitly follow our traditions, normality expectations, and methods, or relate to truth, laws, scarcity of resources, and standards. By story-listening, we get a better idea of how such constraints make a difference for an individual or collective actor and how we can build upon. And by storytelling – in contrast to trials of distant reporting – we set referable system boundaries, shape our identity and become accountable characters in different narratives.

4. Narrative self-reference for the assessment of knowledge

The assessment of knowledge becomes apparent when it has an ambiguous meaning in different structures. Scientific communities formulate observations in systematic self-referential forms of relative context-free condensed expectations and reflect progress only towards their own recent and long-term history (Luhmann, 1992, pp. 136–137). The science meta-narrative is about the anonymous and uninterested experience – what is observed has happened to the observer, so that this knowledge should be accessible to all despite different interests (Luhmann, 1992, p. 143). In references to this meta-narrative, science organizations and interaction actualize their present histories of suspense and surprise in the form of doubts, successes, setbacks, splits and changes in the field of research. These narrative self-references give a convincing, culturally widespread but simplified orientation that does not necessarily have to be shared. All communication is only against the background of functional systems without being able to withdraw to only one functional system. The scientific distinction between truth and untruth emerged historically from the doubt of the sensory perception and, as a second order observation, questions the relation of knowledge to the scientific system (Luhmann, 1992, pp. 167–169). This distinction als serves for authoritarian reasons (Luhmann, 1992, p. 149). It is practically blurred with claims that emphasize honesty and truthfulness to legitimize the quality of an observation that is anyways still to distinquished from an scientific observer (Luhmann, 1992, p. 274). By mentioning relativism, historicism (p. 502), deconstructivism, and the "new literary forms" (p. 93), Luhmann (1992) criticizes that these concepts of self-reference cannot explain the systematic self-references of a unique science system:

> "For if one observer can observe what another person cannot observe, a communication barrier has been established which cannot be broken without destroying the observation of one or the other, the primary or the secondary observer." (Luhmann, 1992, p. 503)

The concept of narrative self-reference doesn't aim to explain the unity of a science system but to explain, address and find ways to deal with the phenomenon of such established barriers of self-referentiality. The self-entanglement in a role play explains the self-referencial establishment of exactly such barriers on side of institutions that hold and focalize the said (see part 3.1). New infrastructures enhance and control the development and stabilization of publics and movements, which nevertheless continue to depend on social structuring through, for example, narrative interpretation (see part 3.2). Application oriented research must take values, norms and interests of the field of application into account, otherwise one misses the sector of application-oriented research and does not meet market requirements (Luhmann, 1992, p. 640). The narrative view situates these aspects in public key-narratives, such as stakeholders' self-descriptions, visions, opinion articles, participation process reports and narrative expectations – here, empirical links must be sought (see part 3.4 and part 2): As we can immerse or methodically analyze meaning inside the sequentiality of a narrative, we can overcome the formal "incommensurabilities" and further barriers of formal structures. Especially in case of models as mediators and because the scientific achievements must later be translated back, the narrative form is seen as an accompanying framework of practice-oriented and interdisciplinary research that determines which aspects are in a certain case taken into account (see part 3.3). On the social dimension, stakeholders emerge when the narrative self-reference meets subjects of the model – this is also the case for public narrators on side of the science. On the factual dimension, the narrative serves as a negotiation about model references and decisions.

4.1. The rigor of power and the rigor of truth

The factual dimension of a narrative can be in conflict with the socio-political dimension. Semantically such a conflict is the normal political struggle about the contingent self-reference of a social system on the horizon of present concerns. In juxtaposition to the expected narrative closure, the narrative may lack continuity or, when the conflict is about adequateness of system boundaries, lack coherence. The implied normality expectations of the narrative give a scope of what and how aspects are taken into account. For example, in a technical project, the stakeholders decide whether to respect, weighting and focalize certain ecological and economic impacts or to neglect and actively prevent them in favor of a preferred storyline. Knowledge could cause unpleasant surprises in ideological storylines, i.e. storylines that rely on the ignorance of contingency (Bruner, 1990, p. 96; Luhmann, 1987, p. 281). Thus, there is a risk and possible interest of ideologists and organizations to hold on to given system boundaries and ignore the knowledge about e.g. human toxicology of agrochemicals within their given possibilities – at least for a certain phase.

To give a historical example, in "Rigorismus der Wahrheit", Blumenberg criticizes Hannah Arendt's report on the Eichmann process not in terms of her scientificity, but in her neglect of its function as a founding myth of Israel state (Blumenberg, 2015, pp. 77–78). Even when Arendt's scientific work was factually right, her report competed with existing narratives and masterplots. The trial and execution of Eichmann already had a meaning following the masterplots of symbolic vengeance and compensation and providing narrative closure to the Jewish persecution history in Israel state. As a result, Arendt experienced a harsh criticism that was untypical of a scientific work. Even Blumenberg discredits Arendt's intended honesty of truth with gross artistic extravagance (2015, p. 98). Taking the exaggerations of Blumenberg, some rigor of power would maybe insist on a populist narrative providing only the most relevant consent, and some rigor of truth on a narrative providing only the most evidence. The rigor of power sets boundaries on the factual perspective by insisting on the normality expectations. The rigor of truth denies boundaries on the factual perspective but ignores the social meaning of its provided narrations. From a system-theoretical perspective, interaction systems and organizations communicate against the background of the functional systems and must deal with these respective restrictions without being able to withdraw to a system: "knowledge function and political function cannot be separated" (Luhmann, 1992, p. 149). Blumenberg concludes that "it seems indispensable that alliances between history and truth are standard to our assessment of both" (2015, p. 93). Such alliances are not just resulted in compromises or contradictive models, but the practical effort to find a viable and adequate negotiation.

The reflection on the narrative self-reference offers different options to adapt and focalize political and scientific feedback as a framework for "peacekeeping" or ongoing critique (Bruner, 1990, p. 95). When expectations are seriously disappointed, for example, in cases of serious diseases, political changes, disappointing modeling results or personal blow, a shift of narratives can reframe perspectives of social systems, individuals or technology, and focalize properties differently. MacIntyre elucidates an identity crisis as the unintelligibility of the narrative that "lacks any point, any movement towards a climax or a telos." (MacIntyre, 2007, p. 217). The virtue and recognition of listening and narration help to stepwise explore new narrative closure through the stability of ongoing practices. Therefore narratives must be recognized in their power to make "all suffering bearable", "do that reconciliation with reality" (Arendt, 1969, p. 367), and even provide viable perspectives with irreconcilable conflicts, such as fulfilling life and inevitable death (Abbott, 2011, p. 55). The practical challenge is to find a viable way between the constant flexibility of the narrative self-reference in parallel practices and systems' constraints and a continuity that allows orientation and the choice of our direction. The key story could be that, despite implicit ignorance, science provides in the long run decontextualized compatible and useful knowledge structures and public

rules that serve as second-order observers for the contextualized interplay of models and narratives. But the long-term view is no guarantee that scientifically meaningful measures will be implemented in good time. Nevertheless, the richness, possibilities, and function of the narrative seem promising for the negotiation of power and truth:

“I sometimes think that we are not lacking in learned prose but in learned poetry. Scientific theories have a peculiar content of the world, which they themselves cannot even formulate (with all incorporation of self-referentiality). The so inadequate attempts at a political interpretation of the "actual" proposition of theories point to this need for a second version, without being able to adequately satisfy it. Perhaps it should instead give a kind of parallel poetry for demanding theoretical work, which says everything differently again and thus rejects scientific language into the limits of its functional system.” (Luhmann, 1993, pp. 176-177)

5. Conclusion and outlook

The abstractness of social systems' theory makes it capable to reflect its conditions of observation in the juxtaposition of other observers. The aim of this article was to show how a perspective of literary theory can be adapted in social systems theory as a concept of a narrative self-reference. As more and more texts about the corporate identities, visions and concerns become public or online available as a data source, the methods of literary theory seem quite promising for the analysis of social systems – or as a supplement of surveys, network analysis, modeling and other forms of policy and technology assessment. In order to provide further insights towards the knowledge assessment against the only contingent background of the science system, narratives are observed in forms of whole lingual structures that serve as self-reference for social and psychic systems and thus become essential and powerful. Narratives give insight of “what matters how to the system in view of the system”: Processual self-reference refers to the sequentiality of events. Reflection refers to the implied system boundaries of this sequentiality to present distinctions. The narrative self-constitution view explains the cognitive meaning of narratives and reality constraints of societal embeddedness. The extended view on narrative self-reference merges this tradition with ongoing research on systems, legitimation and philosophical pretense theory. Narratives are thus taken as the meaningful guidance and boundary of individual and collective action and collaboration – as already applied in psychotherapy, environmental psychology, political science, data science and foresight (Brown, 2017; Jones & McBeth, 2010; Kirmayer, 2007; Perez & Granger, 2015; Schwarz, 2015). For model-based practices, narratives support reproducibility by establishing, organizing and evolving a shared problem-solving perception with transparent and selective references to prevailing public rules. As an outlook, further analytical distinctions must be made to define and reason about the distinct empirical properties of a narrative that provide distinct functions in scientific modeling practice of socio-technical concerns. However, the benefit of this theoretical concept has to prove itself practically. Our further studies aim to empirically elaborate the perspective of the models-narrative-interplay on cases of bioeconomy for real-time policy and technology assessment: Can this reflection on narrative self-reference in practice support the appropriate use of narratives as a viable, dynamically stable common ground for knowledge-based policies and modeling practice?

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Article

Key-Narratives of Microalgae Nutrition: Exploring futures through a public Delphi survey in Germany

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Abstract

This paper analyses public visions of microalgae as a food source to explain present innovation paths of a yet unproven scientific technology. The paper highlights the multi-perspectivity of contested futures, focusing on the role of generalized narratives as boundary objects. Using disaggregative policy Delphi, we reveal the key-narratives of microalgae nutrition with regard to expectability, desirability, and popularity. The study involved a two-round online survey with 229 participants, who were asked open and closed questions. We then clustered the answers and gave feedback in form of generalized narratives. Participants want microalgae to sustainably feed the world, while they also expect microalgae to be more likely a health product or an inconspicuous food substitute. Our findings show that Delphi methods are not only suitable to look into the future, but also for empirical research into perspectives on the future that help distinguish and hone the cognitive interest of politicians and researchers.

Key words: technology assessment; microalgae; narrative; policy Delphi; food; expectations

1. Introduction

The amount of food currently produced in the world must double to meet the needs of the expected population of 9.8 billion people by 2050 (United Nations, Department of Economic and Social Affairs, Population Division 2017). Food production accounts for 20–30 per cent of the total environmental impact (Tukker and Jansen 2006) and for almost 30 per cent of global greenhouse gas emissions (Vermeulen et al. 2012). Some claim that microalgae are a promising source of food with less ecological impact than traditional sources of food. Envisioned as 'bread from the sea' that would feed the world through its high photo-efficiency, manageable technology, and versatility of ingredients, microalgae have occupied a prominent place in the grand narratives of future technologies since the 1950s (Böhm and Dörge 1959: 294–300). Back then, like today, these visions were said to be supported by successful prototypes and experiments on the nutrition of animals and humans (Ploeger 2011; Enzing et al. 2014; Gahmann 2015; Lewandowski et al. 2019). However, microalgae research is still in its infancy, and the scenarios are still based on scaled-up laboratory data, not on commercial plants. Current studies therefore presuppose future technological breakthroughs or point to physical limitations that make the original vision impossible to achieve (Weiss et al. 2016; Rösch et al. 2018). Nevertheless, microalgae play a prominent role in bioeconomy research policies and future food scenarios (Enzing et al. 2014; Lewandowski et al. 2019). This is, as we postulate in this paper, because current expenditure and research is driven by visions of the future in public discourse, not by factual benefits.

Elaborate and expensive research is often justified, guided, and motivated by certain future visions (Borup et al. 2006; Jasanoff 2015; Konrad and Böhle 2019). However, most studies of socio-technical imaginaries ignore the variety of public visions and do not collect, differentiate, or summarize these different perspectives on the same technology. These studies examine how technology development is driven by visions, but rarely how different ideas and representations of the same technical object pull development in different directions at the same time. Therefore, they do not adequately take into account the role of non-expert knowledge and public imagination in technology governance. In order to close this gap and foster the 'science–policy–society interface' (UNESCO 2016: 17–20), we analyse current future projections of microalgae nutrition in the public and bring them into the distinguishable, reportable, and assessable form of key narratives. In contrast to genealogical approaches to the power of futures, the ongoing discussions on the use of algae for food and feed are the central objects of analysis

of this paper. In particular, our adaptation of the public policy Delphi examines the socio-technical aspects and future expectations that are linked to public imaginations of microalgae nutrition in Germany.

The paper is structured as follows: We begin by discussing the multi-perspectivity of *contested futures*[1] as an overlooked strength of the public policy Delphi and focus on the role of narrative representation in socio-epistemic practices. In the next section, we describe the empirical design of this research, which is an adaptation of the 'Disaggregative Policy Delphi' (Tapio 2003). Next, we present our survey-based study on microalgae nutrition and illustrate how key narratives are derived and evaluated. This is followed by a discussion of the contribution of such an approach to current food policies and the added value of key narratives in the context of a Delphi study on future projections. Finally, we end with the proposition that generalized key narratives such as those of the statistical projection of the world's future food demand are empirical research objects that help distinguish and hone the cognitive interest of policy makers and researchers.

2. The Delphi method

The Delphi method is generally used to structure a group communication process in order to allow a group of individuals, as a whole, to effectively deal with a complex problem (Linstone et al. 1975). The core characteristics of this method are anonymity, iteration, and feedback (Woudenberg 1991: 133; Niederberger and Renn 2019: V), and its key functions include: idea generation, that is identifying possible views and aspects, and a judgement function, that is rating their role in the elaboration of future projections (Häder and Häder 2000). The classical consensus-based Delphi approaches elaborate details of a most plausible prognosis. The policy Delphi, on the other hand, tries to compile all options, assess the consequences, and determine their desirability (Turoff and Linstone 2002). Turoff and Linstone (2002) stress, in particular, that the policy Delphi is 'a tool for the analysis of policy issues and not a mechanism for making a decision' (80). Consolidation is discussed as a third general function that corresponds to a step between generating ideas and concretizing them for implementation, for example in scenario development (Schmidt et al. 2001; Okoli and Pawlowski 2004; Nowack et al. 2011). From this perspective, there is an interest in expert assessments of current future projections in order to reflect on the conditions for success.

2.1 Using Delphi methods to reveal guiding perspectives

In this paper, we propose that Delphi methods are not only a useful planning and implementation tool with a view *into the future* but can also serve to open up *perspectives on the present futures* in such a way that the actions and discursive relationships of different actors become comprehensible. In a recent study, Linstone and Turoff (2011) emphasize the importance of a multi-perspective logic and broader participation, since the influence of digitalization and social media make the construction of realities in innovation processes even less technically linear and predictable. The authors make clear that the goal is not to forecast the future as clearly as possible, but to present relevant perspectives on the future, that is present perspectives that would currently be shared and taken into account by stakeholders. Therefore, diversity and layperson participation do not only help identify more creative options or 'weak signals' but also help get in contact with and represent different policy issues (Hussler et al. 2011; Nowack et al. 2011). Recent studies also include computational methods to process data from news feeds or social media, while experts further elaborate on and assess emerging future projections (European Commission 2014; Warnke et al. 2019). Consequently, the communicative function of the policy Delphi method moves more into the focus—it not only serves to construct concrete and coherent futures but also allows a particular group to discuss the multiple perspectives into the future.

Research into the present futures in the form of guiding images ('Leitbilder'), for example, are a common element in innovation research, future studies, and technology assessment (Dierkes et al. 1996; Gransche 2015; Grunwald 2019). Social sciences follow on from this by focusing on the (influence of) making and distribution of visions of the future, for example in the concepts of relational sociology, sociology of expectations, politics of expectations, future imaginaries, and vision assessment (Emirbayer and Mische 1998; Borup et al. 2006; White 2012; Jasanoff 2015; Beckert 2016; Lösch et al. 2017; Miller 2018). However, social sciences are interested in how future projections influence actions and constellations, and thus shape the present as well as the possible pathways into the future. The paradigm assumes stakeholders and visionaries to have pragmatic interests in influencing the design, negotiation, and strategic communication of future projections in order to, for example influence the direction of research projects, technology policy, legislation, and emerging markets. There is, thus, an interest in exploring and understanding the interplay of current practices and particular future projections, regardless of the (rational) credibility and normative judgement of the content. Such a perspective also implies a different evaluation of future knowledge, wherein making of the futures and framing of facts is of central interest, as opposed to scientific validity of future projections through transparent methods, expert knowledge, and scientific props (see Grunwald 2013, 2012: 276). Hermeneutical TA, therefore, reflects on its own practice in relation to the discursive field in order to join the versatile and powerful perspectives of visions and socio-technical futures in democratic processes at different levels (Grunwald 2019). In this context, the Delphi method also serves the systematic exchange between experts and public actors on adequate representations of various contested futures.

To summarize, there are two performances of Delphi studies: (1) systematically expanding knowledge about one or more Delphi statements on future projections and (2) exploring the present interaction and representation of various powerful futures. The former incorporates further expert knowledge to systematically enrich and concretize future scenarios, while the latter aims to identify disaggregated and general differences of future projections in practice. The added value of multi-perspectivity in policy Delphi studies is to reveal and represent different futures. In the following subsection, we describe the forms used to communicate and represent future projections.

2.2 Role of key narratives in the representation of future projections

In order to make conclusions about future projections, one normally refers to material or imaginary objects. For example, by looking at the statistical projection of the world's future food demand, one can conclude that a technology or political measure must fulfil a certain specified function. The representation of a present future should, therefore, be understood not as a description of the future, but as an

instruction for the imagination. Subsequent communication is concerned with imagining a scenario on the basis of the given representations and making statements about it. This approach to representation can be found in Walton's theory of representational arts (1990) and has been adapted for models in technology and science (Frigg 2010; Toon 2014; Currie 2016). According to Walton, a representation is an object that is used as a prop in a game of make-believe. In reference to the objects that are considered as part of the corpus, the fictional propositions possess a certain kind of objectivity (Toon 2016: 281; Currie 2012: 8). In a game of make-believe, one can learn from a future projection about the present without pointing out that the scenario does not correspond to one's own beliefs or an already existing situation. This is supported by the definition of scenarios as 'hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points' (Kahn and Wiener 1967: 6). From a Waltonian perspective, not only the 'realism' of the scenario can be judged, but also the emphasis or ignorance of technical features and whether these are based on common props or unauthorized *ad hoc* props in adaptations.

As stated above, future projections often refer to a combination of prototypes, data, models, simulations, and narratives. Narratives have the function to organize the materials and make objects recognizable as props of a coherent whole (see Morgan 2017: 89). Narratives make readers imagine a sequence of events that embed the meaning of technology. They are therefore best understood as 'rules for the imagination' to see how a system works under certain conditions, and thus to examine and learn about details from a complexity-reduced perspective (Currie 2016). Isolated from specific data and models, narratives introduce a fictitious sequence of events that define the function of technology in its socio-technical embedding and leave technical and theoretical details open. However, one must still imagine certain technical functions to grasp the connection from scene A to scene B according to the story. Thus, in contrast to labels or descriptions of a set of features of a technology, a narrative indirectly specifies the rules for classification and reduces the influence of wording. This focus on plot also makes narratives more resistant to translation problems than poems or a metaphorical understanding of futures (see Culler 2011: 83ff). Compared with lists or a set of arguments, narratives make the audience explore meaning 'from the inside' (White 1980; Bruner 1990; Brown 2017). With an analytical stance, one can nevertheless analyse what certain roles and certain features technology must fulfil in order to be labelled, for example, as sustainable or secure according to the story.

By first providing the key to a fictitious world in a short narrative, one can leave the detailed description open for further inferences and still limit the imagined space of possibility according to a corpus. Interestingly, this corpus besides the narrative can be assembled or elaborated differently depending on the audience and purpose. For example, Sundbo (2016) shows how alternative and elaborated food scenarios for Denmark are developed in a Delphi workshop based on trending food narratives and a global/national/regional scenario logic. In another case, Kovacic and Di Felice (2019) show how a set of narratives methodically developed from policy papers helps distinguish different representations of the energy system in order to better cope with the complexity of energy security governance. While scenarios are elaborated concretizations, the key narratives as a framework ensure coherence, highlight certain aspects, and make the complexity-reduced perspectives distinct. Therefore, by leaving out details, one arrives at a more generalized form of the plot. In this condensed form, the narrative can serve as a 'boundary object' for transdisciplinary collaboration (Star and Griesemer 1989), as it reduces the prerequisites for understanding, such as the basics of statistics or thermodynamics. With a set of key narratives, a heterogeneous group can easily name, explore, and differentiate the highlighted features of a technology according to the different imagined futures. This feature makes them very useful for the Delphi method and technology assessment.

3. Research design

Based on these conceptual considerations, we carried out a public online two-round policy Delphi study, to reveal and assess narrative futures. The first round opened with a short text containing general information on microalgae without anticipating the visions. The closed questions of the first round are based on a discourse analysis on future nutrition scenarios, technological future visions, and microalgae research. In open questions, the participants also had the opportunity to bring in further aspects that have been neglected in their view. We followed Bolger and Wright (2011) in their discussion and recommendation on lay participation with indicators for expertise. After the first round with open and closed questions on important aspects of microalgae nutrition, we provided a summary of the respondents' views and ranking from the previous round. The participants were then encouraged to revise their earlier answers to the same questions, but in light of the replies of other respondents. Besides asking the same questions on visions of microalgae nutrition again, we later introduced structured key narratives and asked about their credibility, popularity, and desirability.

Following Tapio (2003), we applied a hierarchical cluster algorithm[2] on the answers in round 1 to disaggregate the perspectives on microalgae nutrition. In order to provide meaning, all statistics and computational methods require further context and interpretation. Therefore, further results of the first round were taken into account to interpret the clusters and derive key narratives (see Figure 1). 'Narrativization' never only follows directly from the data but includes given narrative structures (White 1980). As in narrative discourse analysis, we keep these structures comparable in form and plot in the style of a 'hero narrative' (Viehöver 2001): each key narrative introduces a challenge (e.g. growing need for balance and health) that the hero masters due to highlighted qualities (e.g. health promising ingredients) so that a solution is obtained. In order to keep the time expenditure and cognitive effort of the questionnaire reasonably low, the narratives were kept short and supplemented by an illustration. These key narratives serve the purpose of making the disaggregated perspectives on microalgae technology equally accessible to transdisciplinary audiences. In order to test whether the orientation on clusters makes a difference, a test narrative of non-correlated elements was also presented. In summary, the two-round Delphi study aimed at including new aspects in open questions, to enable transparent clustering and inductive statistics of closed questions and to provide feedback on key narratives that represent the interpretation of the disaggregating clusters in an easily accessible and comparable way (Figure 1).

4. Results and discussion of the public Delphi survey

The online Delphi survey with open and closed questions was conducted with two rounds focusing on German citizens. The participants were recruited via numerous German social media platform

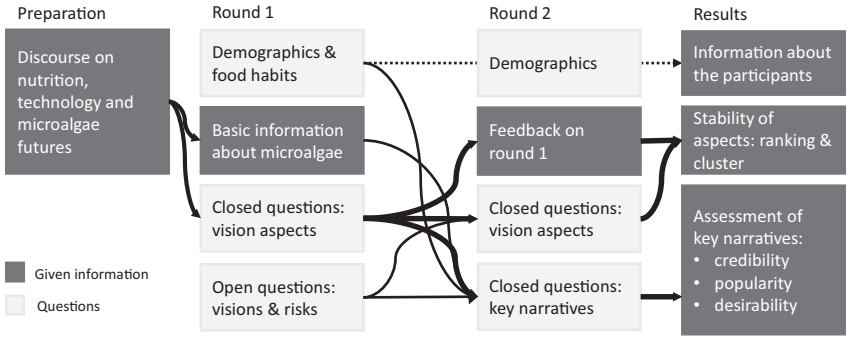


Figure 1. Research design of a two-rounded disaggregative policy Delphi survey to research key narratives. Light gray fields are questions; dark gray fields are given information. The arrows show the input information presented in each step.

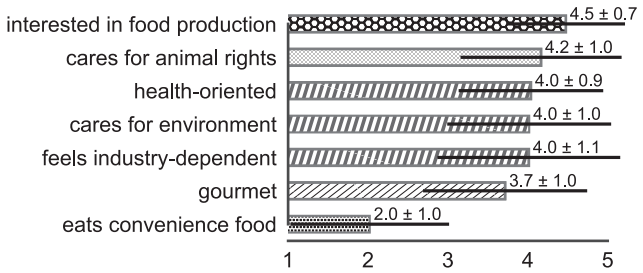


Figure 2. Nutrition habits of the 229 participants. Likert scale. Mean value as a bar, standard deviation as a line. Different colours indicate significant group differences, tested by a MWW.

groups and an evening school by the promise to learn something about nutrition with microalgae and to contribute ideas and opinions into research. The survey was implemented during September 2017 (1st round) and January 2018 (2nd round). The invitations for the second round were only sent to participants who completed the questionnaire of the first round ($n_1 = 229$) and left their e-mail address ($n_{i2} = 147$). Lastly, 58 per cent of them (i.e. 37 per cent of the participants in round 1) took part in the second round ($n_2 = 85$). Compared with the dropout rates in other Delphi-based scenario studies over 100 participants, this dropout rate seems not unusual (Nowack et al. 2011: 1611).

4.1 Demographics (1st round)

Almost two-thirds of the participants were female. This is not surprising since studies show that women tend to show greater interest in food and health (Arganini et al. 2012). Besides, the share of women is higher in the upper quantile. The average age of the participants is 36.0 ± 13.7 years. From the available data, no statement can be made as to whether this is due to the survey's questions or thematic interest. Compared with the national average, the participants are well-educated with 50 per cent of the participants holding a university degree. Almost half of the participants (47 per cent) are not familiar with food from microalgae and first learn about it through the survey. Forty-one per cent of the participants know the topic from the media and 15 per cent have already consciously consumed microalgae.

4.2 Food habits (1st round)

We asked participants about their expenditures for food and the factors guiding them when buying new and innovative products in order to get more background information on the respondents. The results show that the daily food expenditures indicated by the respondents correspond to the average and are almost normally distributed around the mean value: 6–8 € (27 per cent), 8–10 € (30 per cent), and 10–12 € (22 per cent). Around 90 per cent of the participants said they were highly or very highly interested in food production (Figure 2), while they reported consuming convenience food rather less frequently.[3] Animal rights, health orientation and environmental aspects are in the middle field. Respondents also showed an interest in special or gourmet dishes. The results show that the majority of survey participants were already engaged and interested in ethical, healthy, and tasty nutrition.

Our results on factors guiding participants when buying a novel, unknown product show that they focus mainly on ingredients and origin, which should be from regional production (Figure 3). Product labels, such as the label for organic production or fair trade, have also a strong impact on their food buying behaviour. When buying new products, only a few participants consider advertisement and product testings provided, for example, by Stiftung Warentest, a German consumer organization involved in investigating and comparing goods and services in an unbiased way. The decreasing importance of classical advertisement and media in favour of social networks (Sottong et al. 2017) could explain this observation.

The age correlates significantly (Spearman corr. >15) with the expenditures for food, the habit of orienting oneself towards ingredients or product labels, the rejection of synthetic fertilizers and large-scale facilities as well as the expectation to produce gourmet dishes (see Figure 7 in the Online Annexe). The training correlates significantly with the respect for the environment. Male participants answered to consume finished products more frequently and to follow recommendations from friends. In summary, the majority of respondents can thus be described as

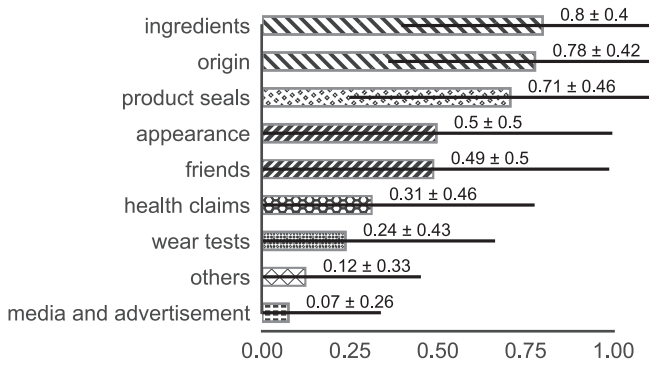


Figure 3. Orientation of the 229 participants. Multiple choice. Mean value as a bar, standard deviation as a line. Different colors indicate significant group differences, tested by a MWW.

Table 1. Questions and rank order (MWW) of normative projections of microalgae nutrition (Likert scale), round 1

Questions on normative projections of microalgae nutrition	Mean	±SD	Rank
Climate benefits: 'The production of food from microalgae should above all be more climate-friendly than the production of conventionally produced food.'	4.63	0.72	1
No agrochemicals: 'Foods made from microalgae should under no circumstances require synthetic fertilisers or pesticides.'	4.36	1.07	2
Location independence: 'It should be possible to produce food from microalgae in urban and rural areas regardless of location.'	4.23	0.9	2
Against world hunger: 'Food made from microalgae should above all defeat hunger and ensure world nutrition.'	4.11	0.94	3
Inexpensive: 'Food made from microalgae should under no circumstances be more expensive than ordinary food.'	3.82	0.96	4
Health benefits: 'Food made from microalgae should above all offer advantages for health and performance.'	3.71	1.14	5
Do-it-yourself option: 'It should be possible to produce food from microalgae oneself using one's own technology (e.g. small cultivation systems, 3D printing).'	3.32	1.22	5
Delicious taste: 'Above all, food made from microalgae should offer exceptionally good taste experiences.'	3.13	1.03	6
Neutral taste: 'The taste of food made from microalgae should under no circumstances be noticeably different from food known to us.'	2.96	1.05	6
No industrial production: 'The production of food from microalgae should not take place in large-scale facilities.'	2.7	1.29	6

environmentally and health conscious, well-trained trend seekers. In addition to this majority, however, there is sufficient diversity and variances that enable significant correlations and thus promise wide and versatile perspectives on the microalgae future projections.

4.3 Participants' responses (1st round)

The ten questions (Likert scale) about the expectations of microalgae nutrition focused on normative projections of the production and consumption of microalgae. The questions cover a wide range of topics extracted from the literature on microalgae research, the future of nutrition, and current technology utopias. The open questions were intended to complement the following list of desirable aspects of microalgae nutrition (Table 1).

The evaluation showed that the positive contribution to climate protection was clearly ranked highest. The taste aspects ('delicious taste' and 'neutral taste'), on the other hand, are found at the bottom of the list. In an expert survey, production on an industrial scale was formulated as a concern, as it could conflict with the naturalness of microalgae (Meyer and Priefer 2018). The participants rather do not or only partly agree with this concern (mean of 2.7 on a scale of 1–5) and thus this aspect is clearly considered the least important. The absence of synthetic fertilisers and pesticides is perceived as rather important (4.36 of 5). Although health benefits are important to the respondents, sustainability aspects rank higher. In addition to these closed questions, the participants were asked to mention further technological opportunities (ninety answers, Table 4 in the Online Annexe) and further risks (120 answers, Table 4 in the Online Annexe). The answers were qualitatively coded and evaluated without text mining. Since many participants saw an extra benefit in the integration of algae technology in other (material and nutrient) cycles or value chains, such as e.g. the aquaponics technology, this question was added as a closed question for the second round. Concerns about toxicity (mainly heavy metals, allergies, thyroid), water contamination, and unknown side effects were mentioned as extra risks and can be taken as mandatory research tasks on behalf of the public interest. Some of the opportunities and risks mentioned (e.g. patents on food and organisms, transparency, and autonomy) are an indication of a perceived dependence and distrust of the established food industry. Other contributions (see Table 4 in the Online Annexe) were rather creative with regard to social embedding, products, and system extensions (e.g. fish farming, dietary drinks for handicapped people, paper production, algae for wastewater treatment, food recipe competitions, and algae ponds as urban wildflower meadow paradise).

4.4 Demographics (2nd round)

The average age of male and female participants increased significantly (MWW) from round 1 to round 2 from 37.7 to 39.7 (female) and from 33.2 to 34.2 (male). The ratio of women to men did not increase significantly ($\chi^2_{\text{independence}}$), from 67 to 69 per cent . Also

the ratio of people with a university degree increased only slightly ($\chi^2_{independence}$) from 50 to 54 per cent.

4.5 Participants' responses (comparison of rounds 1 and 2)

In the second round of the Delphi survey, the participants were presented with the results of the first round with the invitation to use the opportunity to consider them or orient themselves towards them in their answers. The mean value changed significantly (MWW) only for the questions on 'inexpensiveness' (from 3.82 to 3.65) and 'no industrial production' (from 2.7 to 2.4). Only for the question of 'no industrial production', this led to a lower ranking (MWW). When looking at the correlations of 'no industrial production' depending on 'age', 'gender: male' and 'highest educational level' (Figure 7 in the Online Annexe), this is an unexpected development given the slight demographic differences between rounds 1 and 2 (see above). It can, therefore, be considered as a sign of orientation towards others. The form of production was now seen as by far the least important aspect (MWW)—as long as no agrochemistry is used (see Table 2 and Figure 4). The newly included aspect 'integration into further cycles' ranked second together with other sustainability aspects (MWW). The variance or standard deviation has in total decreased, but only significantly for health and climate benefits (Levene's $test_{center=mean}$, $P < 0.05$). With the Delphi method, decreasing standard deviation indicates that slightly more consensus was strived for. In qualitative terms, however, the ranking is rather stable, so that the qualitative interpretation from round 1 still holds (see Figure 4): The sustainability aspects were considered of particular importance to the public, and the positive contribution to health and an affordable price were in the midrange. The taste was seen as less important, which does not mean, however, that taste is not an essential purchase criterion in the end.

Table 2. Rank order (MWW) of normative projections of microalgae nutrition (Likert scale), round 2.

Normative projections of microalgae nutrition	Mean	±SD	Rank (MWW)
Climate benefits	4.74	0.62	1
Against world hunger	4.29	0.95	2
Location independence	4.26	0.78	2
No agrochemicals	4.21	1.18	2
Integrated cycles	4.11	0.99	2
Health benefits	3.84	0.97	3
Inexpensive	3.65	0.88	3
Do-it-yourself option	3.40	1.14	3
Neutral taste	3.06	0.95	4
Delicious taste	2.93	0.99	4
No industrial production	2.40	1.15	5

5. Interpretation and assessment of key narratives

In order to analyse ambiguities and different perspectives, a clustering algorithm was used to structure correlations between individual statements and the views of participants in the first round. Based on these results, four equally structured narratives on microalgae nutrition were identified and derived. The embedding in a plot gives meaning to technology in its function and illustrates and highlights its value and features in contingent socio-technical contexts. Since stakeholders and developers of novel technology orient themselves towards shared expectations, such key narratives form and frame the public interface for cooperation, critical discussion, and evaluation of the socio-technical evolution.

5.1 Cluster analysis

The method involved grouping a set of objects in such a way that the objects in the same group (called cluster) are more similar to each other (correlating in some sense) than to those in other groups (clusters). In addition to the cluster analysis, we performed a correlation analysis in order to confirm that the clustered aspects all correlated positively with each other (see Figure 7 in the Online Annexe). For example, the participants who considered location-independent production of microalgae products important tended to favour small cultivation facilities (Spearman corr. >0.2). The cluster analysis (complete linkage) of the 1st Delphi round (Figure 5) was complemented by the statements from the 2nd round (Figure 6) to give further insights. Certain aspects still belong together, such as 'securing the world's food supply' and the 'positive contribution to climate protection' or the above-mentioned location independence and DIY

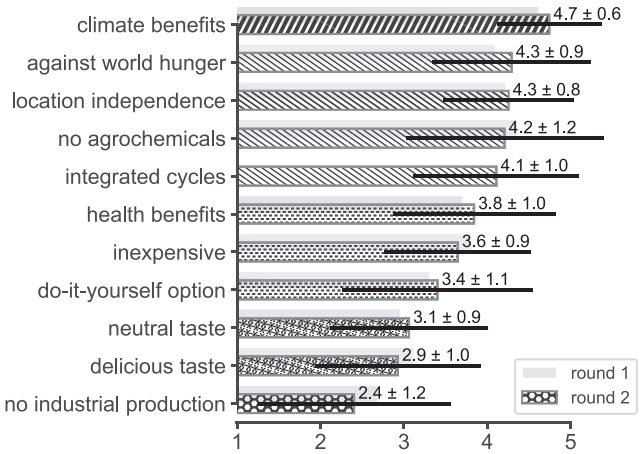


Figure 4. Ranking (MWW) of the different normative projections for the nutrition with microalgae, asked in round 1 (pale colour) and round 2 (strong colour). Mean value as a bar, standard deviation as a line. Different colours indicate significant group differences within each round. Colour changes indicate class upgrade (e.g. health benefits).

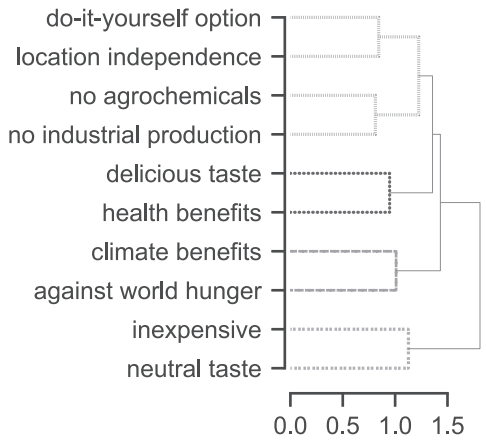


Figure 5. Dendrogram of the complete linkage clustering shows the strongest correlations between aspects in round 1.

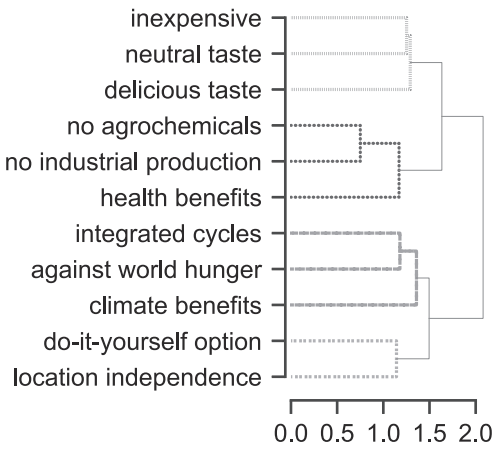


Figure 6. Dendrogram of the complete linkage clustering shows the strongest correlations between aspects in round 2.

production. Naturalness aspects, however, moved from the cluster of self-generation into the vicinity of health products, and cheap, inconspicuous products should also taste very good. Interestingly, delicacy product visions are always associated either with inexpensiveness or health benefits. Moreover, agrochemicals and industrial production do not seem to be in conflict with climate protection and global food supply.

The evaluation of round 1 provided a further framework for the interpretation of cluster data. The clusters can be interpreted as follows:

(1) Health benefits are associated with wellness (1st round) or a non-industrial, non-agrochemical, maybe more natural products (2nd round).
(2) Production for a sustainable world food supply should, in fiction, be integrated into existing cycles as part of a holistic approach.
(3) DIY plants should enable decentralized production. In the first round, these fictional plants were also considered to offer more natural products.
(4) Cheap and unpretentious products should in fiction not be inferior to conventional ones.

At this point, the interpretation continues to refer primarily to the clustering model but gives no instructions on how to imagine a coherent future projection of microalgae technology. Depending on the audience, one would normally highlight aspects and make references to individual life experiences in order to guide the imagination. But the idea of the Delphi study is to structure communication in a way that allows giving feedback with reference to the emerging common ground. The common ground at this stage are the evaluated perspectives and the previously given information on ideas, such as CO_2 emissions and techno-functional properties. In order to compile the empirical material and make it 'a coherent whole' (Morgan 2017: 89) that serves as a 'boundary object' (Star and Griesemer 1989) in the second part of the 2nd round of the Delphi survey, we wrote four equally structured narratives. Together with the clustering results, these narratives represent the field of ambiguous perspectives on future microalgae nutrition.

5.2 Participants' responses to key narratives

The participants of the 2nd round were asked to vote on the desirability and likelihood of occurrence of the four narratives presented and rank the narratives by popularity. In addition, two non-correlated aspects were brought together in the test narrative called 'gourmet food for everyone' to assess the feasibility of our cluster interpretation (see Table 3). In the participants' ranking, this vision should come off worst due to a lack of plausibility of disjointed semantic worlds. Here, the added value of differentiating key narratives from pure ranking aspects is evident: The imaginary fulfilment of several attributions in one scenario does not seem plausible and sounds more like a joke.

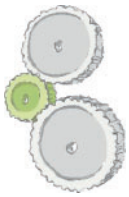
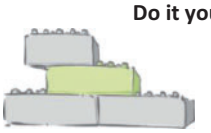
The evaluation (MWW) shows that the sustainability narrative is significantly the most popular with 88 per cent of consent, and the testing narrative, as expected from a definite rank order, significantly the least popular with 28 per cent. The popularity of the other three narratives is around 45 per cent, that is all three share rank two (MWW). The sustainability narrative is also significantly the most desirable one (90 per cent), while it is considered significantly less probable (66 per cent) than the narratives of healthy wellness products (80 per cent) and unpretentious products (76 per cent). Only the do-it-yourself (59 per cent) and the test narratives (57 per cent) are considered even less probable.

The results show that the participants distinguished the meaning of technology via the narratives and had a clear attitude towards desirability, feasibility, and popularity. Surprisingly, the most popular and most desired narrative, 'sustainable nutrition with microalgae', was considered less feasible than the 'health' and 'unpretentious' visions. In the 1st Delphi round, one participant put this dilemma in a nutshell: 'To whom should the microalgae be made accessible? Poor people food or delicacy for rich people?'

6. Discussion and conclusion

In this paper, we postulate that current expenditure and research on microalgae nutrition is driven by public visions of the future, rather than by proven or tenable benefits. The aim of our study was to reveal these visions in a public policy Delphi survey in Germany.[4] The two-round survey showed that the characteristics attributed to microalgae have a different significance for the participants and can be clustered into four ambiguous perspectives, each of them highlighting different challenges and features of microalgae nutrition. On the one hand, participants want microalgae to contribute to a more sustainable world diet, while, on the other hand, they consider microalgae to be more likely used in health products or as an inconspicuous food substitute or techno-functional ingredient. Feeding

Table 3. Narratives derived from the results of the first round of public Delphi survey on food from microalgae, with illustrations (Illustrations cc by Jonathan Wright).

Short name and illustration	Key narrative
 **Inexpensive and unpretentious**	'People have their habits and new foods have a hard time. But microalgae unobtrusively and reliably meet the requirements of established routines and food production. Their neutral taste makes them in many products a cheap ingredient and substitute for soy and animal protein. As a consumer, you will not notice a difference.'
 **Health and wellness**	'In an accelerated society, there is a growing need and desire for a balanced and healthy diet: In addition to meditation and yoga, algae will also be rediscovered in the context of mindful traditions. The ingredients and variety of microalgae promise health and an individual feeling of fitness and satisfaction. Microalgae will contribute to a healthy and enjoyable future.'
Do it yourself 	'A handful of industrial giants control almost all food production—only those who produce themselves are safe from empty promises and the use of synthetic additives. Small, modular algae plants will enable independent, regional self-sufficiency in the future. We share knowledge, recipes, and ideas—microalgae bring back a bit of regionality, independence, and freedom.'
 **Feed and save the world**	'There are currently over 7.5 billion people living on Earth: Either we are cutting our global resource consumption today, or tomorrow we will be forced to do so by the impact of a demolished environment. Microalgae could be the solution: They store CO_2. Their production is possible without arable land and the use of pesticides. Microalgae will be an important pillar of sustainable world nutrition.'
Test narrative: gourmet food for everyone	'Good food is expensive and not everyone can afford this pleasure. This has been the case for a long time. The special protein structure of the microalgae makes it possible to produce novel and better foods. Thanks to algae technology, in the future everyone will be able to enjoy delicious and healthy dishes for little money.'

public visions on microalgae nutrition back into research and development therefore serves as an 'extended peer review' of research objectives and their imagined socio-technical embedding (Funtowicz 2001).

The survey results were aggregated and transformed into key narratives of future imaginaries that serve as boundary objects (Star and Griesemer 1989). Future imaginaries have a strong impact on the design of technology and products since they go beyond the established state-of-the-art. Future imaginaries also form a framework of current technical possibilities and values attributed to this technology (e.g. Lösch et al. 2017). Moreover, such visions can be found in scientific introductory sections, presentations, and business visions which imply values and legitimacy in dealing with the subject—regardless of whether these future projections are entirely scientifically justified. In uncertain situations, the expected reception by others provides a point of reference for one's own expectation, so that public 'expectability' is a possible indication of emerging markets or expected innovation paths (Beckert 2016). From this perspective, the participants' expectations regarding feasibility and realization suggest that the use of microalgae for health and wellness products or as inconspicuous and functional food ingredients is more likely to become economically successful than their use for climate saving technology. In contrast to an anonymous bet on the future, the public discourse emphasizes the possible contribution of microalgae to the common good. This explains why the most desired and popular vision addresses sustainability. The current future projections help stakeholders and scientists tell their story and can be generalized to narrative boundary objects.

Narratives stabilize future imaginaries when actors continuously frame and report their practices and experiences from a certain perspective (Emirbayer and Mische 1998; MacIntyre 2007; White 2012). Narratives represent, so to say, the contexts and goals in which actors relate themselves to their respective socio-technical environment, and sketch up possible networks and contexts for action (ibid.). In order to reveal and distinguish these narratives, we adapted the policy Delphi method as described in Section 3 and systematically 'narrativized' clustered aspects (White 1980; Viehöver 2001). However, the gap between data and aggregated meaning cannot be made completely transparent—a challenge that the argumentative Delphi methods also struggle with (e.g. Seker 2015). A detailed discussion of narrative representation in the field of technology and research policy (e.g. Schwarz 2015; Kovacic and Di Felice 2019) could advance recent debates in philosophy and help clarify the interplay of narratives, make-believes, and scientific facts in

future visions (e.g. Currie 2012; Toon 2014; Frigg and Nguyen 2016; Kind 2016). This study instead focused on how key narratives are empirically reconstructed with an adaptation of the disaggregative policy Delphi (Tapio 2003). Based on our results, novel collaborations are conceivable, for example if actors in the wellness and health sector, the environment movement, or the Makers and DIY scenes were to follow adaptations of the key narratives. The key narratives are therefore useful to (1) represent the clustered attributions to technology in a reportable, coherent, and extendable way; (2) make the ambiguous perspectives on the future distinguishable; and (3) determine the valence of perspectives that show possible ways of getting involved. Key narratives are therefore a meaningful outcome of a Delphi study to explore the contested present futures.

In a conventional Delphi study for scenario or policy development, key narratives would have to be enriched and concretized by means of regional, local, and technical props in order to look into the future. In the case of microalgae, we do not only show that there is a general trend towards microalgae nutrition but also that there are ambiguous visions. Further studies on 'futures in action' could take the key narratives as a starting point for long-term monitoring surveys, analyses of narrative self-descriptions, or ethnographic methods (Mische 2014). We expect changes of intended aims and fields of application because their plausibility depends on temporal–local circumstances such as ignorance, present knowledge, interests, and power. Science communication can take up the key narratives in order to systematically address convictions in public discourse, summarize 'key issues and concepts simply, quickly and effectively' (Davidson 2017: 3) and critically correct or underline the proposed story with scientific evidence. The clear benefit of key narratives for policy studies and technology assessment (Grunwald 2019) is that they help classify and integrate current developments and public imaginaries, which then easily allows for switching perspectives. In summary, the study shows that the Delphi method is not only suitable to look *into the future* but also for empirical research of present *perspectives on the future* that help distinguish and hone cognitive interest of policy makers and researchers.

Supplementary data

Supplementary data are available at *Science and Public Policy* online.

Conflict of interest statement. None declared.

Notes

1. Brown (2000) makes a distinction between looking 'into the future' and looking 'at contested futures'. Similarily, Luhmann (1976) distinguishes between the study of 'present futures' and the prognosis of a 'future present'. Our research interest is in the description and analysis of present contested futures.
2. A cluster algorithm is a transparent set of rules for ordering correlated or similar perspectives and distinguishing clusters following specified conditions. Especially with a large number of participants, a computational algorithm is a scalable and transparent tool to reduce the variances to a set of about, for example four distinct perspectives.
3. Since the data are not normally distributed and left-skewed, a Wilcoxon–Mann–Whitney test (MWW) is used to distinguish different groups for ranking the elements sorted by consent—rejecting the null hypothesis that there is no significant difference in consent with $P < 0.05$. The MWW serves in the whole evaluation to distinguish insignificant from significant differences in consent distributions, that is rank differences in consent. Spearman correlation ($P < 0.05$) is used to assess general correlations.
4. Malone et al. (2017) showed that technology narratives differ depending on the national context—the results observed on microalgae should therefore be mainly seen as German visions of the future. Moreover, since the survey demographics are not representative for Germany, you could rather speak of interested multipliers or trendsetters in this field. On the other hand, this may rather dramatize the assessment that the use of microalgae for health products is considered more likely than that for sustainability products.

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Vision as make-believe: how narratives and models represent sociotechnical futures

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ABSTRACT

When prominent experiments, simulations, and prototypes fail, sociotechnical futures become contested. This paper discusses the negotiation of visions as make-believe to give the considered feasibility of future narratives a more significant account in explaining innovation dynamics. Following Kendall Walton's theory of representational arts, I propose that imagined futures depend on both material and socio-cultural constraints. On the one hand, the considered data, models, and artifacts give make-believe futures a veto right and a certain kind of objectivity. On the other hand, sociotechnical imaginaries prompt promissory considerations and implications. The contingency of employed objects allows accounting responsibility for fictional truths to imagining subjects. Drawing from a scenario workshop on microalgae nutrition, I demonstrate how stakeholders use uncertain props and imaginaries to negotiate the ambiguous boundaries for the assessment of the unproven technology. I argue that the non-fixity of both authorized sources and promissory narratives explains the uncertainty of innovation dynamics.

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Make-believe; science and technology studies; sociotechnical imaginaries; microalgae; technology assessment

Introduction

Imagined futures are the driving force of the present as they represent promissory pathways for action. Although the future is uncertain, stakeholders disclose details in various economic, political, and scientific contexts to justify the present actions accordingly. As such, the boundaries of what is considered sociotechnically debatable, feasible, and desirable emerge at different sites and phases of technology development. However, people differentiate between realistic future projections, such as climate change or prognoses regarding the current Covid-19 pandemic, and less realistic imagined futures and give them different relevance in politics, economy, and their aspired life course and actions. Likewise, considered feasibility according to models, simulations, and prototypes makes a difference for the assessment and motivational power of sociotechnical futures. In this paper, I argue that the consideration of such representational objects can alter imagined futures and affect their motivational power and dissemination.

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The concept of 'present [imagined] futures,' a concept coined by Luhmann (1976), became a hot topic in sociology and science and technology studies (STS). In particular, the prominent critique of the linear innovation model incites to disclose the social construction of conditionalities in the co-production and design of technologies (MacKenzie and Wajcman 2010). Emerging technology does not merely follow disinterested studies and material constraints, which automatically leads to social benefits. Instead, sociotechnical imaginaries and networks of politicians, investors, and researchers alike shape research and development as well as attainable values, even at early stages (Brown, Rappert, and Webster 2016; Jasanoff and Kim 2013). The theoretical approaches, however, assign different importance to the sociotechnical practices and imaginaries explaining the constraints of emerging technologies. Within this gap of the discursive realm and the situational/material realm of actors, I consider the generation of futures as make-believe. Therefore, I introduce Kendall Walton's make-believe theory of representational arts into the analysis of imagined futures and illustrate the concept at the example of a stakeholder workshop about the futures of microalgae nutrition. Finally, I discuss how this concept explains the dynamics of imagined futures and opens novel perspectives for empirical research.

Social imagination between the material and the social realm

In sociology, there are not only theories that give priority to objects and actor networks in practice, but also theories that give priority to discourse to explain the emergence and impact of imagined futures. In the course of the linguistic turn, social sciences focused on the semantical conditions to form accepted propositions about the future. Of central importance is Charles Taylor's concept of social imaginaries, or 'the way ordinary people "imagine" their social surroundings, and this is often not expressed in theoretical terms, it is carried in images, stories, legends, etc. [, to make] possible common practices, and a widely shared sense of legitimacy' (Taylor 2007, 171–172). Since social imaginaries are 'a-theoretical' (Binder 2019, 21), they reach a broad public beyond specific debates in economics, science, or politics. In STS, Jasanoff and Kim (2009, 123) derived the now well-established concept of sociotechnical imaginaries 'in the reservoir of norms and discourses, metaphors and cultural meanings.' Sociotechnical imaginaries are 'collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects' (Jasanoff and Kim 2009, 120). Examples of sociotechnical imaginaries are 'Containing the (American) Atom [for peace]' vs. 'Atoms for [South Korean] National Development' (Jasanoff and Kim 2009, 126–132), 'The USA is a technical powerhouse' (Hilgartner 2015, 36), 'sustainable growth' (Strand et al. 2018, 1851), 'digitization as the driver for a new industrial revolution,' or 'unbounded benefits while risks are limited and manageable' (Jasanoff and Kim 2013, 190). In the concept of sociotechnical imaginaries, one could narrow down 'almost anything' to the available cultural frames. The concept of sociotechnical imaginaries explains how semantic structures shape the social construction of technology.

However, if one acknowledges that social imagination and the constitution of a group are performative efforts with uncertain success, social imaginaries hardly explain motivation or collective action (Hilgartner 2015, 35). In the course of the new materialism and the practical turn, social sciences opened up to study the co-production of meaning in

actor networks and the situated condition of knowledge (see Haraway 1988; Jasanoff 2010; Latour 1996). In particular, the Actor-Network Theory (ANT) opened up the study of sociotechnical conditionalities of knowledge and technology in constellations. Karin Knorr-Cetina (2001, 182) argues that objects do not only stand for something else, but enable meaning-generating practices. Her laboratory studies show that the generation of scientific evidence and meaning involves material confrontation. Therefore, the situational and phenomenological experience in practical constellations is another potential source of imagined futures, besides the discourses about the future. However, these perspectives consider the socio-historical dimension, power constellations, and functional differentiation with symbols to distinguish, for example, economic and scientific communication from a science fiction story as secondary.

A symmetrical account of the social and material realms finds the present meaning and meaning generation of objects being given by both discourse and local practices with the resistant characteristics of material objects. Sheila Jasanoff (2010, 3) sees 'co-production […] as a critique of the realist ideology that persistently separates the domains of nature, facts, objectivity, reason and policy from those of culture, values, subjectivity, emotion and politics.' However, abandoning this predominant distinction of a considered 'real world' would mean a loss of analytical rigor regarding social power structures and assigned feasibility of imagined futures. If no characteristics of the object play a role, then drinking something very bitter would equally suit to represent enjoyment or healing. It might be conceivable if someone does not believe that it tastes bitter, but this is practically difficult to bear in the long run when the future projection motivates drinking it. The material realm, i.e. what imagining subjects believe about their factual environment, influences how people imagine and act concerning the future. This practice allows them to learn about their environment, e.g. that the drink is bitter or drinking it is not suitable to represent pleasure. A comparison of history and imagined futures aims to illustrate this relationship.

Hayden White stated that narrated history is more than a list of historical data and follows socio-cultural narrative structures and present needs of their narrators (White 1980). Reinhard Koselleck (Koselleck 2007, 71) observes the prevalence of realism in forms of a 'veto right of the sources' against the potential arbitrariness of narrated history. However, contesting or abandoning historical sources alters not only the immediate surroundings, but also the structure of narrated history (Weberman 1997). Armin Grunwald (2013) makes a similar distinction with regard to the scientific validity of non-arbitrary future projections. Imagining the future based on conditional sources, for example, an official weather forecast or local data about the progression of a pandemic, makes it more plausible. When such models or parameters change, the imagined future is contested. Other authors distinguish, for example, more or less realistic scenarios or a realistic range in the scenario funnel to indicate the deviation of an assumed trend line (Kahn 1965; Kosow et al. 2008; Reibnitz 1991). The materially ascribed 'realism' of future projections also has a half-life until new data replaces them. Therefore, I propose that considered prototypes, simulations, models, and data practically have a similar 'veto right' to enforce and contest imagined futures. Both present past and imagined futures build on a 'non-fixity' of considered material sources, i.e. 'ingredients' or 'skeleton,' and socio-cultural templates for their 'composition' (Grunwald 2013; Weberman 1997). On the one hand, the 'veto right of the sources' makes future narratives more

plausible than mere daydreaming. On the other hand, the authorization, situation, and availability of these sources are uncertain, as prominent experiments, simulations, and prototypes can fail or be ousted. Therefore, this paper suggests an approach to research uncertain futures that is not only based on the study of socio-cultural frames, discourse, and imaginaries, but also on the material situation. In this pursuit, I suggest using Kendall Walton's concept of the games of make-believe.

Visions as make-believe

With 'Mimesis as Make-Believe,' Kendall Walton (1990) developed a theory of representative arts widely recognized in philosophy. To explain how fictional works such as novels, paintings, and plays represent and evoke emotions or even motivate action, Walton compares them with props in children's games of make-believe. The discourse about scientific representation applied the concept in different accounts outside the analytical aesthetics and philosophy of imagination (Currie 2016; Frigg 2010; Toon 2014). Jens Beckert (2016, 66–68) was the first to introduce this approach to the social science discourse on imagined futures to explain the role of props, such as a lottery ticket or business plan, 'to stimulate the imagination of fictional worlds.' The person holding the lottery ticket makes believe becoming a millionaire. However, the date printed on it makes the imagination materially/situationally dependent if the rules for generating the game consider them. Make-believe is a suitable concept for the co-production of powerful futures because it defines fiction, not ontologically, but generated in a practice that symmetrically includes characteristics of the material and social realm. As long as people use objects as props in promissory games of make-believe, these objects are of particular interest for economic valuation, political consideration, and the epistemic assessment of situated knowledge.

Make-believe is best explained using the analogy of a children's game in the forest (Walton 1990, 23). The game of make-believe is based on the shared rule that tree stumps are bears (principle of generation). As the children stroll through the forest, they expect, according to their rule, that bears are lurking. Just as tree stumps, the bears are of different sizes and sometimes appear in groups. This follows as an indirect fictional truth from the situational phenomena in the forest and the applied game rules. The children know from stories that bears are dangerous. In the game, they experience fear and fright when an overlooked bear suddenly appears beside them, and they are relieved when a supposed bear turns out to be a 'false alarm' (Walton 1990, 37). They gain fictional beliefs about where bears are and how they react when faced with a group of large bears. They experience situations by interacting with their environment and following the common principles of generating the game.

Make-believe is not a solitary practice because it is not the individual actor who decides what a bear is, but the joint application of rules. The generation of meaning results from both social conventions and situational/material characteristics of the environment. The practice has consequences not only for the bodies or objects, but also for the social actors involved. The actors share experiences and memories about themselves as individuals and as a collective in the game of make-believe. In this symmetrical relationship of the sociotechnical constitution and the feedback of make-believe practices (Figure 1), I find the emergence of social facts and the dynamics of imagined futures.

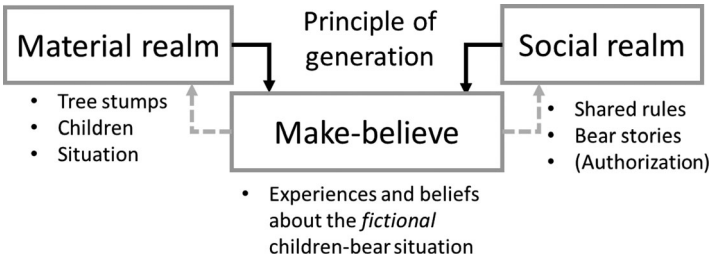

Figure 1. The children's game of make-believe according to the principle 'tree stumps are bears' is exemplified in its condition and feedback to the social and material realm.

Representations as props in games of make-believe

Make-believe is not a solitary practice like daydreaming, but a social practice of generating a game in which other things are considered true than outside the game.[1] Truth-according-to-the-representation follows the principle of generation by instructing what is to be imagined under which circumstances (Walton 1990, 40). Representations are things with the function of serving as props in games of make-believe (Walton 1990, 105). Neither the properties of an object nor the intentions of speakers generate a make-believe game. Instead, objects become representations by being treated as such in practice (Walton 1990, 70–105). Books, music, and pictures are not only regarded as individual delights, but invite people to talk and pursue the fictional worlds in the form of make-believe. What is written in a book counts as *true-according-to-the-book*,[2] just as a narrated story is considered *true-according-to-the-narrator*. In the subsequent communication and practices, certain things are considered set, just as children use dolls or toy cars in games that enable them to distinguish between appropriate and inappropriate actions. The objects are part of the world, but how the truth *according-to-a-representation* relates to claims without make-believe reference is unmarked and can even accidentally turn out to be true or false. Herein lies a crucial point: The principle of generation instructs what the props instruct in the imaginative activities so that one can distinguish between *truth-according-to-given-instructions-for-the-imagination* and *truth-according-to-someone's-individual-imagination* (Walton 1990, 67). Imagining futures likewise involves prototypes, studies, data, and expertise to reinforce the sociotechnical feasibility. However, they base imagined futures on uncertain facts in the material and social realm.

The generated worlds only according to the props would be relatively 'empty' if they were based only on direct principles of generation. In the example given at the beginning, it must be clear that, according to the knowledge of the children, bears have certain characteristics and so one has to be afraid of them. To make clear what is obviously to be represented, Walton distinguishes the direct principle of generation and the indirect principle of generation, or rather, the principle of implication (Walton 1990, 144). Direct principles, such as 'stumps are bears,' ensure that participants consider the same props to the extent that they play the same game together. The indirect principles depend on other fictional truths in the game, following the direct principles (Walton 1990, 143). Indirect principles are further instructions for the imagination resulting from the direct

principles, such as that, for example, bears in the forest have large teeth, claws, and are hungry. That bears appear in groups could even be a discovery of the children. Walton attributes a 'complicated and shifting and often competing array of understandings, precedents, local conventions, saliences' to the second principle of generation (Walton 1990, 169). Therefore, I locate the indirect principle in the social realm. What follows implicitly for the imagination is materially and socially determined. In the STS, this perspective coincides with the concept of 'situated knowledges' (Haraway 1988) and the sociotechnical emergence of visions (Schneider and Lösch 2018; Schneider, Roßmann, and Lösch 2020) (Figure 2).

The principle of implication is of major interest because 'imaginings induce actions only in conjunction with beliefs about the environment of the imagining subject' (Schellenberg 2013, 497). Walton distinguishes between the reality principle (RP) and the mutual belief principle (MBP) (Walton 1990, 164). For the former (RP), unless otherwise stated, the same applies to the game as to common sense and perceived reality so that, for example, historical novels of fictional futures can represent old stories in the world of a present future. For example, the old vision of feeding on the unexplored wealth of the oceans then meets high-tech and science in the context of present ideas of reality. For the latter (MBP), you consider possible outdated beliefs and the intentions of the author's society as the basis for the imagination (Walton 1990, 158). In such a game, one would, for example, draw on beliefs about the historical state of research to learn not about the current techno-economic possibilities of microalgae nutrition, but about historical possibilities. However, you can only build any game according to the MBP on the basis of your best knowledge about the perspective, or, respectively, the present discourse about the author's society. Besides, Walton points out that you cannot break down the diversity of known myths and legends that give further implications. Many official games presuppose 'familiarity with the medium, genre, and representational tradition,' which are not covered by either MBP or RP (Walton 1990, 184). Thus, Walton emphasizes that fictionality is not *defined* by the principles of generation, but rather consists of prescriptions to imagine (Walton 1990, 166–185). This clearly defines make-believe as socio-culturally embedded practice (Friend 2008; Walton 1990, 104). For the social sciences, this means that they can empirically study, for example, the disciplinary or transdisciplinary implications considered adequate by the participants, or, respectively, their socio-cultural backgrounds, by keeping the direct principle of generation invariant.

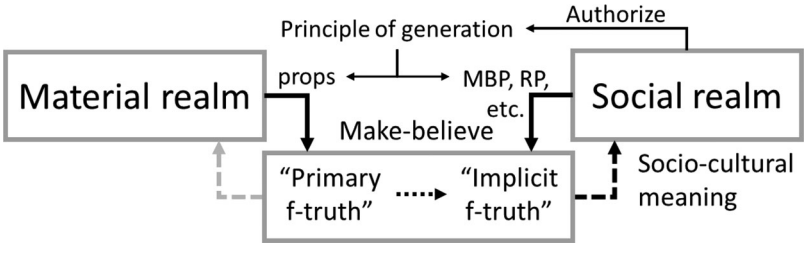

Figure 2. Make-believe of primary truth and implicit truth in fiction according to props and the principle of implication

Limitation of make-believe: matching, suiting, and authorized games

A key factor in the social embedding of make-believe games is their authorization. A game is authorized when it generates acknowledged features of an imagined object. A doll obviously represents a baby in children's games and novels represent certain adventures. However, the aforementioned unofficial game with the tree stumps requires explicit instruction, although it might be easy to understand (Walton 1990, 406–407). By distinguishing between authorized and unofficial games, Walton finds the cultural-related recognition of representations (Walton 1990, 104, 406). He gives the example of a weather map, where the position of the sun indicates where to imagine sunshine at what time (Walton 1990, 331). The imagination does not visually depict the weather map and yet it is clear how the game works and how it appeals to phenomenological experiences with sunny or rainy weather. Of course, you can also make believe about the future using historical weather charts or unauthorized forecasting models. However, these games would require further instructions for projecting a future target system, and people would not ascribe the same 'ontological force' or 'veto right of the sources' as to an official game. The distinction between authorized representations makes it possible to analyze socio-cultural scopes of contested futures. At different sites, different objects represent imagined futures, and in some sites, as I propose, imagined futures are unspecific sociotechnical imaginaries without official representation.

Models that fall in line with public narratives or sociotechnical imaginaries are more likely to count as props in authorized games. However, in our society, science is an institution that, in many cases, decides on the authorization and validity of future representations (see Grunwald 2013). Authorization of a game does not imply that the imagined object perfectly matches beliefs of the imagining subjects (Figure 3). A work may represent something it does not match in detail, or match something it does not represent (Walton 1990, 108). A painting, for example, can represent Napoleon, but it can be wrong in matching or 'misrepresent' his body size (ibid.). This fact becomes obvious when beliefs about Napoleon, for example, based on another source, do not correspond to the actual prop-based instructions for the imagination. A novel about Napoleon, on the other hand, might match the life path of someone else, but officially, it does not represent it (Walton 1990, 128). One could, however, propose a game of make-believe, in which the novel counts as a representation of another person and determine how well it matches. In the same way, one could propose a historical weather chart to represent

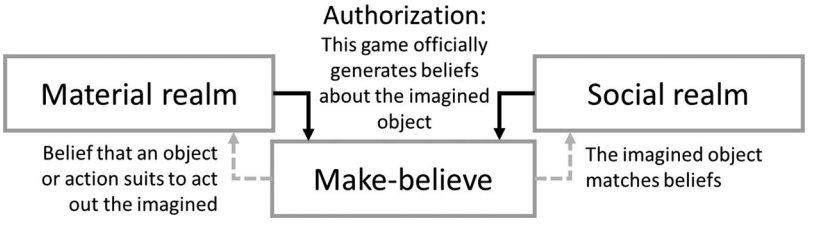

Figure 3. Authorized games officially generate beliefs about the imagined object. Make-believe can incorporate beliefs about the environment of the imagining subject, namely about the imagined object and suitability of objects or action to act out the imagined (see Schellenberg 2013).

future weather. Whether they match or not, both objects would not be official representations of another person or of tomorrow's weather, unless the games are authorized. Nevertheless, one can learn from them by drawing inferences from projected beliefs in the model-world comparison (see Salis 2016; Schellenberg 2013).

In practical contexts, a game of make-believe has an evaluative element regarding suitability. One could claim that the aforementioned book or model does not only misrepresent, but is even unsuitable to represent the person or weather, respectively. Walton explains suitability using the example of a pirate game, in which not climbing a tree is supposed to fictionally count as climbing a mast, but crawling through a tunnel or eating watermelon (Walton 1990, 238–239). He notes that these props are not equally suitable, if at all. He later concludes that narratives are not suitable for visual games (Walton 1990, 301). Similarly, both visual models and functional models only suit their particular application purposes. It depends on the contextual requirement whether eating melon suits fictionally climbing the mast or crumbling sand cake suits fictionally eating a cake. People believe or find out whether an object or action suits to act out the imagined (Figure 3). From a pragmatist perspective, one can observe that a model is suitable when it makes a move in the practical context, for example, in conversation about the feasibility of a project or by assigning a new value to the prop. As with William Labov's (1972, 366) evaluative element of narratives, a narration is worth telling, and similarly, employed props are suitable, when the audience does not merely respond 'so what?' but rather 'he did?' (ibid.) or any other evaluative statement indicating immersive inference with pre-existing beliefs and desires.

As mentioned above, Walton's theory is applied in philosophical aesthetics and philosophy of science. However, examples from the existing literature are rather distant from empirical studies on imagined futures. Therefore, the following sections examine a stakeholder workshop from the perspective of make-believe and discuss the concept's suitability for empirical studies and implications for subsequent research.

Stakeholder workshop on key-narratives of microalgae nutrition

This section of the paper gives an insight into the contested futures of microalgae nutrition. It applies the make-believe concept to a stakeholder workshop to illustrate the understanding of communication about the future. It should emphasize that the motivational power of visions fosters fictional concretization of their feasibility using different representations that generate beliefs about both the imagined future technology and suitability of representations. The history of technology development for microalgae nutrition goes back to the 1950s. There are many studies about the potentials of microalgae, but the actual benefits of microalgae remain obscure (Böhm and Dörge 1959; Meffert and Stratmann 1953; Ploeger 2011; Rösch and Posten 2012). Kean Birch prominently criticized that bioeconomy research, which, among others, includes microalgae research, is strongly driven by uncertain future projections (Birch 2017). The value of present research builds on practices that turn expertise, simulations, and prototypes into assets. Stimulation of future expectations and 'management of sentiments' thus became the central goal of various actors within and outside of science. Nevertheless, research agendas at the European, national, and regional levels and various stakeholders strive to research and develop technologies for microalgae nutrition (Enzing et al. 2014;

Lewandowski et al. 2019). The research goals formulated therein are optimistic and multifaceted.

The workshop about 'Key-narratives on microalgae as food' took place on 5 September, 2018 at the Food 2030 Conference in Hohenheim. It is the second part of a TA study on nutrition with microalgae, which first analyzed public perception and then asked experts to evaluate these visions. Four scientists from engineering, natural, and social sciences, two students, and three stakeholders from the public and industry participated in the workshop. The workshop applied the classic scenario method to analyze and assess technical limitations, knowledge gaps, or exaggerated public expectations to give recommendations to decision-makers in science, economy, and politics (University of Hohenheim 2018). By definition, scenarios are stories that draw attention to present options for decision making: '[Scenarios] are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points' (Kahn and Wiener 1967, 6). Thus, scenarios differ from forecasts and explicitly do not claim to be true, but to be useful for different purposes.

Since reference to fiction presupposes its generation, I asked participants of the workshop to imagine nutrition with microalgae according to four key-narratives[3] that distinguish visions as coherent wholes. The narratives drew the participants' attention to connecting distant and heterogeneous elements and contextualized an imagined technology as salvation by making their characteristics appear necessary to achieve social value. Each of the narratives (55–65 words, see Annex) represents a crucial and valuable food challenge that microalgae technology is supposed to overcome, described in different scenarios: 'Sustainability,' 'Do-it-yourself (DIY),' 'Cheap and inconspicuous,' and 'Health and wellness.' At the same time, precise details, such as price, scale, or process, are left open. In the next step, I asked the nine workshop participants to discuss the feasibility of each visionary narrative based on their technical know-how, market knowledge, and insights into current political and legal discussions to foster the shared imagination. The entire discussion lasted 77 minutes and was recorded and transcribed by a third party. In terms of make-believe, the workshop aimed to generate and explore games of make-believe based on four key-narratives to reveal how the future narratives translate into contested games of make-believe (Figure 4). Since theoretical conceptions of visions as make-believe were completed after the workshop, the transcripts do not intend to validate, but to illustrate the application of make-believe to study imaginary

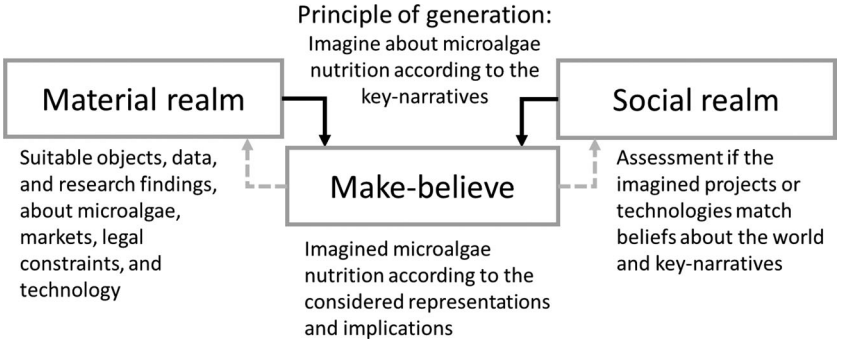

Figure 4. Stakeholder workshop on visions of microalgae nutrition in terms of make-believe.

futures. The subsequent discussion elaborates on limits and further empirical and theoretical perspectives.

Concretization and representation of microalgae and technology

The participants shared their expertise and associated it with the narratives to identify challenges and assess their feasibility. Research objects were selected from various alternatives and found to be suitable for the imagination. For the sustainability vision, for example, 'no heterotrophic microalgae' (Scientist 2) and 'a simple open pond' (Scientist 4) were considered as the biological and technical objects that can be imagined because they are simple and require the least material. Based on objects considered suitable, the participants further explored how the technology matches the sociotechnical vision according to the narrative. Below you will find excerpts from the workshop on how the participants discussed concretizations and major challenges of the narratives for the fictional realization. With these remarks, the participants further instructed themselves to follow a joint imagination. They represent socio-cultural implications for the game that were not directly represented by instructing key-narratives (see Annex):

Cheap and inconspicuous

> So, if I get it right, the end-use product, we actually don't say it's algae. So, we just add it because of some property we want the food to have. (Scientist 1)
>
> I think that's the biggest question: if we can compete with soy and corn. (Student 2)

Health and wellness

> You cannot talk about the health benefits because this is on the regulation of EFSA, so it will be hard to transport the message. (Industry 1)

Do-it-yourself

> So, everyone has their own little bio-reactor in their garden and frequently just gets a liter of microalgae soup, and then you just dry it … , and then that's it. (Scientist 2)
> Or maybe an old vision, it's like the old village bakery house where everyone in the village comes together. (Scientist 4)
> I would say it's quite risky … (Scientist 2)

Sustainably feed the world

> I think it's the carbon dioxide storage, we're always looking for. (Student 2)
> We have to produce very cheap to feed everyone … when we have a great investor […], then the price is not the focus. (Scientist 4)
> Using diluted hydrogen peroxide … you don't need antibiotics or pesticides or whatever. (Industry 1)

Although the key-narratives mentioned neither the color nor the taste of algae, the participants considered these attributes important for deriving further implications. The participants imagined about microalgae and derived characteristics from their

experiments and insights. Interestingly, the characteristics of microalgae were considered differently depending on the framework of each narrative: Extractions, heterotrophic stems, or masking make microalgae feasible convenience products, while the troublesome green color counted as a positive feature for a health product:

> [You can make] use of additives to mask the taste … but then you have maybe even more ingredients as you had before. (Industry 2)

> Right now only heterotrophic culture can be neutral in taste. (Scientist 2)

> People maybe also accept the taste maybe if you say it's healthy. (Student 1)

> And green now is a color attuned to the health. This was different also 15 years ago. (Industry 1)

> … the color could be a benefit […], and we can also sell the product with a higher price because the consumers are in a higher class. (Scientist 4)

The following two cases show how the participants ambiguously resort to different objects to meet the imagined challenges.

Case 1: animal feed to mask the taste or to use cheaper feedstocks

The feeding of microalgae seems to be a process that is suitable for different games of make-believe, as it matches the required characteristics according to the narratives in different ways. The participants imagined feeding algae in the first instance as a way to 'mask' the bitter and fishy taste of unprocessed microalgae for cheap convenience products. Interestingly, they also considered feeding microalgae in other visions; however, for different reasons. In the sustainability vision, the feeding should enable the use of wastewater, in the do-it-yourself vision to dispense with complex downstream processes at home and to better integrate into food and cooking habits:

> If you use your wastewater from your community to grow microalgae to feed it to … fish or whatever, chicken, then it could work in a sustainable way. (Industry 1)

> I was also thinking about just kind of the integrated production systems for aquaponics … And the fish taste better than algae. (Student 2)

The participants exemplified the imagined features to reinforce the feasibility of masking algae taste for the do-it-yourself visions or using purified wastewater as a cheap nutrient supplier in the sustainability vision. What is more, fictionally valuable properties were found, as the social imagination turns closer to feeding mice and chickens with algae:

> I know that mice are doing fine on 25. I would even guess that if you gave them 50%, it would be okay because they have all they need in the algae. (Scientist 2)

> There was a study with chickens where they showed that the yellow of the egg gets more color if you feed algae, and I think they did 5% or 10%. It was quite high, so it was not like we pull in like 0.1 g/kilo. (Scientist 4)

> But that's not only because of the coloring in eggs; it's also because you can increase the content of nutrients and for fatty acids. (Industry 1)

> And then you can say omega-3 rich eggs. (Scientist 2)

> That's already on the market in some cities. (Industry 1)

Case 2: prototyping against contamination claims reveals new lifeworld visions

The openness to incorporate props into the game of make-believe became particularly visible when the do-it-yourself vision was first considered as too risky, until 'surprisingly' a prototype was mentioned that represented ways to solve the challenge of contamination:

> I would think that's quite risky. Whatever you cultivate, maybe then you get one of either cyanobacteria or [?], and [kaput sound]. (Scientist 2)
>
> Or just lower bacteria. (Scientist 1)
>
> But the funny thing is we are working exactly on this right now, and a prototype is ready. […] It's just a few liters. It looks not like a microwave, more like a coffee or espresso machine. (Industry 1)

The participants showed tremendous enthusiasm, since they had not expected a prototype. We had a break from the schedule to look at the photos and discuss further details, such as the aging of algae cultures, experiences with algae harvesting, and quality control. Although the existence of a prototype does not count as a scientific report or proof of function, the representation was suitable to imagine the system's integration into a household:

> You could also use this to lighten your TV, so you just do an algae course around your TV, and then you just pump it through. (Scientist 2)
>
> In the lounge. (Scientist 1)
>
> And you use the light to grow your algae, but then, of course, it looks also very beautiful. (Scientist 2)
>
> And then the algae grow, and maybe after one week, you can change it.
>
> […] and dry and press the patty. (Scientist 4)
>
> Gibt es denn schon einen Preis? [transl.: Do you already have a price?] (Public 1).

The participants explored implications, discussed the matching, and faced new challenges in finding solutions. The convincing argument of the prototype, as well as that of the feeding studies, does not merely lie in the characterization of specific process variables, but in the ascribed suitability of photos and narration to supplement imagined process steps of functional models in a vivid and visual game (see theory section, above). However, since the prototype counted as the only prop to represent the feasibility and design ideas of a home-brew microalgae system, a failure of the prototyping process would hardly contest the fictional vision of microalgae nutrition for do-it-yourself purpose. Prototypes that match imagined futures are valuable props and of common interest to vanguards of the DIY vision. In other words, the prototype's authorization to officially represent visions of 'do-it-yourself' microalgae nutrition would make it a political and economic asset. However, the more a particular prototype officially represents an imagined future, the more a failure of the prototyping would theoretically contest the imagined future.

Contested futures of microalgae nutrition: how visions evolve at the limits of feasibility

Besides technology, present economic and legal boundaries represented challenges in all four debates. A dynamic of contested representations became visible, since fictional boundary conditions were considered irresolvable. The insistence on the limits of feasibility revealed a mismatch with the given narratives. With regard to the example of cheap and inconspicuous food with microalgae ingredients, the participants found reasons to compete economically with soy products despite a higher price per gram and because of the advantages of the absence of soy:

> [The soy market is] huge, it's huge. Very huge. (All)

> You can sell it for a higher price, because … you just need to add 1% of the extract to get the functionality you want. (Scientist 1)

> I would even say it makes sense to substitute soy protein with algae protein because soy is known for having very high levels of phytoestrogens. (Scientist 1)

When people talk about microalgae-based food in public, they imagine higher algae contents and larger quantities. However, the considered representations made the workshop participants conclude that a feasible soy substitute either requires much cheaper production costs or that the phytoestrogens of soy justify a higher price. They diminished the visionary promise of low-cost mass production of microalgae food to a smaller, but still important segment. In this case, make-believe using further objects contested the official understanding and revealed a viable scenario between the 'health' and the 'cheap and inconspicuous' food narratives.

The considered representations and beliefs also contested and developed the other microalgae narratives. The experts acknowledged that the European Food Safety Authority (EFSA) sets the regulatory framework for health benefits. They even subordinated their scientific efforts to promote the success of microalgae to these constraints, according to the present legal framework:

> You cannot talk about the health benefits because this is on the regulation of EFSA, so it will be hard to transport the message. That is why […] products in the healthy lifestyle segment [… are] just plain algae. (Industry 1)

> We need to work on a substantiation paper to apply for a new claim, but that will take time. (Industry 2)

> If you can just label the actual ingredients [… and] the product is high in protein […], that is all you have to say. (Student 2)

> I think when you're focused on the promises on the healthiness of this product, in your company you have to focus on marketing and less on studies. (Scientist 4)

With the proposal to submit a substantiation paper, an alternative representation of the legal framework was proposed, which, however, does not match the time frame. Instead of changing the considered legal or technological framework, the participants imagined consumers to believe in the health benefits of microalgae even without officially authorized health claims. They also consider a market for advertised health products without official labeling of their effectiveness as possible. One could attribute this either to

common sense or to a socio-cultural imaginary of successful wellness products lacking scientific evidence. Due to the considered constraints, the vision of microalgae for health benefits tends to develop into a vision of wellness products. The imagined boundaries resisted the call for a substantiation paper to overcome them.

Just like the promised health benefits, also the promised autonomy was understood as a consumer demand to be satisfied. The imagined do-it-yourself plants did not meet the promised independence and self-supply; they only promoted the joy of homemade products:

> […] would you be really self-sufficient with a little tank? (Student 1)

> At least they get some homemade vegetables as if you get your jam from your grandmother […] I would like it, especially because it's homemade. (Scientist 4)

The participants abandoned the vision of greater autonomy from leading companies through standalone plants for the visions of producing and sharing homemade products. In both cases, the represented technologies contradict the promises of the narratives. Nevertheless, the participants considered the given narratives to advertise and highlight characteristics of the future microalgae products that imaginary consumers can imagine.

In the sustainability vision, however, the current microalgae technology was successful under fictional market conditions that were different from the actual ones. Hence, societal boundaries differed in fiction in favor of dealing with the challenge of the plot. By locating the vision in a later future, the participants abandoned economic constraints, so that the narrative of sustainable world nutrition seemed plausible:

> But then imagine agricultural land going down because of droughts and whatever we see right now … we would reach that point, and then the price doesn't matter because you need something to eat, and you will pay for it. (Scientist 2)

> The prices will also change for other products. We are facing, for instance, also peak phosphate. (Industry 1)

However, this is interesting because popular sustainability narratives, such as Silent Spring (1962), Limits to Growth (1972), or Soylent Green (1973), already propose systemic dependencies and threatening catastrophes that need to be averted. Structurally, sustainability narratives are closing future projections that give only limited space to deliberate design and action since preventing the catastrophe is the main goal of the action (Koschorke 2019; Mische 2009, 700). The niche in which the characteristics of future technology prove to be significant is rather restricted. However, participants did not imagine microalgae technology to prevent such a catastrophe early in time, but placed it as a successful technology at a time of advancing, but livable arranged apocalypse. Thus, under the considered circumstances, the technology is not suitable for initiating the desired turning point in the sustainability plot, but finds a niche within a rather post-apocalyptic, capitalist variation.

In summary, the analysis of the workshop shows how the participants, starting from the key-narratives, have made references to models, experiments, prototypes, and studies that seriously challenge an optimistic future of microalgae nutrition. Instead of imagining visions that would present microalgae technology as a safe solution to global challenges, the stakeholders pointed out their challenges and their reasonable doubts about

the feasibility of the visionary promises. The participants engaged in a game of make-believe that projected practical limitations instead of just selling a promising story. They are, nevertheless, aware of the importance of public imaginaries when sociotechnical limits stand in the way of the realization of unspecified visions.

Discussion

The study cannot test the make-believe concept, but it illustrates the make-believe perspective on anticipatory practices in technology development and assessment. This paper emphasizes that the generation of imagined futures equally depend on social and material constraints. Following Kendall Walton's make-believe theory, I compared the generation of present futures with the generation of the present past. I maintain that the generation and success of imagined futures equally depend on the material and social realm (Figure 5). Visionaries invoke sociotechnical imaginaries and mobilize props to reinforce, contest, and shape imagined futures. Studies on experiments, prototypes, and recognized institutions are given the same 'veto right' regarding future narratives as ruins or historical certificates in present narrated histories. A changing situation of sources, for example, due to new measuring instruments, influences not only the immediate environment, but also but also the narrative. Thus, from limitations of make-believe in both the material/situational and socio-cultural realm results a non-fixity of present futures and present pasts, explaining their dynamics and uncertain motivational power.

Make-believe does not only depict facts, but is 'doing something with a proposition one has in mind' (Walton 1990, 20). This theoretical notion of following socially instructed imagination, for example, according to key-narratives and further employed objects, qualifies make-believe as propositional imagination and distinguishes it from daydreaming (also see Salis and Frigg 2020). Participants found suitable representations to make believe viable futures, i.e. the fictional-technology-according-to-considered-objects matched participants' beliefs about the world. Thereby, the follow-up communication about a mismatch or further considerations stabilized the imagined pathway. The

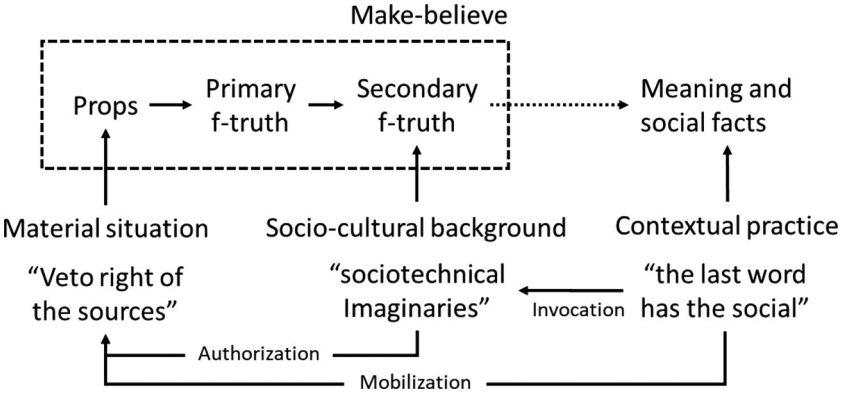

Figure 5. Fictional truth in a game of make-believe is based on the material situation and socio-cultural background. The power and significance of imagined feasibility are generated in practice.

advice to follow instructions for imagination in scenario workshops could improve stakeholder and lay participation because it justifies propositions about the future. The workshop shows how employed props, such as scientific studies and the prototype, guide attention and reveal the feasibility constraints of imagined futures to which other considerations are supposed to respond. This gives new attention to 'boundary objects' between the contexts of research, economy, and politics (see Ewenstein and Whyte 2009; Star and Griesemer 1989).

As a moderator of the workshop, I structured the make-believe with key-narratives and left the further shaping to the participants through secondary instructions for the imagination. In the game, further consideration and discussion of the (mis)matching of employed props then revealed constraints and the resulting dynamics of imagined pathways. Both the authorization of additional sources and the invocation of imaginaries followed a socially embedded process. The workshop shows that the selection of objects considered suitable for future representation is not restricted to academic studies, but also included, for example, photos of a prototype. On this basis, participants imagined different features of future algae technology. As a moderator, I did not assess the scientific validity of projected futures based on the quality of models, data, and estimates (see Grunwald 2013). However, the experts did not draw a sharp line or make explicit what kind of objects, for example, scientific studies, are authorized to make a difference. Not only statements about the future, but also the examination of fictional propositions based on considered props serve to criticize projected futures. In that way, imagining about the prototype leads to the rejection of the vision of self-sufficiency, not because of contamination risks, but because of the small production quantity. However, the extent to which authorized props help to overcome the social hierarchy to make-believe and contest imagined futures (this objection came from a student) must be further investigated.

The workshop exemplified the ambiguity of present evidence within sociotechnical futures. The imagination about the same factual object highlighted different characteristics and related challenges according to the narrative frameworks. Instead of merely charging words like 'microalgae' with new meaning, the participants discovered characteristics and hypothesized meaning about factual technologies, actors, and studies to assess current pathways for action. The participants imagined removing and covering the green color and bitter taste of microalgae as a significant task for down-stream processing because participants believed that microalgae are green and taste bitter. As part of the health vision, they even identified these characteristics as potentially valuable. The studies on feeding microalgae were suitable props, on the one hand, to make believe the use of wastewater in the sustainability vision and, on the other hand, to transform microalgae into something edible without the need for extensive downstream processes. The key-narratives helped to distinguish the visions and to consider ambiguous prop characteristics accordingly.

The desired matching and the uncertain authorization of studies, data models, and prototypes are key ingredients for contested futures' dynamics. Visions foster practices that challenge the premises of their generation in addition to the underlying challenge of uncertain political, economic, or legal assumptions. Stories that play in the past do not stimulate the disappearance or 'de-authorization' of historical sources in the same way, despite similar political relevance. The prototype of a home-brew system, mentioned by one participant, gives an excellent example of how an object reinforces the

imagined feasibility. Public visions of microalgae nutrition inspire the development of the mentioned prototype or strive for the substantiation process as a health product. Signs of success give the promissory vision the 'ontological force' to foster technology development, revealing more details – without any academic motivation to acquire knowledge. However, the new material situation of considered props might also be disappointing and contest the vision in the event of a major failure. In this case, stakeholders can either drop the visionary narrative in favor of a new story promising a different social benefit due to the technology. An alignment with sociotechnical imaginaries then helps to reframe the technology's value. Alternatively, they can doubt the authorization of the failed prototype or substantiation trial to represent the vision and keep the visionary narrative. Then, introducing novel props can help to keep the vision seem plausible.

The long history of promising microalgae futures speaks against an overly intense contestation due to disappointing experiences. According to the confirmation bias, people are more likely to report results in line with their desires and routine (Nickerson 1998). Nevertheless, there are journalistic reports and scientific studies about projects that failed due to high prices, space requirements, contamination, and other problems also mentioned by the workshop participants. I propose that the visions of microalgae nutrition persist since stories of both failure and hope transport the link between value and technology. Albrecht Koschorke (2013, 32) describes a inverted Chinese whispers effect, wherein it is not the craziest but most compliant narrative that disseminates. Considering the fact that shifting the attributions of errors can turn setbacks back into hopeful stories, technology visions propagate, in principle, regardless of what is considered feasible. Even if attempts to realize grand visions fail, utopian ambitions remain worth telling so long as societal problems prevail.

However, when it comes to the feasibility of the vision and possible action, people employ beliefs about their environment and engage with fictional propositions. Therefore, besides the familiarity of sociotechnical imaginaries, the availability and authorization of props are also crucial for the vision's motivational power. In games of make-believe, people employ and learn both beliefs about the (maybe desirable and utopian) object imagined and how to use props and act out what is imagined. Susanna Schellenberg argues that both beliefs are a prerequisite for imaginings to induce action (Schellenberg 2013, 497, 505). In the workshop, the participants imagined about feeding algae to animals because they believe microalgae to be too bitter for humans to enjoy in larger quantities. They did not believe but imagined feeding algae to animals to learn about viable pathways of microalgae nutrition. However, due to the game, participants also learned about the value and suitability of particular feeding studies, data, and models to represent the feasibility of microalgae nutrition. The crucial point is that new belief about suitable props and how to act out what is imagined already motivates new actions. Therefore, on the one hand, the desire to develop and own models, devices, or data arises to learn about the imagined. On the other hand, in competition for research funds, scientists and technology assessors gain means and motives to publicly make believe futures for increasing the value of their assets, such as laboratory equipment or expertise (see Birch 2017). This indicates that the availability, provision, and ownership of material objects mutually influence the dissemination of promissory stories and gives empirical studies on imagined futures a new interest and means to study relationships between power, truth, and ownership of representational objects.

The workshop's announcement to officially advise microalgae innovators from a scientific conference and the presence of industry stakeholders added a certain seriousness to the game. Authorized models and data sources represented cost assessments and viable options for action. The setting of a more entertaining or creative future game might have led to a different consideration of props. The debate indicated that participants anticipate which representations are suitable for the negotiation of relevant aspects and feasible scenarios. Instead of, for example, building on novel or unknown algae species, the conventional green color and bitter taste remained an imagined challenge for the coming years. The marketing proposal indicated the participants' awareness to distinguish between sites for making a profit using public desires and health-benefit imaginaries and sites of critical examination. Therefore, I propose that both beliefs about the suitability of props and imagined futures are relevant socio-cultural factors for studying imagined futures.

The empirical design did not allow any statements on long-term effects. However, the prospect of reminders of the game, such as an official report or stories of a collaborative network, enforces the anticipation of rather conservative or progressive make-believe cultures. After all, the participants' make-believe attitude also contributes to their characterization as charismatic vanguards, experts, skeptics, or unorthodox thinkers in social networks. The participants learned, for example, that some participants make believe little success of the substantiation process. This allows for orientation to the expectations of others and gives rise to the stabilization of networks and semantical institutions, such as imaginaries, which as unrepresented stories make sense of the social and sociotechnical order. However, studying the co-production of imaginaries, future knowledge, and social order requires empirical methods that cover temporal and spatial distance, such as ethnography or longitudinal surveys (Jasanoff 2010; Mische 2014, 438).

The distinction of make-believe practice from both the socio-cultural realm and the material realm, allows the accounting of responsibility for imagined futures. Indeed, sociological studies revealed how imaginaries and conventions about suitable models constrain imagined futures shaping the present. One can nevertheless attribute the selection of models and narratives representing sociotechnical futures to people's imagination. From this perspective, the irritation of imagined futures due to changes in the material world gives employed objects not the same agency as the imagining subjects. For example, imagining the future using a model of the gross domestic product (GDP), CO_2 emissions, or utopian narratives makes a crucial difference because selected props bring up different constraints, uncertainties, and implications (see Oomen et al. forthcoming). When engaging with fictional propositions using props is a prerequisite for imagined futures' motivational power, the deliberation a future narratives and suitable props becomes an ethical question of responsible research and innovation. Policymakers, technology assessors, and scientists should be aware of conventions and habits about the contingent selection of models and data employed to make future statements. Besides, responsible research should reflect the intended application of published studies as powerful props with respect to contingent future narratives and their use in present power constellations (Roßmann et al. 2020; Saltelli and Di Fiore 2020). However, since imagining the future, reflecting on considered beliefs, and practical action are materially and socially embedded, iterative practices, the rational deliberation about the future must not be overemphasized (Emirbayer and Mische 1998, 963).

Conclusion

For imagined futures to be the driving force of the present, they must relate to beliefs about the imagining subjects' environment. For this to happen, people need to believe, not in imagined futures but rather in contestations, for instance, relating to their feasibility, desirability, or usefulness. In other words, it is not the science fiction narrative that motivates action but rather the examination of implications. Kendall Walton defines the examination of 'a proposition one has in mind' as a game of make-believe (Walton 1990, 20) and presents an analytical framework. I situate my theoretical inquiry within this framework to focus on the concepts of generating and authorizing a game, the suitability of objects involved, matching of beliefs and fictional truth, and describing future imagination as a social practice. In this paper, I have argued that people use objects as props for different reasons, such as exploring, conveying, and reinforcing the feasibility and details of uncertain technology or increasing their assets' value. In comparison with narrated history, I claim that props, such as models, simulations, and prototypes, have a similar veto right for statements about the future as historical sources do about the past. It is for this reason that imagined futures become contested when prototypes, experiments, or simulations fail.

This paper illustrates how actors engage with fictional propositions by drawing on a scenario workshop about the key-narratives of microalgae nutrition. An analysis of the workshop showed how different narratives reveal actual technology ambiguities and how imagined futures change due to constraints of representational objects such as data, models, illustrations, and prototypes. Furthermore, by understanding representations, such as narratives or models, as instructions for imagination, participants distinguished, assessed, and criticized the suitability of objects for representing an imagined future and the extent the imagined matches implications of a narrative. These implications became explicit as participants openly thought about obstacles to the realization of visions. Therefore, the workshop showed how actors integrate beliefs about their environment into a game of make-believe, i.e. beliefs about an imagined object and beliefs about props' suitability. However, the empirical study design does not allow any insight into learning effects and motivational power because it did not document the difference before and after the workshop. Further research is needed for a more thorough investigation of the motivational power and the dissemination of representations and authorization across temporal and cultural contexts.

In order to examine to what degree imagined futures become contested, I also discussed in this paper how make-believe relates to other concepts about the future in STS and sociology. I point out that Kendall Walton's theory of make-believe aligns with conceptional insights of 'situated knowledges' and 'co-production,' as the situation and alteration of objects in the imagining subject's environment have a crucial role in constraining and irritating fictional truth. The distinction between the imagining subjects and the included objects allows one to attribute responsibility and distinguish make-believe from actor-network-theory. Besides, the authorization of games points to socio-cultural structures beyond the current interaction, such as the scientific and economic valuation of representations to assess the scientific validity of future projections and the price of an asset with consequences on subsequent action. On a cultural level, social and sociotechnical imaginaries facilitate the generation of make-believe games and direct

implications by sketching out what can be expected. Imaginaries have no fixed or authorized material representation to which they could be pinned. However, they become more specific in examining whether a game of make-believe matches collective expectations, for example, concerning technical obstacles to overcome or the desirability of the overall picture. This allows games of make-believe to actualize, transform, and disseminate imaginaries but never fully grasp or overcome them. Therefore, when models, simulations, or prototypes fail to match expectations, only beliefs about the suitability of these props and the feasibility or credibility of the imagined future are contested. However, imaginaries prevail and disseminate so long as people find a reason to engage with their fictional propositions.

Notes

1. According to Suits (2005, 41), to play a game is to engage in 'the voluntary attempt to overcome unnecessary obstacles' – you voluntarily follow the (often implicit) instructions for the game instead of simply moving towards a 'target.'
2. The hyphens emphasize that make-believe does not necessarily question the truth-according-to-an-unspecified-reality-without-reference. Gregory Currie (2016) uses the hyphens in a similar way arguing that there is no general place to call 'truth in fiction' but only truth-according-to-a-representation.
3. For the empirical and theoretical backgrounds to the design of key-narratives, see Roßmann and Rösch (2019).

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Annex

Key-narratives of microalgae nutrition

Sustainability

There are currently over 7.5 billion people living on Earth. Either we are cutting our global resource consumption today, or tomorrow we will be forced to do so by the impact of a devastated environment. Microalgae could be the solution: they store CO_2 and can be produced without arable land and the use of pesticides. Microalgae will be an important pillar of sustainable nutrition in the future.

Health and wellness

In an accelerated society, there is a growing need and desire for a balanced and healthy diet. Thus, microalgae are rediscovered as a part of Far Eastern teachings. The ingredients and variety of microalgae promise health and an individual feeling of fitness and satisfaction. Microalgae will contribute to a healthy and enjoyable future.

Cheap and inconspicuous

People have their habits and new foods have a hard time. However, microalgae inconspicuously and reliably meet the requirements of established food production. Their neutral taste makes them a cheap substitute for soy and animal protein in many products. As a consumer, you will not notice a difference.

Do-it-yourself

A handful of industrial giants control almost the entire food production – only those who produce themselves are safe from empty promises and synthetic additives. In the future, small, modular algae plants will enable independent, regional self-sufficiency. We feed ourselves and share knowledge, recipes, and ideas – microalgae mean a bit more freedom.

Chapter 15
Comparability of LCAs — Review and Discussion of the Application Purpose

Maximilian Roßmann, Matthias Stratmann, Nadine Rötzer, Philipp Schäfer, and Mario Schmidt

Abstract This article discusses the comparability of Life Cycle Assessments (LCAs) and the central role of the application purpose in a study review. According to ISO 14040, an LCA study design emerges in continuous reference to the "intended application". Goal and scope, case-specific assumptions, as well as methodological freedoms, should be justified by their significance for the specific application purpose, e.g. for process optimization or for advice on a political issue. In contrast, our systematic review of 58 LCA studies shows that LCAs hardly name applications, and more generally, applications are difficult to reconstruct. This lack of transparency makes the LCA methodology attackable through meta-studies that ignore the problem-oriented and case-specific approach. Since these studies are valuated for different purposes by a diverse set of actors, quantification in any study that does not represent the context and purpose of its generation can disguise as much as it can enlighten. Therefore, we propose what a study should look like that is problem-solving, concrete and yet provides transferable results for other studies.

Keyword Life cycle assessment · Application · Comparability · Biofuels · Technology assessment · Systems theory

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15.1 Introduction

Life Cycle Assessments (LCAs) quantify the environmental impacts of products and services over the entire life cycle. They, therefore, play an important role e.g. in strategic planning, advertising and current social and political debates, such as the energy transition or world food supply. Thus, the European Commission (European Commission 2003) concluded that "life cycle assessments provide the best framework for assessing the potential environmental impacts of products currently available". Several ISO standards and several manuals, textbooks and regulations are meant to ensure and improve comparability, resilience as well as reproducibility within a given framework (European Commission—JRC 2010; Klöpffer and Grahl 2012; Hauschild et al. 2018; DIN EN 1404 2009). However, various meta-studies show how different interpretations and methodological choices within the given framework lead to very different results, as for example for packaging systems (von Falkenstein et al. 2010), aluminum applications (Liu and Müller 2012), biofuels (Martin et al. 2015; van der Voet et al. 2010) and the metal and mining sector (Yellishetty et al. 2009). One could say that the methodology is not approaching consensus, but seems to be diversifying (Klöpffer and Grahl 2012). The emerging "LCA-Spin-Offs", like Footprints or beyond-product-LCAs (OLCA, IO-LCA), nowadays, rather have the character of an "LCA alphabet soup" than of a uniform method with similar or robust assumptions (Guinée et al. 2018; Finkbeiner 2014). If an LCA is considered a basis of the advertisement or organizational strategy in a highly debated field, such opacity can lead to protracted disputes. For the purpose of evidence-based policy, modeling such as the LCA, in general, is even considered to be in a crisis (Saltelli and Giampietro 2017).

The mentioned ISO standards already stipulate that the preparation of LCAs is to be geared to their intended application. In the ISO standards, the purpose of application plays a central role; every step in the preparation and interpretation phase of a study should reflect the purpose (DIN EN 1404 2009). According to the standards, the definition of goal and scope, the selection of allocation methods and the assessment data quality should be oriented towards the intended purpose. Facing the differences between the studies, this claim is already being discussed in the LCA community, for example in the distinction between policy LCAs, which should be particularly robust, and analysis LCAs, which aim to understand systems (Wardenaar et al. 2012). While Tjerk Wardenaar et al. (2012) consider the influence of the application on the allocation method, Christian Bauer, Liselotte Schebek, and Mario Schmidt (Bauer et al. 2007) see the influence on all levels of modeling, respectively the selection of modeled processes, flows and impact categories.

In this paper, we take up the debate and argue for inevitable methodological diversity and different assumptions to address particular problems of an application purpose. On the one hand, there are good reasons to claim for a stricter methodology, a general data basis for all further studies and the purist restriction to attributional LCAs (Guinée et al. 2018). On the other hand, model assumptions and methodological diversity are reasonable when the model is only measured by the purpose for

which it is used (Saltelli 2019). The different demands of recognized plurality and a scientific-political consensus on the "correct LCA" are not contradictory but emphasize different perspectives. Both serve to reject the general critique regarding their opaque assumptions and unnecessary diversification by emphasizing the purpose of the study. We, therefore, question if an analysis of different application purposes can reject the claim for a stricter methodology and give perspectives for better LCA studies?

In a first step, we will discuss the application from a system-theoretical perspective and narrow down the term "application case" in order to make it empirically classifiable. In an analysis of 58 studies on biofuels, we show how little one can learn about the application purpose and justification of the model assumptions. In our discussion about the state and transferability of this critique, we will follow up on the debates about application purposes against the background of methodical freedom. We conclude that the pure reference to the correct application of the ISO or otherwise specified LCA standard does not justify a comparable, transparent decision basis for responsible policy processes and organizational planning. The LCA community, therefore, should take the critique seriously as a demand to better take into account and communicate the context and purpose of LCA studies.

15.2 Review of the Application Purpose

The argument to evaluate models according to their usefulness for a particular application is not limited to material flow models. We call different material and abstract objects models if they are used to represent a phenomenon of the world without matching the target in every aspect. Models represent, for example, the general balances or certain causal relationships of a target system, often involving generalized system knowledge. A model that matches in every aspect would be a duplicate of the target system. When modelers try to represent too many aspects, the additional assumptions create additional uncertainties that, taken together, reduce the scope and usefulness of the model (Saltelli 2019). For our consideration, it is only important that the model matches in so far that it is suitable for a certain purpose. The goal and scope of an LCA are to define the framework in which the model should represent the target system in order to draw attention to the characteristics of this representation. In science, models serve to learn about a target system. We learn with models, by constructing models and by varying parameters (Frigg and Nguyen 2016). The scientific communication about models serves to share procedures for generating certain experiences that are discussed and acknowledged as facts in the community. Within scientific communication, it is clear that truth statements refer to models and do not correspond to an external world: One the one hand, something is not considered objectively true, but only true according to this or that model (Walton 1990; Toon 2014). On the other hand, this or that model is discussed and considered suitable for a certain purpose, for example, to construct a factory building, to analyze energy costs, or to balance environmental emissions of a product lifetime. These aspects

describe the goal and scope of a model. However, the intended purpose, and thereby the necessary abstraction and representation of complex contexts, refers to the social function of a model. How will people use the LCA to make a difference?

If one follows Niklas Luhmann's system-theoretical distinctions, models in politics serve to gain power and to promote collectively binding decisions (Luhmann 1986, 1987). That means models are used to persuade others to recognize one's own assumptions as the basis for further consideration, action, and decision-making. But even for this, they must seek acceptance of shared bases. Scientifically authorized modeling shows ways for formulating truth claims that are considered true to the extent that their conclusion based on the assumptions can be understood and reproduced by everyone in a certain scientific community (Luhmann 1992). Since scientific truth is widely acknowledged in our society, scientific truth is linked to power. But the politically relevant conclusions often exceed the scientifically supported ones. Therefore, for example, further model assumptions must be collectively supported, for example by stakeholder participation. The normative conclusions, i.e. which practical measures and decisions stakeholders derive from modeling, must also be shaped politically. This challenge of dealing with normative assumptions in scientific policy advice has been the subject of ongoing critical and fruitful debates on technology assessment since the 1970s (Nierling and Torgersen 2019; Grunwald 2019; Wynne 1975). Besides the science-politics-interface, there are also perspectives on models from law and economics. At the point of institutional decisions, model assumptions and scientific opinions are woven into legal norm systems. This means that models that follow norms and hermeneutic blanks provide a general basis and interface on which particular cases can be interpreted and decided. Relying on legal standards ensures that assumptions do not have to be negotiated every time, but that all those possibly affected would be given justice in the same way. However, from an economic perspective, models, in the end, aim to make a profit. They can be used to convince others to invest or buy products (advertising and motivation), to show potential benefits and savings (process analysis), to position oneself strategically in the long term (orientation), or to prove the fulfillment of legal standards for e.g. tax benefits or funding. In order to perform these functions, models do not have to be supported by all those potentially affected, they do not have to be transparent in every respect and they do not have to be based on legal standards. But for different purposes, they can attempt that.

This systems theoretical perspective illustrates the environments in which modeling takes place: Even if the modeler does not follow any further intentions when creating his model, but only his intuition, his work can be observed and utilized in various perspectives. The functional system reference does not refer to a person, but to the communicative connection of his or her communication. A scientist's statements can, for example, also have political, legal and economic effects. On the other hand, we see that there are studies that would not satisfy scientific requirements but which form the basis for political and economic decisions, we see that there are scientific models that do not contribute to making a case legally decidable, and we see that there are industrial studies that elude scientific assessment because, for example, the data are not publicly accessible. As models have different application

purposes, different characteristics are in the foreground. This general view of models in society can also be applied to LCAs. At first glance, it becomes clear that modeling anticipates different success criteria for different purposes without allowing a real prediction of practical success. In the next step, we observe degrees of freedom in the LCA, which can be aligned to a specific application purpose.

15.3 Assumptions and Methodological Freedoms

The common reference to ISO standards primarily shows that a legal framework is considered at the basis for modeling and assessment. The training for dealing with ISO standards in LCAs enables the normal interpretation of standards, so that in LCA practice, for example, a reviewer can speak of a correct or incorrect application of standards. Before the standardization and establishment of textbooks or technical journals, however, there were life cycle assessments, in particular, due to the interests of the industry. Matthias Finkbeiner calls these early times the "wild west times", in which the use of life cycle assessments was detrimental to credibility due to strong bias and misuse (Finkbeiner 2014). Nowadays, one speaks of an established method and a worldwide community, and many studies are divided into a goal and scope phase, an inventory phase, an impact assessment phase and an interpretation phase — just as recommended in the standards.

There are various references in the standards that the intended application belongs to the study and should be taken into account:

- "The goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application" (Chap. 4.2.1 in (DIN EN 1404 2018)).
- "The choice of elements of the physical system to be modeled depends on […] its intended application and audience […]" (Chap. 5.2.3 in (DIN EN 1404 2009)).
- "Recommendations should relate to the intended application" (Chap. 4.5.4 in (DIN EN 1404 2018)).
- "Therefore, special care is necessary to ensure that the information is applicable to the context in which it is likely to be applied" (Annex A.2 in (DIN EN 1404 2009)).
- "Clarifications, considerations, practices, simplifications, and options for the different applications are […] beyond the scope of this International Standard" (Annex A.1 in (DIN EN 1404 2009)).

The latter point, in particular, indicates that a study has a purpose that is not specified by ISO. An LCA can have different purposes. However, it is not specified how these purposes are to be fulfilled. The modeler must decide for himself what is sufficient, essential or suitable. The same is true for freedoms shown by terms such as "suitable", "sufficient", "essential", "potential" and "relevant". Grunwald (2016) calls these terms in comparison with indefinite legal terms "hermeneutic blanks" as compared to indefinite legal terms, which must be filled with meaning for the particular case. An indefinite legal term is a term that is not filled in by a clearly

defined fact but must be specified during the application of the law for every individual case. Further freedoms are shown above all in the choice of allocation, the attribution of environmental impacts to the different valuable outputs of a system (Wardenaar et al. 2012). Just as social coexistence is guided by formalized legal and social norms but cannot be determined, the LCA practice of formal standards and informal norms requires interpretation and good scientific practice. The attempt to take into account any special case would make the body of rules grow immeasurably. In this way, it has also been historically shown that science embraces versatile practices without a general formula or method (e.g. Lakatos and Musgrave 1974).

The practices of LCA seem too different for implicitly shared norms to emerge as a common ground for all application purposes. In their review, Wardenaar et al. (2012) find such large variations that they propose to distinguish generally between political LCAs aimed at the robustness and more diverse analytical LCAs for different more explorative purposes. On the one hand, the European Commission is developing the Product Environmental Footprint, which is a very standardized LCA-method, where "comparability is given priority over flexibility" (European Commission 2013). On the other hand, industrial users of LCAs try to include real process data if possible to optimize a process in a company. In the same way, it would be scientifically nonsense if standards were to prevent systems from being modeled and explored more appropriately on the basis of empirical data. In the cases of strategic consulting and foresight, LCA models are coupled with upscaling, market estimates and other model extensions already. However, from the perspective of policy-assessment, there is a growing concern about an increasing number of "similar-but-different" methodologies and approaches (Galatola and Pant 2014). Likewise, companies are more interested in satisfying customers' requests for information about environmental impacts by means of self-designed labels than in provoking and going through complex certification procedures. In summary, there are different applications and interests in conducting life cycle analysis, which involve different assumptions and promote model diversification. But can these purposes also be revealed in published studies?

15.4 Review of the Meta-study

In order to scrutinize the general criticism of LCAs, we analyzed the LCA studies considered in the meta-study by van der Voet et al. (2010) in terms of their intended application and assumptions made. In total, we were able to review 58 studies. The initial idea was to investigate if there is a relationship between application purpose and the different attributes (application, functional unit, system boundary, allocation method). However, this turned out to be not feasible as we will explain later. We, therefore, included further attributes such as the ranking of the journals (impact factor) and the reference to the ISO standard to explain differences between the studies.

In order to classify the application purpose of an LCA-study published in a paper, it is not sufficient to specify a set of search terms for automated text analysis. The

reference to an application purpose does not seem to be sufficiently specified. The analysis thus consisted of a careful and iterative elaboration of the purpose of the application in the introduction and discussion and final section of the studies as common in discourse analysis. To give an example, the decision is briefly played through on a paper named "Can ethanol alone meet California's low carbon fuel standard? An evaluation of feedstock and conversion alternatives" (Zhang et al. 2010). On the one hand, the paper does not name an intended application purpose. On the other hand, the title refers directly to a specific application and the paper contains concrete references to the Low Carbon Fuel Standard (LCFS) program in California. It contains bits of advice like: "The inclusion of metrics other than solely GHG [Green House Gas] emissions offers insights potentially relevant for avoiding unintended consequences" (Zhang et al. 2010). Without wanting to deny the advertising effect and the scientific sharpness, this indicates the purpose of political consultation. The political intention is also represented in the subsequent acknowledgments to General Motors (GM) for sponsoring the study. Without now discussing the neutrality or standards of independence, it can be postulated that this study is only politically successful if it makes assumptions that are robust enough not to be easily refuted by political opponents. The study thus carries the political story that in signing the law it is better to take certain factors into account—not in order to do GM a favor but because otherwise undesirable consequences arise. On this level, we reveal a political application case of the study, which was made plausible with the help of an LCA. While the review of LCA studies was blindly divided up between the authors of this paper, in cases of uncertainty joint agreements were reached to ensure a consistent approach.

15.5 Results

The results of the study are rather sobering. Only 17 out of the 58 (equals 29%) studies indicate an application purpose (Fig. 15.1). The majority of these studies were carried out within the framework of ISO 14040/44. Another interesting observation is that, on the other side, although studies are carried out in accordance with the ISO standard they do not state the application purpose (in a sufficient manner). The general low naming of the application purpose did not allow further analysis of relations between the different attributes. Additionally, we investigated whether the publication media has an influence on whether the application is mentioned or not. Two observations could be made: papers in journals with a higher impact factor tend to name the application more often and papers in journals with a thematically broader scope and readership, respectively, also more often state the application purpose. This could indicate that information about the intended use and backgrounds of the work appeals to a wider audience and makes it more successful, as we will discuss later.

Nevertheless, there are huge differences in the assumptions, so we agree with the statement of van der Voet et al. (2010) that opaque assumptions have a huge impact on the results. However, we do not take these findings as the basis for the

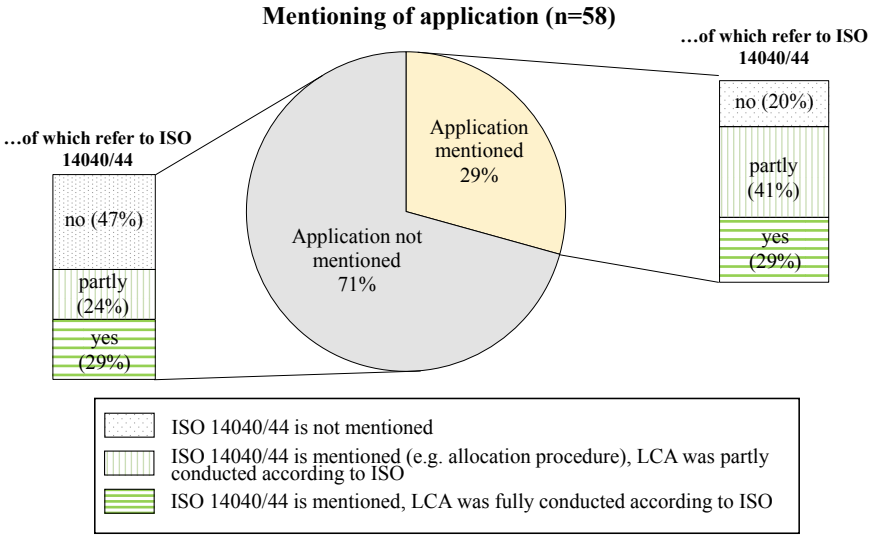

Fig. 15.1 A review of the application case is mentioned in the 58 LCA studies that served the base of the meta-study of (van der Voet et al. 2010)

demonization of the method, but instead, examine reasons for this observation and discuss perspectives for the present developments of life cycle assessment.

15.6 Discussion

The discussion of the results focuses on two levels: First, we argue that the application purposes in the studies were not apparent for various reasons so that the differences in LCA assumptions cannot be empirically justified by the application. On this basis, we propose to drop the concept of objectivity and self-purpose studies in order to focus more on the societal embedding of life cycle assessment and application purposes in research and teaching.

Despite training in life cycle assessment, engineering, and social sciences, we were not able to methodically determine the intended applications within the given corpus. Since our review was limited to a metastudy on biofuels only, further studies are needed to validate our findings and extend its scope to other fields of LCA. A wider corpus might reveal linguistic structures that facilitate clustering and categorization into application purposes and sharpen the review methodology. Nevertheless, we consider biofuels to be a vivid example for the discussion of the application purpose. While issues of food, water, energy, and mobility, and in particular, the focus on “tank versus plate”, attract a wide audience, the life cycle assessments were a common reference point for different stakeholders. The considered studies and the societal debate impressively represent the methodological challenges and demand.

We, therefore, consider the critical reflection of the intended purpose of biofuel life cycle assessments to be particularly important and a good starting point for further studies.

With regard to methodological criticism, it is, on the one hand, possible that we were not able to find a purpose because we have mainly studied scientific publications, but industrial studies are rarely published. Our finding that articles in high ranked and wider addressing journals mention the purpose more frequently indicates that the target audience makes a difference. On the other hand, the authors of published LCA studies may even wish to keep the use of the study open or have no interest in practical application at all. This attitude may be further encouraged by the scientific ethos of disinterestedness and universality for the scientific publication, which forbids the indication of purposes (see Merton 1968, pp. 607–616). This idea could also have been reinforced by the community and journal specifications if the purpose was not explicitly asked for. Not mentioning the application purpose, however, only disguises but can not replace the justification for the assumptions. You do not even have to assume a manipulative intention. Studies are likely to be influenced by the habit of a chair or industry, by the available budget as well as the software learned and its technical limitations (see Wynne 1975; Lakatos and Musgrave 1974). Many decisions are made unconsciously or, respectively and, in the best intention of an individual for appropriate analysis of a system. But a lack of reflection on normativity and social consequences does not absolve us of our social responsibility. If there is no interest at all to say something about a target system, but only to play with and explore features of a toy-model, one could at least spell out this application purpose. In order to further reveal the application purpose, what we found in the written studies was not sufficient. Nevertheless, it would be possible to interview the authors of studies or to make a survey in a follow-up study. Alternatively, we would like to address the community directly to communicate the purpose of studies more strongly for the following reasons.

We could not show in our text analysis that there are connections between application purposes and assumptions of an LCA. We, therefore, assume that the reference to ISO 14040 is not sufficient to justify the results. However, we point out that the reflection and indication of the purpose of an LCA are helpful in justifying and making comprehensible assumptions in a study. The methodological development and the results of the meta-study show that LCA does not seem to converge to a consensus. Our theoretical consideration explains this diversification through the different societal environments of an LCA. The application of an LCA for a practical case is always a particular challenge. Mastering these practical problems, such as dealing with the data availability, different stakeholders and unclear objectives of the stakeholders, is another actual achievement of the studies. We, therefore, consider it important to communicate the handling of the application purpose in the studies so that other practitioners can learn from dealing with these problems. To do this, however, one must give up the idea of objective science, or unambiguous allocation of environmental impacts.

Objectivity or universality only make sense as the ideal to make the insights of a study independent from subjective impressions but transparent and comprehensible

for a wider audience. We, therefore, claim that only the purpose of application relieves the modeler of subjective impressions, political bias and random circumstances in the justification of assumptions, considered input data, and simplifications. Therefore, not only the quantitative results of a study are the scientific achievement, but also the application of the general model to a concrete problem in a way that justifies assumptions, results and uncertainty assessments against the background of its social embedding, respectively the societal purpose of the application. Therefore, written instructions to the reader's imagination, for example in forms of narrative structures, are used to communicate relevant contextual knowledge and determine the framework in which the study was carried out. To illustrate particular problems, references to standards, methods, and stakeholders must be combined with observed interrelationships. The reasons for assumptions are then derived from this. Highlighting these multiple challenges would also open LCA for interdisciplinary exchange. With their help, studies could be geared more closely to the perspectives of stakeholders and find further commonalities in how assumptions in the creation of an LCA can be traced back to a list of application purposes.

15.7 Conclusion and Outlook

LCA is a success story, but with its success, there seems to be a crisis caused by the purpose-driven diversification. The scientific idea that the LCA studies might approach a consensus in methodology and results on e.g. a technology must be abandoned. But this is not a loss. There is no formal method to distinguish good science in other disciplines either but only heuristics and scientific virtues that guide the versatile practices (Lakatos and Musgrave 1974). Good engineers and scientists do not blindly follow rules given to them but solve cognitive and practical problems keeping in view, and in dialogue with, those affected by them. We, therefore, agree with the meta-studies that opaque assumptions strongly influence results. We conclude that mere reference to ISO standards or "the LCA method" does not justify the assumptions made and results obtained. And we go with the standards that LCAs are not an "end in themselves" but have a purpose. But we reveal that the application purpose can hardly be reconstructed (only in 29% of the studies). We, therefore, learn little about its applications and the associated peculiarities in the making and justification of assumptions. Thus, we can assume the worst case that the assumptions are arbitrary and manipulative. Then, LCAs are practically unusable in many cases (e.g. for policy and decision support). Or we consider the best case that the assumptions are based on particular definitions, practices, and purposes because LCAs are solutions for specific problems. Therefore, instead of the failed embedding into an (e.g. deliberative or strategic) practice, the LCA method was wrongly criticized. The intended purpose lies outside the standards that commonly define the LCA method, but is actually considered a part of every life cycle assessment study. The problem of LCAs is the lack of communication of the application purpose—on the one hand, as a prerequisite for the comparability of LCAs and, on the other hand, for the establishment

of a culture that shares, discusses and appreciates revealed ways of solving practical problems. Our review uncovers and discusses this deficiency with the example of biofuels in order to encourage the reflection on the application purpose, especially in this field but also in the wider fields of life cycle assessment.

In view of the current global challenge of climate change, the comprehensive application of an LCA in industry, politics, jurisprudence, and science is considered to be important. There are experiences for successful projects so that not every study would require elaborate risk analysis or citizen participation. Nevertheless, these strategies play an important role in dealing with uncertainty in LCA—and are of varying importance for different application purposes (Heijungs and Huijbregts 2004). As mentioned above, tight legal standards are needed to create meaningful legal incentive systems or labels. At this point, a reference database with usual emissions would also make sense in order to easily check the plausibility of information provided by companies, for example, as there are standard rates for tax returns. From the point of view of consumer protection, it would also be helpful not to leave the eco-labeling to the economy. This works well in some areas, but not in all. Standardizations are only successful if they include different perspectives on feasibility, for example, concerning the cognitive and practical possibilities of consumers and audit institutions, without forgetting their purpose of environmental protection. In the political dimension, the policy level must be considered: for local projects, it is important to take the current situation and concerns of the public stakeholders into account. Discourse-analytical and participatory methods seem to be as necessary as robust assumptions and simple models. At a higher political level, for example, to advise the European Parliament, the Numeral, Unit, Spread, Assessment and Pedigree (NUSAP) system and the "post-normal-science" mindset that goes beyond the mere application of methods ("normal-science") have proved their benefit (Funtowicz and Ravetz 1990; van der Sluijs et al. 2005). The central idea of our criticism is to place the intended application at the center for consideration, selection, and justification of all assumptions and methods in the life cycle assessment. There are many approaches to consider different application purposes—and with this invitation, we provoke life cycle assessment to become the ultimate alphabet soup. But we expect a new structure of LCA exchange to emerge when the commonalities of studies with similar intended applications then become visible.

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OPINION

WILEY GLOBAL CHANGE BIOLOGY BIOENERGY

Microalgae for integrated food and fuel production

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Abstract

Microalgae have a great potential for the sustainable production of food and fuel for a growing world population with increasing demands and changing habits. Since they are cultivated in technical systems, they do not contribute to land use competition, loss of biodiversity, and environmental pollution like other food and energy crops. Despite these advantages, the commercialization of algae technology is still in an infant stage. Algae fuel production has so far failed due to low oil prices and lack of economic viability. However, integrated food and fuel production is considered promising because the food market is more diversified and open to new and innovative products than the energy market. Integrated food and fuel production from microalgae can not only achieve higher returns on investment but also greater acceptance than fuel production alone. From the sociotechnical point of view, it is however crucial that the integrated algae production system will fulfill the promises of health and sustainability. To achieve this, a codesign approach is used, considering public perception and the views, knowledge and values of citizens and stakeholders already at an early stage in the research and innovation process.

1 | INTRODUCTION

Microalgae are considered a promising source of fuel as they represent a diverse group of single-cell photosynthetic organisms that grow rapidly in a wide range of habitats. In contrast to traditional crops, they can be cultivated in technical systems on marginal land with nutrient- and CO_2-rich waste (water) streams (Pulz & Gross, 2004; Rösch & Maga, 2012). They have an outstanding photosynthetic efficiency and biomass productivity and can have high contents of fatty acids, polysaccharides, and proteins depending on species and cultivation conditions (Becker, 2007; Spolaore, Joannis-Cassan, Duran, & Isambert, 2006). Some algae species contain up to 40% fatty acids and high amounts of polysaccharides, which can be converted easily into diesel, jet fuel, and ethanol. Because of these advantages and since they do not have the drawbacks of first-generation biofuels, such as land use competition, loss of biodiversity, and environmental pollution through pesticides and fertilizers, and of second-generation biofuels, such as straw or forest residues (Haase, Rösch, & Ketzer, 2016), algae fuels are classified as third-generation biofuels.

Government and private investments in various countries and at different scales have launched pilot-scale programs to develop third-generation biofuel production from microalgae. In the United States, some companies such as Solazyme, Sapphire Energy, and Algenol started to produce diesel and jet fuel, ethanol, and gasoline from algae at a commercial scale (Wesoff, 2017). Most efforts, however, have been abandoned due to the lack of economic viability. Some algae fuel companies have gone bankrupt, while others have adopted new business plans and moved on to high-value markets such as cosmetic supplements, nutraceuticals, pet food additives, pigments, and speciality oils (Wesoff, 2017). These changes indicate that algae technology developed for fuel production can also be used for food production and vice versa. This is due to microalgae's ability to produce a variety of (high-value) food compounds, such as carotenoids and polyunsaturated fatty acids (PUFAs), and bioactive compounds, such as pigments, vitamins, and enzymes (Chew et al., 2017; Draaisma et al., 2013; Matos, Cardoso, Bandarra, & Afonso, 2017; Milledge, 2011; Wijffels & Barbosa, 2010; Wijffels, Barbosa, & Eppink, 2010; Williams & Laurens, 2010). Since

these products have beneficial nutritional qualities and health claims, they can achieve high sales prices, which ensure return on investment in algae technology (Enzing, Ploeg, Barbosa, & Sijtsma, 2014; Vigani et al., 2015).

In this paper, the chances and challenges of integrated food and fuel production from microalgae are outlined and discussed based on the results of the microalgae research network funded by the state of Baden-Württemberg, Germany. First, algae species and cultivation, harvesting, and extraction technologies are discussed. The next sections are devoted to economic and environmental aspects. The last section deals with public perception, because consumer acceptance is essential for exploiting the potential of microalgae. Since algae species and their cultivation are similar for food and fuel production, it is expected that only minor changes in the upstream process are required to switch from fuel to food and fuel production. The downstream process, however, becomes more complex in order to valorize different algae compounds for the food and fuel market (see Figure 1).

2 | MICROALGAE SPECIES

The diversity of microalgae in oceans, brackish, and freshwater is vast and promising (Fehling, Stoecker, & Baldauf, 2007; Massana, Terrado, Forn, Lovejoy, & Pedrós-Alió, 2006; Stern et al., 2010) and has been estimated to include anything from 30,000 to more than 1 million species (Guiry, 2012; Richmond, 2004). The broad range is due to uncertainties regarding what organisms should be included as algae and what a species is in the context of various algal phyla and classes. Part of the diversity was screened by the Aquatic Species Program (1980 to 1996) supported by the US Department of Energy to identify promising species, technologies, and processes to produce oil from microalgae. Of this diversity, only few species have been used for fuel production or have commercial relevance for (health) food production (Lee, 1997; Liang, Sarkany, & Cui, 2009; Pulz & Gross, 2004).

Nannochloropsis sp., Neochloris oleoabundans, Scenedesmus obliquus, and *Dunaliella tertiolecta* have been considered as promising candidates for fuel production in terms of quantity and quality of fatty acids (Gouveia & Oliveira, 2009). Some of them show an increase in oil quantity (~50%) when grown under nitrogen shortage. The algae food market is dominated by *Chlorella vulgaris and Arthrospira platensis* and *extracts of Dunaliella salina* (β-Carotene), *Haematococcus pluvialis* (astaxanthin) or *Crypthecodinium cohnii* (docosahexaenoic acid) due to commercial factors, market demand, specific preparation, and food safety regulations of the European Food Safety Authority (Chacón-Lee & González-Mariño, 2010). Besides, they have a positive public perception as they are recognized as a natural source of a healthy diet that can prevent health problems of modern lifestyle such as obesity, heart diseases, and diabetics. Table 1 shows the fatty acid, protein, and carbohydrate content (under optimal, N-/P-replete cultivation conditions) of the above-mentioned and other microalgae in comparison with traditional oil and protein plants. It can be noticed that, in these three categories, some algae have a

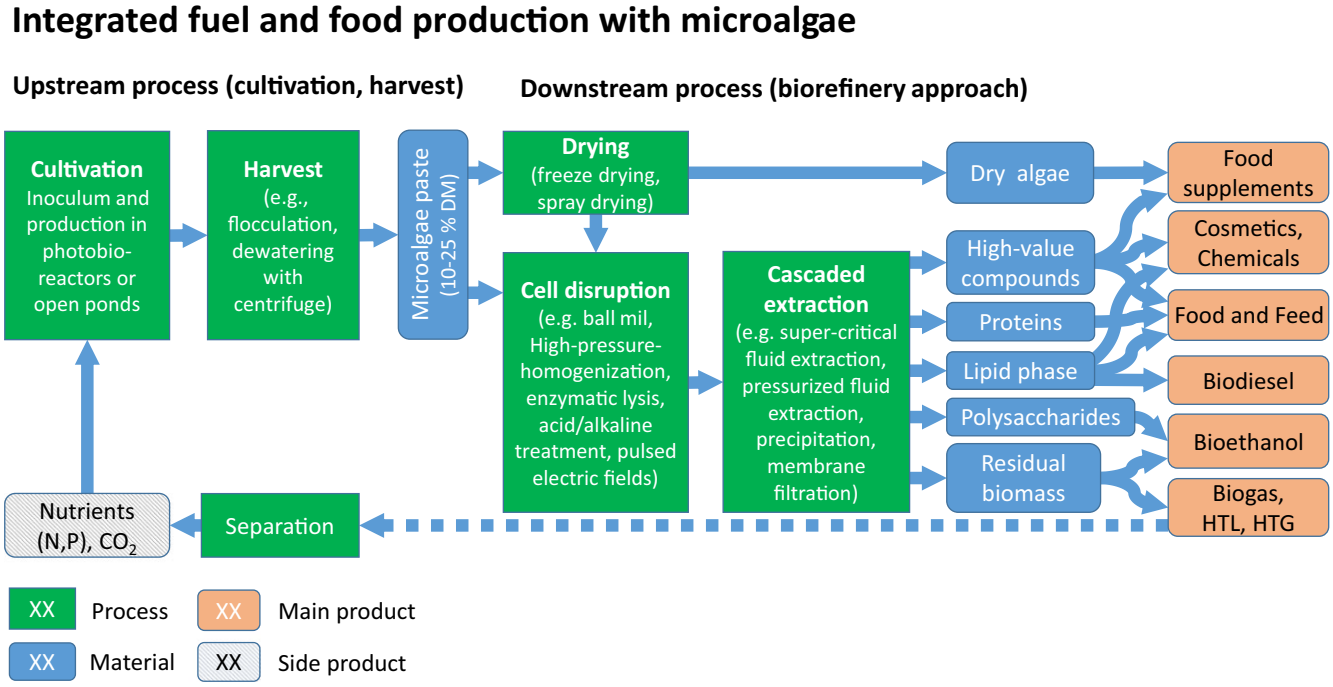

FIGURE 1 Integrated production of fuel and food with microalgae

TABLE 1 Composition of main biofuel and food sources with microalgae (% dry weight; Spolaore et al., 2006; Becker, 2007; Gouveia, Batista, Sousa, Raymundo, & Bandarra 2008; Chang, Ismail, Yanagita, Esa, & Baharuldin, 2014; Haar, Müller, Bader-Mittermaier, & Eisner, 2014)

Commodity	Protein	Carbohydrates	Lipids/fatty acids
Animal products and soybeans			
Meat	43	1	34
Egg	47	4	41
Milk	26	38	28
Oil palm kernel	16–27[a]	6–11[a]	50–70
Rapeseed	14–18[a]	12–15[a]	40–45
Soybeans	37	30	20
Microalgae			
Chlamydomonas reinhardii	48	17	21
Chlorella pyrenoidosa	57	26	2
Chlorella vulgaris	51–58	12–17	14–22
Dunanliella salina	39–61	14–18	14–20
Haematococcus pluvialis	48	27	15
Scenedesmus dimorphus	60–71	13–16	6–7
Spirulina maxima	46–63	8–14	4–9
Spirulina platensis	52	15	3

[a]Content calculated with data of defatted kernels and seeds in Haar et al. (2014) and Chang et al. (2014).

similar composition to traditional oil and protein plants such as soybean and rapeseed, which is a first-generation biofuel crop. The chemical composition of some microalgae can vary due to nitrogen or phosphate depletion. As a result, the lipid or carbohydrate content increases, while the amount of proteins decreases.

For fuel production, the composition of fatty acids is relevant. Suitable microalgae provide a high proportion of unsaturated fatty acids (50%–65%, predominantly polar membrane lipids) and a significant content of saturated palmitic acid (C16:0; 17%–40%; Gouveia & Oliveira, 2009). Among the undesirable unsaturated fatty acids, special attention has been given to the linolenic (C18:3) and polyunsaturated (≥4 double bonds) contents, where European Standard EN 14214 (2004) specifies a limit of 12% and 1%, respectively, for quality biodiesel. Not all the oils extracted from microalgae have linolenic and polyunsaturated fatty acid contents within specifications (Gouveia & Oliveira, 2009).

For food production, not only the amount and purity of protein or fatty acids but also their quality and context are important. The media provide conditions for certain protein structures and qualities—a purified powder, denatured protein, or oxidized fatty acid might be of little value for certain applications. The quality of proteins can vary depending on techno-functionality, digestibility, and availability of essential amino acids (EEAs), which humans are unable to biosynthesize. Although tryptophan and lysine are often limiting amino acids, algae are regarded as viable protein source, with an EAA composition that meets the requirements of the Food and Agriculture Organization (FAO) of the United Nations (Volkmann, Imianovsky, Oliveira, & Sant'Anna, 2008).

3 | UPSTREAM AND DOWNSTREAM PROCESSES OF FOOD AND FUEL PRODUCTION

Food and fuel production from microalgae can be separated into upstream processes, including cultivation and biomass harvest, and downstream processes (see Figure 1). The main cultivation systems are open pond systems (raceway ponds with paddle wheels) and closed photobioreactors (PBRs), which can both be used for food and fuel production. Open ponds have been well established since the 1950s because of lower investment and operating costs and lower labor intensity. Despite the higher costs, PBRs are of interest because they allow for better control of the cultivation conditions than open systems. In addition, they achieve higher biomass productivities and allow for a more effective prevention of contamination. A large variety of PBRs has been developed (e.g., tubular, flat plate, green wall). They are mainly used for the production of high-value products (Zijffers et al., 2010) or in hybrid cultivation systems to supply high cell density algae to open ponds (Ben-Amotz, 1995). In PBRs, a high surface-to-volume ratio is needed. Sophisticated and complex constructions including a huge number of surfaces are required to provide optimal light intensity for algae cultivation. This

results in a high-energy demand for pumping and mixing to optimize the supply of light, carbon, and nutrients and for maintaining a constant temperature of 20–30°C.

Microalgae can be either autotrophic or heterotrophic, but some photosynthetic algae are mixotrophic, that is, they have the ability to both perform photosynthesis and acquire exogenous organic nutrients. Photoautotrophic microalgae use CO_2 as carbon source and photosynthesis as energy source. Technically produced CO_2, CO_2-rich emission streams, or waste streams with high CO_2 concentrations can be used to increase yields. CO_2 consumption by algae results in the formation of O_2, which needs to be removed. Further challenges of PBRs are fouling (biomass film formation), and loss of the light transparency of reactor walls made of plastic or glass as well as cleaning to reduce contamination, infestation, and predation by nontarget organisms (Da Silva & Reis, 2015). Both systems (open ponds and PBRs) are in principle suitable for food and fuel production. For integrated food and fuel production, however, the technology of choice would be PBRs in order to meet the quality and safety standards of the food sector.

Cultivation is followed by the separation of algae cells from the growing media and subsequent extraction of a lipid phase containing fatty acids, polysaccharides, proteins, and other high-value compounds. In the harvest and separation process, there is an increase in the dry matter content of dilute algae solutions ranging from 0.05% to 0.075% DM (open ponds) to 0.3% to 0.4% DM (PBRs) up to 10% to 25% DM (Wileman, Ozkan, & Berberoglu, 2012) by flocculation, filtration, centrifugation, sedimentation, or a combination of any of these techniques (Milledge & Heaven, 2013). After separation from the culture medium, algae biomass must be quickly processed to avoid loss of quality or spoilage.

A technologically rather simple way to use microalgae for integrated food and fuel production is to feed them into biogas plants or to further increase the DM content by spray drying, drum drying, and freeze drying and to sell them as complete (dried) algae. For an integrated food and fuel production process, stepwise extraction raises the content of the main valuable compounds, for example, fatty acids, proteins, and polysaccharides as well as the high-value compounds, such as carotenoids, phycobilins, PUFAs, and sterols (Borowitzka, 2013). To this end, after drying, the complex cell walls must be broken or disrupted for the release of the metabolites of interest. Several methods can be used depending on the microalgae cell wall characteristics and on the product nature to be obtained either based on mechanical or nonmechanical technologies. The mechanical methods include high-pressure and high-speed homogenization, bead mills, and pulsed electric field, microwave and ultrasound assistance, or autoclave. The nonmechanical action comprises freezing, organic solvents, and osmotic shock and acid, base, and enzyme reactions (Demuez, Mahdy, Tomás-Pejó, González-Fernández, & Ballesteros, 2015; Gerde, Montalbo-Lomboy, Yao, Grewell, & Wang, 2012; Günerken et al., 2015; Khanra et al., 2018).

Processing is a major technical (and economic) limitation to the integrated production of food and fuel and high-value compounds that is difficult to discuss, since it is highly specific and strongly depends on the desired products. For algae diesel production, fatty acids are extracted from the lyophilized biomass with solvents such as hexane, ethanol (96%), or a hexane–ethanol (96%) mixture. However, also other extraction methods such as ultrasound- and microwave-assisted extraction are suitable. However, more selective solvents and knowledge about process conditions regarding the type of lipophilic compound to be extracted are needed to enable different ways of processing for each compound. Algae fuels are technologically produced in a form akin to existing processes and technologies used for other biofuel feedstock. By transesterification in a multiple step reaction, the triglycerides are converted to monoglycerides, and these are then converted to esters (biodiesel) and glycerol (by-product).

For protein extraction, it is of great importance to ensure that the process will not have an impact on protein functionality and quality. Protein extraction involves centrifugation, ultrafiltration, precipitation, chromatography techniques (Sari, Mulder, Sanders, & Bruins, 2015), or solvent extraction and fractionation via lyophilization (freeze drying; Brentner, Eckelman, & Zimmerman, 2011). For more complex and integrated extraction of protein and fatty acids, protein extraction should be performed before lipid extraction to avoid impairment of protein quality. Polysaccharides, which are part of the cell walls or accumulated starch remaining from protein and lipid extraction, can be fermented into bioethanol or butanol. The integrated extraction of the desired food and fuel compounds in sufficient amounts and qualities without them damaging each other is considered a critical bottleneck for the integrated approach. Besides, the scalability of integrated production has to be further investigated due to different market sizes and requirements.

4 | ECONOMIC ASPECTS

The economic aspects of integrated food and fuel production with microalgae are difficult to assess since such a process does not exist yet. Beyond that, hardly any data on commercial algae production for fuel or food are available, and those that exist are based on either laboratory- or pilot-scale data or on assumptions only. Cost assessments found in literature vary widely depending on data and assumptions on, for example, productivity, energy price, and labor costs (Christiansen, Raj Raman, & Anex, 2012; Norsker, Barbosa, Vermuë, & Wijffels, 2011). The variety of calculation methods and

a lack of transparency in system and process design make comparison even more difficult (Acién, Fernández, Magán, & Molina, 2012; Bastiaens, Roy, Thomassen, & Elst, 2017).

As mentioned before, PBRs are characterized by high capital and operational costs, in particular due to high investment, energy, and labor costs (Da Silva & Reis, 2015). The small size of microalgae and the large volumes to be processed are main reasons for the high capital expenditure and energy consumption. The main cost driver is cultivation, but harvesting and dewatering account for at least 3%–15% of the total costs (Fasaei, Bitter, Slegers, & Boxtel, 2018). According to calculations, commercial production requires a significant reduction in production costs by a factor of 10 to 20 for food and 100 for feed and even more for fuels (Bastiaens et al., 2017; Enzing et al., 2014; Vigani et al., 2015). These numbers indicate that fuel production can only become economically feasible in combination with food production in the medium and long term. Besides, an increase in process stability and reliability is necessary to make integrated food and fuel production viable and competitive.

Cost reductions can be achieved by upscaling downstream processes, reducing labor costs through automation, and integrating recycled waste streams for the supply of nutrients (mainly nitrogen and phosphor) and CO_2. Increasing biomass productivity through genetic engineering and more efficient PBR systems can also help to reduce production costs. However, the use of waste streams and genetically modified algae (even with CRISPR-Cas) is difficult or impossible for integrated food and fuel production for reasons of quality, image, consumer acceptance, and current regulations.

Cost reductions through increased yields can hardly be realized with the phototrophic approach, since 80 tons DM per hectare and year are considered as maximum productivity that can be achieved with large-scale microalgae cultivation due to bio-technical limitations (Tredici, 2010). This is only possible by heterotrophic cultivation (Liang et al., 2009), an approach (fermentation technology) that is easily scalable and established at commercial scale for bacteria and yeasts. Heterotrophic cultivation involves lower land and investment costs due to a small surface-to-volume ratio, easily soluble and distributable carbon and energy sources, and reduced downstream costs (Da Silva & Reis, 2015). Besides, production is possible throughout the year with consistently high productivity since it is independent of climate conditions (Bumbak, Cook, Zachleder, Hauser, & Kovar, 2011). However, also heterotrophic cultivation is not competitive due to the costs of the organic carbon source, which account for 60%–80% (in case of glucose) of total costs (Yan, Lu, Chen, & Wu, 2011). Less expensive carbon sources such as glycerol and acetate are not promising either due to lower algae biomass productivities (Lowrey, Brooks, & McGinn, 2015; Perez-Garcia & Bashan, 2015). The most important argument against heterotrophic cultivation, however, is the fuel versus food dilemma, which will arise again if edible sugar is used for integrated production with microalgae, since part of the sugar will be used for fuel production.

5 | ENVIRONMENTAL ASPECTS

Like any production process, microalgae food and fuel production is linked to resource consumption and environmental impacts such as climate change. The results of life cycle assessment (LCA) studies on microalgae cultivation, mainly performed for fuel production, differ widely. Depending on the data used and assumptions made, for example, on productivity, content of fatty acids, proteins and polysaccharides, and energy requirement, the energy return on investment (EROI) varies from 0.01 to 3.35 (Ketzer, Skarka, & Rösch, 2018; Weiss, 2016). The highest environmental impact on the global warming potential of algae cultivation in PBRs is related to the consumption of energy, especially electricity for mixing, temperature control, as well as—depending on the concept—lighting (Mok & Rösch, 2017; Smetana, Sandmann, Rohn, Pleissner, & Heinz, 2017). These results are also applicable to food production in PBRs.

Life cycle assessment results for (small-scale) protein production from microalgae in Europe show that the environmental impact and resource footprint are higher than that of imported protein concentrate from large-scale soy meal production in South America (Taelman, Meester, Dijk, Silva, & Dewulf, 2015). In terms of land use, emissions from land use change, and ecotoxicity, algae protein provides benefits, for example, in densely populated areas of Europe, as microalgae can be grown on marginal land compared to traditional agriculture (Rösch, Skarka, & Wegerer, 2012; Walsh et al., 2016). To reduce the environmental impact of microalgae production, energy consumption for mixing and CO_2-rich flue gas supply must decrease, and the electricity supply must shift from fossil fuels to renewable sources (e.g., PV, biogas, or wind; Beach, Eckelman, Cui, Brentner, & Zimmerman, 2012; Taelman et al., 2015; Weschler, Barr, Harper, & Landis, 2014). It can be expected that the LCA results for algae protein production can be improved by integrated fuel production according to the allocation principle.

Besides energy, water demand is a crucial factor for microalgae production. The water demand is influenced by climate conditions, system design (open pond or closed PBR), harvesting, and cleaning technologies, but also by species (marine or freshwater algae) and the salt and heat tolerance of algae strains (Rösch & Marting Vidaurre, 2018). The freshwater demand can be reduced by marine or salt-tolerant algae and by recycling culture media after biomass separation. Particularly in southern locations with water scarcity during the summer months, the water demand has a significant

impact on the water footprint. For closed PBR systems, however, the water demand/yield ratio is significantly lower than for traditional agricultural crops.

The nutrient requirements (nitrogen, phosphate) for high algal productivity present another environmental challenge (Pate, Klise, & Wu, 2011). Instead of using chemical fertilizers, nutrient supply for cultivation can be sourced from available organic waste streams (e.g., food industry and communities), agricultural activities (e.g., digestate from biogas plants), or wastewater treatment (Shurtz, Wood, & Quinn, 2017; Walsh et al., 2016). However, this is only applicable for fuel production without costly recovery processes. For integrated food and fuel production, this would require changes in European and national regulations and conditions (Walsh et al., 2016). Reducing nutrient demand can also be achieved by closing nutrient cycles through reuse of nutrients after extraction of compounds for food and fuel production (Rösch et al., 2012).

6 | PUBLIC PERCEPTION

Despite large-scale investments and government mandates to expand biofuels development, little is known about how the public thinks about first-,second-,and third-generation biofuels. Public opinion on first-generation biofuels is less favorable due to the food versus fuel debate. Third-generation algae fuels have the advantage of not competing with arable land. However, with an increasing demand for algae food and fuel, also arable land could be used. In this scenario, integrated food and fuel production is expected to meet with greater public approval than fuel production only. As indicated by the results of a European survey focusing on the use of genetically modified algae to improve fuel productivity, a critical factor for public acceptance and willingness to buy even higher priced algae fuels is that algae technology and products fulfill their promises regarding climate change and environmental protection (Rösch & Varela Villarreal, 2018; Varela Villarreal & Rösch, 2017).

With regard to food production from microalgae, there is no evidence of rejection. In contrast, edible insects and cultured meat, which are also considered as alternative protein sources, face the challenge to mimic traditional meat in terms of sensory quality at an affordable price or to overcome rejection (BfR, 2016; Verbeke, Sans, & Loo, 2015). Microalgae food products focus on health aspects and are offered to consumers as superfoods and dietary supplements. Besides the motivation "health and wellness," Roßmann and Rösch (2018) identified three other key narratives for microalgae food products: microalgae (a) for cheap and unpretentious products, (b) to sustainably feed the world, and (c) for decentralized, regional food supply. According to their Delphi study, respondents believe that microalgae will contribute to tackling climate change and world hunger as well as to integrating local food supply into other production cycles. Roßmann and Rösch (2018) did not identify any concerns about large-scale microalgae production, which is in contrast to the expectation of experts (Meyer & Priefer, 2018, p. 126). The taste characteristics (gourmet food or unpretentiousness) seem to be of minor importance, although in daily life this is the most important criteria for the purchase of food products.

7 | CONCLUSIONS

Considering the high capital costs of building and operating production systems based on microalgae, the environmental challenges, and the sociotechnical risks of algae technology, the potential of microalgae should be fully exploited by using an integrated approach for food and fuel production. This way, algae fuels are expected to create an ever more favorable public perception and acceptance since there will be no land use competition even if microalgae cultivation increases and expands from marginal to arable land. Among the different compounds, protein is the most promising coproduct of fuel production since the market for plant protein is large and the demand cannot be matched by current European production. Other coproducts such as cosmetic supplements, nutraceuticals, pet food additives, and pigments may achieve higher returns on investment, but have only small markets, which would limit coproduction of fuels. With an ever-growing consumer awareness of health and sustainability, it is expected that the attractiveness of algae products as well as the willingness to buy these products despite higher prices will increase if algae keep their promises. From the sociotechnical point of view, it is crucial that algae food and fuel products will meet the expectations of consumers and promises regarding health and sustainability. The high expectations, acceptance, and trust in microalgae provide a good, but not self-evident basis for the development of integrated food and fuel production from microalgae. Excessive promises in terms of health benefits and sustainability briefly attract attention, but bear the risk that public attitudes will change in the long term if the promises cannot be fulfilled. Integrated food and fuel production from microalgae should therefore be developed using the codesign approach to integrate public perceptions and the views, knowledge, and values of citizens and stakeholders at an early stage into the research and innovation process.

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