University of Hohenheim

Doctoral Thesis

The bioeconomy:
A knowledge-based innovation paradigm to foster sustainability transformations

Thesis in fulfillment of the degree of doctor oeconomiae (Dr. oec.)

at the

Faculty of Business, Economics and Social Sciences

supervised by Prof. Dr. Andreas Pyka

Institute of Economics

submitted by Sophie Urmetzer, M.Sc.

2020

First advisor: Prof. Dr. Andreas Pyka

Second advisor: Prof. Dr. Iris Lewandowski

Chair of the committee: Prof. Dr. Klaus Prettner

Dean: Prof. Dr. Karsten Hadwich

Day of defense: 17.06.2020

The bioeconomy:

A knowledge-based innovation paradigm to foster sustainability transformations

Sophie Urmetzer

Dissertation

University of Hohenheim

2020

Acknowledgements

I like to picture my dissertation as an emergent phenomenon, an exceptional outcome of a system made up of wonderful people whom I met on the way, with whom I exchanged knowledge and ideas, discussed and argued, became frustrated and felt joy. I owe this thesis to every single one of them, particularly to Prof. Dr. Andreas Pyka, Prof. Dr. Iris Lewandowski, Michael Schlaile, Jan Lask, Ricardo Vargas-Carpintero, Dr. Kristina Bogner, Dr. Matthias Müller, Bianca Janić, and Anja Buck.

Thank you, Andreas Pyka, for all the inspiration and support during my studies. I am grateful for your trust in the power of interdisciplinary teams. You hired me when I knew nothing about creative destruction or technological paradigms and we spoke quite different languages. You let me keep up my aspiration for sustainability until we realized that our languages were quite compatible, even complementary. Thank you, Iris Lewandowski, for encouraging me in my endeavor and for accepting to co-supervise my thesis. Many thanks to all my co-authors, for your patience and the controversies we always managed to resolve. I am grateful, Micha, for your linguistic rigor and your companionship. Thank you, Jan and Ricardo, for your enthusiasm and your critical minds. Thank you, Kristina, for sparring and your infectious humor. Thank you, Matthias, for analytical thinking and steady support with computer problems. Thank you, Bianca, for your trust and warmth and the greatest assortment of Christmas cookies I know of. Thank you, Anja, for your assistance in formatting the thesis.

But, of course, the system which carried me all this time is larger than this. I want to express my gratitude to my adorable family, Paul leading the way: Working full-time, renovating one of the oldest houses in Plieningen, pampering three headstrong children, and enduring my changing moods – you are my hero. Thanks to my parents, Gesine and Bernhard Pahlmann. You were always prepared to suspend your multiple charity projects to support our family when I was not available. And you always believed in me, no matter what.

I am grateful for the financial support of the Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector for our research on academic bioeconomy education.

I dearly hope this dissertation proves worthy of the effort and trust every one of you contributed to its emergence.

Content

List of figures

List of tables

List of abbreviations

BM	Business model(s)
BMBF	Federal Ministry of Education and Research, Germany
BMEL	Federal Ministry of Food and Agriculture, Germany
COMEST	World Commission on the Ethics of Scientific Knowledge and Technology
DIS	Dedicated innovation systems(s)
EC	European Commission
EU	European Union
HRB-TBL	Human rights-based triple bottom line
ILUC	Indirect land-use change
IS	Innovation system(s)
MLR	Baden-Württemberg Ministry of the Rural Areas and Consumer Protection
MWK	Ministry of Science, Research and the Arts, Baden-Württemberg
RBA	Rule-based approach
RI	Responsible (research and) innovation
SDG	Sustainable Development Goals
SKBBE	Sustainable knowledge-based bioeconomy
TK	Transformative knowledge
UM	Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
WBGU	German Advisory Council on Global Change

Chapter I

Introduction

I. Introduction

"We can't save the world by playing by the rules, because the rules have to be changed.

Everything needs to change - and it has to start today."

Greta Thunberg (2018)

Humanity does not seem to come to grips with the global challenges it is currently confronted with. After 40 years of international negotiation on climate change, a recently published warning signed by more than 11.000 scientists from around the world invokes decision makers to read the unequivocal signs of various environmental and social indicators as wakening call to instantly act upon the "climate emergency" (Ripple et al. 2019, p. 1). And the sustainability challenges are not restricted to a changing global climate. The threats also include the convergence to other planetary boundaries, for instance, due to biodiversity loss, disturbed biochemical cycles, and the acidification of the oceans (Steffen et al. 2015) as well as to societal ills due to inequality, corruption, or missing access to health services and education, to name just a few (Raworth 2017). The wickedness that unifies all these problems is reflected by their mutual interconnectedness, their emergent and complex nature, their embeddedness in social structures and lifestyles, their uncertain effects, as well as by their obvious difficulty to be overcome (Hulme 2009; Wehrden et al. 2017; Rittel and Webber 1973; Schlaile and Urmetzer 2019). Despite this admittedly dire starting point, this thesis offers a carefully optimistic outlook on transformations to sustainability. No matter whether you call it change of rules, as Greta puts it, or change in paradigms as I will frame it – the reader will understand why and how a new common logic can help to trigger innovation processes that perpetuate a dedication to sustainability in a way that may eventually become as powerful as the current orientation to increasing profits and economic efficiency. In a nutshell, the basic narrative of this dissertation reads as follows:

(1) Sustainability challenges must be considered systemic outcomes of unsustainable innovation patterns of production and consumption, which is why solution approaches must address the systemic root causes of unsustainable innovation systems.
(2) Outcomes of an innovation system are determined – among others – by a specific innovation paradigm shared by the innovating actors.
(3) Innovation paradigms determine and are in turn determined by the knowledge base of the system, which is why a paradigm shift must be knowledge-based.
(4) The sustainable knowledge-based bioeconomy may be viewed as a new innovation paradigm which potentially changes innovation systems towards producing more sustainable outcomes.

1. The systemic nature of sustainability challenges

Several authors argue that the reason for humanity's inability to solve the most urgent sustainability challenges lies in their *wicked* nature (Hulme 2009; Blok et al. 2016; Stenmark 2015; Murphy 2012). Problems that display wicked characteristics cannot be tackled by conventional planning approaches (Rittel and Webber 1973) which have proven useful for dealing with 'tame' problems. Such approaches usually start with an analysis of the problem, based on which a solution is designed and finally implemented (Conklin 2006). Why is it that, although we know that carbon dioxide and other gases cause climate change, we cannot just stop their emission? If we trust that micro plastic infiltrates our food chains and harms human bodies, why can we not just cut the use of plastic and introduce functioning recycling systems? Such linear, top-down policies have rarely worked to counteract global threats for sustainability. Instead, wicked issues of unsustainability must be looked at in their systemic context, because they are usually the problematic outcomes of multiple, interconnected, and interdependent mechanisms unfolding at the intersection of social and ecological systems (Folke et al. 2005; O'Brien and Sygna 2018). Murphy (2012) identifies three features of systemic problems that make it especially hard to change modern production and consumption practices according to sustainability requirements: (i) The distance of consequences of unsustainable behavior in time and space, (ii) the difficulty to scale locally effective sustainable solutions, as well as (iii) the embeddedness of economic practices in cultural structures, social norms, and infrastructural conditions.

These features of the interplay of economic activity and socio-ecological systems directly reflect some general topics of systems thinking (taken from Meadows 2008). These concern (with reference to i), in terms of temporal distance, *delays* in systems behavior, for instance due to a delayed realization that something goes wrong or due to a deferred implementation or effect of counteractions. Another feature of systems reflects the issue of distance also in geographical and cognitive terms: due to their *complexity*, systems often create surprising outcomes. This holds true especially from the perspective of bounded rational actors like us (Simon 1972), who may make quite reasonable decisions on the basis of the information we have, but lack knowledge about more distant or otherwise invisible parts of the system. Distance between unsustainable behavior and its consequences, here, can mean that influencing mechanisms are effective in unknown parts of the global economy or at places in the system that have not been recognized to play a role. In this respect, natural ecosystems that we base our economy on (such as, for instance, forests, oceans, lakes, or agricultural ecosystems) feature a particularly wicked characteristic: they are usually able to buffer a lot of damage remaining seemingly stable and functioning for a long period of time until a certain threshold or tipping point is reached and the entire system suddenly collapses (Scheffer et al. 2001; Reyer et al. 2015; Lenton et al. 2008).

Another typical feature of systems is their *hierarchical structure* (with reference to ii) meaning that they are made of subsystems which again are made of subsystems and so forth. Subsystems of different hierarchic levels cannot be compared in their functioning even though they might appear to play by similar rules. Seyfang and Haxeltine, for instance, have observed that a transfer of the transformative power of local grassroots innovations, such as the transition towns movement, to larger geographical entities is usually bound to fail (2012). Likewise, the generation, application, and diffusion of sustainable technologies encounter different institutional settings if implemented at different governmental levels, for instance regarding markets and regulatory frameworks (Dewald and Fromhold-Eisebith 2015). In general, the scalability failure is a feature of transitions research that has been problematized before (Coenen et al. 2012). Furthermore, "our linear-thinking minds" (Meadows 2008, p. 91) are often surprised that a scaling of interventions rarely succeeds by proportionally increasing inputs because of non-linear relationships, unforeseen feedback loops, and unknown power-relations.

Finally, when dealing with systemic issues – especially in the social context – one must consider that the behavior of systems likely follows a certain *paradigm* (with reference to iii). These "shared social agreements about the nature of reality" (Meadows 2008, p. 163) are deeply rooted in cultures and determine the goals of the system as well as the entire way the system works. Consequently, when a change in system outcomes is aimed for, for instance because the current outcomes are unsustainable, a change in paradigm promises to be an extremely powerful lever (Meadows 1999; Abson et al., 2017). Unfortunately, a paradigm change is also extremely hard to accomplish. This is due to the inertia of paradigmatic conventions along with their material manifestation in infrastructures, technologies, knowledge, and production processes.

It goes without saying that delays, complexity, and the hierarchical structure of production and consumption systems are necessary to be considered when dealing with wicked sustainability problems. For anyone aiming at alleviating some of these challenges, it is imperative to understand the systemic interconnections of the problems within their social, ecological, and economic context – a body of knowledge which has been termed systems knowledge (ProClim 1997; Abson et al. 2014; Urmetzer et al. 2018). However, to be able to trigger and shape transformative change, it is not sufficient to know how the system functions. Transformative knowledge, the know-how for developing strategies for the transformation to sustainability must also be created and used. But strategies for change require a goal. What is needed is a sense of direction, a vision determining the goals towards which the transition should move (ProClim, 1997; Abson et al. 2014; Urmetzer et al. 2018). This normative dimension of development paths – also referred to as normative knowledge – is embedded in the socio-cultural context of systems and shapes the rate and direction of their development, often implicitly and unobserved.

2. Innovation systems and innovation paradigms

Systems of production and consumption do not develop randomly. The way economies evolve is strongly determined by natural circumstances as well as by what has been termed the *social environment* (Freeman 1991) or *institutional factors* (Dosi 1982). These act as either a stimulus or a prevention mechanism for the deployment of new technologies thus regulating the rate and direction of innovative activity. Quite obviously, the current social environment seems to allow for an economic evolution that aggravates the global sustainability challenges rather than solving the problems. In the same vein, Murphy has described today's unsustainable market logic as *non-ecological economic modernization* (2012). It encourages innovations that create economic growth and increase efficiency (Schlaile et al. 2017) while approving economic practices that contribute to the degradation of natural ecosystems and to the exacerbation of climate change (Murphy 2012).

Undoubtedly, it must be acknowledged that technological progress in our economic systems has improved the living conditions of millions of people worldwide. At the same time, a large part of the causes of global sustainability challenges have come along with it (Pyka et al. 2019). To reduce the negative impact of industrialized processes technologically, material and energy efficiency must be improved tremendously, and industries must be installed that are based on new, less harmful, and cleaner technologies. However, such developments cannot be expected to take place precisely because of our current market logic. And if they would, for instance as a result of authoritarian policies, a mere technical optimization of current production and consumption patterns towards economic growth and system efficiency would not lead to conditions necessary for humanity's prosperous future on Earth (Frantzeskaki et al. 2012; Schot and Steinmueller 2018; Fischer and Riechers 2019). What is needed are altered societal and economic practices, values, and attitudes, also referred to as social, ecological, and political innovations (Cajaiba-Santana 2014; Pyka 2017). Innovations that contribute to achieving the Sustainable Development Goals (SDG) (UN 2015) thus require concepts that tackle the challenges on the basis of radical shifts on a technological, but equally on an organizational, economic, institutional, socio-cultural, and political level (Patterson et al. 2017; Grin et al. 2010; Markard et al. 2012).

To better understand the dynamics and actor configurations behind the urgent socio-economic transformations, it has proven useful to study such processes of change towards sustainability through the lens of innovation systems (IS) (Markard et al. 2012; Urmetzer and Pyka 2019; Weber and Truffer 2017; Jacobsson and Bergek 2011; Smith et al. 2010). As a response to the desire of political and academic experts during the 1980s to improve our understanding and to enhance the competitiveness of nations (Klein and Sauer 2016), scholars around Dosi, Freeman, and Nelson (e.g., Dosi et al. 1988; Freeman 1987; Nelson 1993) developed the idea of conceptualizing innovation as a product of systemic interaction. In IS, those actors and institutions that promote the acquisition and diffusion of new knowledge are seen to be part of a specific socioeconomic system (Lundvall 1992). Actors can be, for instance, private businesses, state authorities, research institutions, and consumers, while institutions comprise regulations, standards, and practices, as well as assumptions and world views. Within IS, "political and cultural influences as well as economic policies help to determine the scale, direction and relative success of innovation" (Freeman 2002, p. 194).

Until recently, the direction of innovation processes has not been sufficiently addressed in IS research (Daimer et al. 2012; Tödtling and Trippl 2018; Lindner et al. 2016; Urmetzer and Pyka 2019). In fact, it is still debated how the complex and evolutionary nature of IS (Edquist 2005) and the fundamental uncertainty of innovation (Knight 1921) on the one hand, can be reconciled with the strongly normative goal orientation of sustainable development on the other, as expressed, for instance, in the SDG (UN

2015). A way out of this dilemma may be a conceptual shift from driving transformations of the innovation outcomes to transformations of the underlying logic of innovation, or *innovation paradigm*.

Although paradigms have not been explicitly conceptualized in the IS literature, they implicitly play a role in what is being termed "institutions" in IS jargon. The idea of a common innovation principle shared by all elements of an IS is not new. Several authors have proposed and discussed various functions delivered by IS. Among them they describe, for instance, the guidance of the direction of search processes (Jacobsson et al. 2004), guidance of the search (Hekkert et al. 2007), or the influence on the direction of search and legitimation (Bergek et al. 2008) as important engines of technological progress. A relatively new advancement of IS concerned with the quality of innovation paradigms is the *dedicated innovation system* (DIS) (Pyka 2017). It is based on the assumption that in order to integrate a normative dimension in IS, a redefinition of the logic of the search heuristics underlying innovation is required. "While the creation, diffusion, and use of knowledge in IS aim at innovation for enhancing international competitiveness and economic growth (…), dedicated innovations shall improve sustainability performance (…). Such dedicated innovation systems (…) can be thought of as IS that explicitly go beyond their traditional orientation by allowing for paradigmatic change toward sustainability" (Urmetzer and Pyka 2019, p. 8, based on Gregersen and Johnson 1997).

Various evolutionary economists have emphasized the crucial role of paradigms in economic development (Freeman 1991; Dosi 1982; Perez 2010). The idea of paradigms shaping technological progress has been inspired by the epistemological notion of a *scientific paradigm* (Kuhn 1962). Technology related paradigms can be interpreted as a theoretical construct to connect the macro-level of technological change and progress of an economy to the meso-level of the emergence of new industries and to the micro-level of innovation decisions within firms. In analogy with the scientific paradigm a *technological paradigm* refers to "a 'model' and a 'pattern' of solution of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies" (Dosi 1982, p. 152). It is shaped by the respective *technological trajectory* which can be thought of as "the pattern of 'normal' problem solving activity (i.e. of 'progress') on the ground of a technological paradigm" and which "embodies strong prescriptions on the *directions* of technical change to pursue and those to neglect" (Dosi 1982, p. 152).

For the purpose of this dissertation, the conventional scope of Dosi's technological paradigm shall be expanded in a way that it will not only account for the creation of new technologies. An innovation paradigm, instead, shall be understood here as guiding the rate and direction of radical shifts in IS on technological, organizational, economic, institutional, socio-cultural, and political levels. This involves an expansion of all three of Dosi's pillars: the problem definition space must expand beyond technological problems, the selected principles must open-up towards natural and systemic processes that have not been considered, and the solution space must expand beyond material technologies (Figure 1).

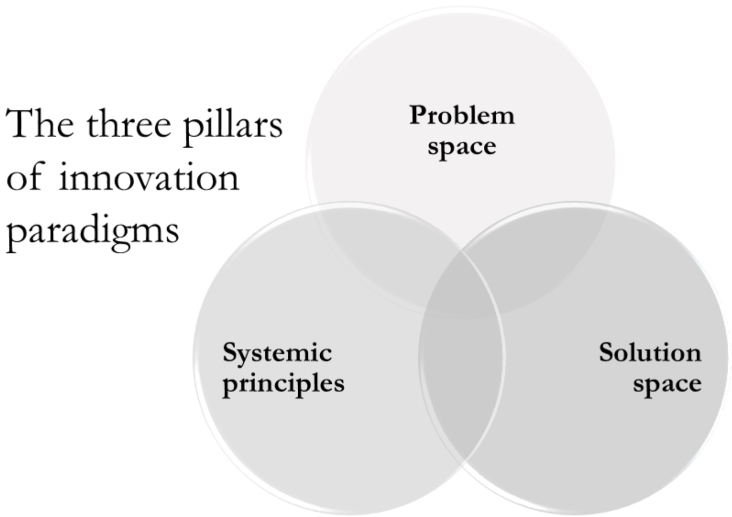

Figure 1 The three pillars of innovation paradigms based on Dosi (1982)

3. Knowledge and innovation paradigms

While we cannot design an IS in a way that guarantees presumably desirable outcomes (Edquist 1997), research is able to identify and better understand manifestations of innovation paradigms within an IS that are responsible for undesirable outcomes. The better we understand innovation paradigms that encourage unsustainable economic practices, the better we will be able to inform interventions to transform IS to dedicated engines of sustainability at the powerful leverage point of paradigms (Meadows 1999) – be it in the field of policies, education, or businesses.

Let us now consider, as an example, one of the problematic principles of current production and consumption patterns: the excessive use of fossil resources for providing mobility. From a paradigmatic point of view according to Dosi (1982), such system behavior seems to be driven by the selection of technological problems or needs ("safe, fast, and convenient automobiles"), the selection of natural principles ("big and strongly motorized cars are safe, fast, and convenient"), and the selection of material technologies ("fossil-based combustion engines"). Within this innovation paradigm, "normal" problem solving activity has – despite expected efficiency improvements due to technological development – notoriously favored the development of heavier vehicles run by more powerful combustion engines. As such, this technological paradigm has led to a further increase of oil production and the related emissions of carbon dioxide[1].

[1] I will omit other negative sustainability effects for the sake of precision of argument. These include the sprawl of traffic infrastructure with its impact on natural ecosystems (see, e.g., Næss and Vogel 2012; Borén et al. 2017) or the arms race happening on the roads, which produces ever more armored vehicles with severe safety issues for other traffic participants (see, e.g., Banister 2015; Anderson and Auffhammer 2014; Li, 2012).

A quite widely diffused proposition to stop or reverse this development is to transform economic systems into bio-based economies, which are based on biological resources and processes. But will the substitution of the material technologies from fossil-based to bio-based really solve the problem? Can bioeconomy principles shake the underlying systemic logic of unsustainable patterns of production and consumption? Recent history has shown that a replacement of the resource base in combustion engines did not solve the problem. On the contrary, it created new problems in sectors and geographical areas no one had foreseen (Leemans et al. 1996; Searchinger et al. 2008). And aside from the fact that a full substitution would raise serious issues of biomass availability (Lewandowski 2015; Kircher 2012), the selection of material and technologies only represents one part of the innovation paradigm.

Obviously, on top of that, a paradigmatic counter draft of an IS requires a redefinition of the relevant problems or needs as well as a reconsideration of principles derived from natural sciences. In other words, apart from the technological knowledge necessary to develop solutions for current problems, there is a need to fundamentally update our knowledge on the systemic principles currently at work in fossil-based IS and the socio-ecological systems they rely on. Likewise, producers, consumers, science, and politics need to come to terms with what the relevant problems are that need to be solved and to what end. In the same vein, sustainability science suggests that, next to technological knowledge, additional types of knowledge are required to successfully spur and shape transformation processes to sustainability: Systems knowledge, normative knowledge, and transformative knowledge (Urmetzer et al. 2018). Consequently, a paradigm shift will be built upon a fundamental reconsideration of the knowledge we take for granted regarding the needs or problems, the natural principles, and the potential solutions. This revelation resonates well with Abson and colleagues' assertion that the way a society produces and uses knowledge strongly influences societal outcomes (Abson et al. 2017). The authors conclude that in order to spur a fundamental system change towards sustainability, the available knowledge base must be reviewed, knowledge production processes must be reconsidered, and societal beliefs that may impede the desired transformation must be identified and addressed (ibid.).

Reciprocally and following what has been developed before, technological trajectories take their starting points in innovation paradigms. In that, trajectories comprise the search heuristics that establish the paths of research to pursue and those to avoid (Dosi 1982). Put differently, innovation paradigms determine the kind, the rate, and the direction of new knowledge produced in IS. This leads to the conclusion that we are faced with an intricate and co-evolutionary relationship between knowledge and innovation paradigms: While the collective knowledge base of IS actors, such as private businesses, state authorities, research institutions, and consumers determines the innovation paradigm, the paradigm itself provides the search heuristics for the creation of new knowledge. This self-reinforcing loop may be understood as the knowledge-based root-cause of paradigmatic inertia. It directly relates to evolutionary economists' theories about the conservative behavior of economic systems which have been framed as path-dependency of economic change (David 1985), lock-in of economic evolution (Unruh 2000), or the stability of socio-technical regimes (Geels 2004).

In the following Section, I will introduce the concept of a sustainable knowledge-based bioeconomy as an example for a new innovation paradigm with the potential to spur sustainability transformations. It will be shown that for the bioeconomy to become an important contributor to sustainability it must be framed, planned, and implemented in a way that it obtains the opportunity to change areas of the IS that go deeper than mere resource substitution.

4. The sustainable knowledge-based bioeconomy – a new innovation paradigm?

Around the world and through the diverse arenas of science, politics, and industry, the concept of a bio-based economy or bioeconomy is advertised as an important contribution to climate protection, an engine for employment and innovation, and as facilitator of resource productivity (Carus et al. 2011; Staffas et al. 2013; EC 2018). However, the perception of its substance as well as the expectations regarding its potential vary widely (Hausknost et al. 2017; Bugge et al. 2016; Vivien et al. 2019; Levidow et al. 2013). The common thread connecting most of the definitions of bioeconomy is the convention that the "basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal sources" (McCormick and Kautto 2013, p. 2590). It is widely agreed that a bioeconomy potentially reduces our dependence on fossil carbon thereby alleviating the impact of economic activity on the global climate. It is debated, however, in which way bioeconomy affects other aspects of sustainability (D'Amato et al. 2017), for instance regarding its impact on natural ecosystems and biodiversity or regarding its social implications (Pfau et al. 2014). While the US-American administration pictures the bioeconomy as an additional sector to be created around the biological sciences (The White House 2012), the OECD International Futures Programme offers a more holistic perspective for the bioeconomy as "a world where biotechnology contributes to a significant share of economic output." (OECD 2009, p. 8). The European Commission (EC) recognizes the bioeconomy as an already existing but expandable part of the current economic system. The EC include in their definition "all sectors and systems that rely on biological resources (…), their functions and principles" (EC 2018, p. 4). According to the Commission, the future development of the bioeconomy must safeguard sustainability, modernization, and environmental protection as core requirements.

Departing from these relatively static and sectoral perceptions of the bioeconomy, the federal German administration understands a bioeconomy as being based "upon a *structural transition* from an economy based on finite resources of fossil origin – mainly petroleum – to an economy more strongly based on renewable resources" (Federal Ministry for Food and Agriculture 2014, emphasis added). It emphasizes the centrality of new *knowledge* to be created in the life sciences and technical sciences to better understand those global biological systems that provide the basis for an efficient and *sustainable* use for economic development. Finally, the German strategy expects that the bioeconomy "not only replaces raw materials sourced from fossils; it also develops wholly new products and processes." (Federal Ministry for Food and Agriculture 2014, p. 14). With this definition, the German view on the bioeconomy already anticipates, albeit perhaps not fully intentionally, three important characteristics of a new innovation paradigm for sustainability transformations: (i) the aim for a *transition* to an economy based on renewable resources, including the dismissal of pure replacement strategies, (ii) the centrality of *knowledge*, and (iii) the requirement of *sustainability*. However, the German knowledge-based bioeconomy with its commitment to sustainability, as well as other European endeavors still seem to lag in providing an important contribution to a system-wide transformation to sustainability (Besi and McCormick 2015; Heimann 2019). One explanation could be found in my earlier argumentation that a sustainable knowledge-based bioeconomy has got the potential to contribute to sustainability transformations only if it is understood as a new innovation paradigm that changes the inner logic of IS. To do so, it must guide the rate and direction of radical shifts at all levels of the IS. This requires challenging the current innovation paradigm at its three pillars: the problem definition space, the natural mechanisms at work, and the solution space.

However, such radical changes at the fundaments of innovation automatically create winners and losers, since creation of the new always entails destruction of the old (Schumpeter 1943). It seems to be a common phenomenon that the focus of innovation policy is generally put on creation rather than on destruction (Kivimaa and Kern 2016). This might be a reason why the dominant bioeconomy narratives still overemphasize the solution space by celebrating new technologies, or the *means* of the bioeconomy instead of discussing more generally "the aims, contours, limits, moral standards and principles of that future economic model" (Hausknost et al. 2017, p. 19). This general imbalance is also reflected in the bioeconomy research landscape where natural and engineering sciences by far dominate the publication charts (Bugge et al. 2016; Sanz-Hernández et al. 2019). Yet, innovations that are guided by a new paradigm – as reflected by an extended problem definition space, different systemic principles, as well as a widened solution space – will be likely to invoke self-reinforcing systems of innovation that contribute to the transformation to sustainability without compromising the openness of technological development. The knowledge-based requirements for achieving a true paradigmatic change dedicated to a sustainable knowledge-based bioeconomy will be discussed at the end of this dissertation.

5. The aim and structure of the thesis

The dissertation proposes a new perspective on transformations to sustainability. By turning the attention from the innovation as an outcome of IS to the innovation paradigm as guiding principle for IS processes, I present different theoretical gateways for knowledge-based interventions in presently unsustainable systems of production and consumption. Figure 2 illustrates the collocation of the research questions guiding the dissertation. The main question (to the left) is subdivided into the four research questions (to the right), listed according to their appearance in the Chapters. The guiding research question is:

How does the innovation paradigm approach offer leverage on sustainability transformations and what are the implications for the introduction of a sustainable bioeconomy?

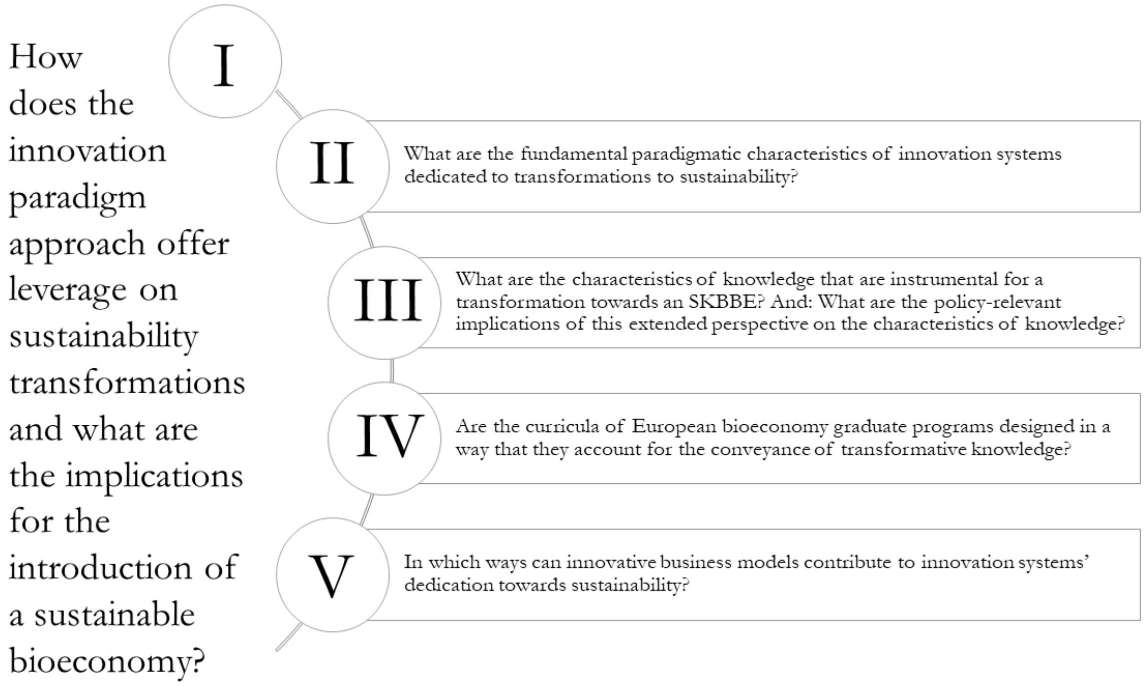

Figure 2 The overall research question and the sub questions according to their appearance in the Chapters.

Chapter II starts out on this journey with a critical analysis of the conceptual framework that provides the backbone for this thesis: the innovation systems (IS). It is shown that a fundamental paradigm shift in IS research is necessary to account for a more explicit and integrative consideration of the normative concept of sustainability. The characteristics of a new IS paradigm are carved out as compared to the implicit logic of conventional IS. This raises issues of how to give outcomes of IS a direction, how to legitimize them, and whom to make responsible for them. Recent academic approaches that address these issues are displayed and the notion of IS dedicated to sustainability transformations (Pyka 2017) is further refined. After this introduction to the normative dimension of IS, Chapter III explores in detail the knowledge base required for transformative paradigms in IS. The sustainable knowledge-based bioeconomy is used as an example to detail the characteristics of systems knowledge, normative knowledge, and transformative knowledge (Abson et al. 2014) as fundamental building blocks for a paradigmatic change in IS. The findings help to better understand and possibly cure knowledge-related gaps in current bioeconomy policies in Europe. Chapter IV turns from knowledge-related theory to knowledge creation in practice by exploring closely some of the academic skills necessary for future decision makers in bioeconomy transformations. The analysis of higher education bioeconomy programs across Europe reveals that our future academic bioeconomists are relatively well trained in transformative skills, such as communication, participation, and decision making expertise. One element of transformative knowledge that seems to be underrepresented in European bioeconomy curricula is the ability to revise and reflect personal values –an important quality when it comes to the task of breaking conventional innovation paradigms. The last study is presented in Chapter V and observes the potential of private businesses to contribute to paradigmatic change in IS. An altered innovation paradigm cannot be expected to gather pace without the contribution of some of the incumbent firms. On the basis of a systematic literature review, this Chapter proposes avenues for business model innovation that proactively alter innovation trajectories within IS and thereby promote an overall shift in the innovation paradigm. Chapter VI discusses the overall results against the backdrop of a new bioeconomy paradigm and concludes.

Chapter II

Innovation Systems for Transformations towards Sustainability? Taking the Normative Dimension Seriously

II. Innovation Systems for Transformations towards Sustainability? Taking the Normative Dimension Seriously

Abstract

The aim of this article is to complement research on transformations towards sustainability by drawing upon the innovation systems (IS) framework. The IS framework already serves as a suitable and influential basis for research on processes of technological innovation and economic change. We argue that improving the capacity of an IS framework for dealing with wicked problems and the normative complexity of sustainability requires a fundamental paradigm shift because in the current IS paradigm innovations are considered as per se desirable and in mostly technological terms. Therefore, we call for IS dedicated to transformations towards sustainability by opening up for systemic innovations beyond the technological dimension and by acknowledging that stakeholders have conflicting visions, interests, norms, and expectations with regard to sustainability goals. Taking the normative dimension of transformations towards sustainability seriously thus requires more explicit and integrative research on directionality, legitimacy, responsibility, and their interrelation in IS. The article concludes by proposing suggestions for future research based on IS-related approaches that can serve as building blocks for an IS framework capable of incorporating legitimate goal-orientation for transformative innovation by and for society.

Keywords

Wicked problems; transformations towards sustainability; innovation systems; normativity; paradigms; directionality; legitimacy; responsibility; dedicated innovation systems

Status of publication

This article has been published. Please cite as follows:

Schlaile, M., Urmetzer, S., Blok, V., Andersen, A., Timmermans, J., Mueller, M., Fagerberg, J. & Pyka, A. (2017). Innovation systems for transformations towards sustainability? Taking the normative dimension seriously. Sustainability, 9(12), 2253.

The content of the text has not been altered. For reasons of consistency, the language and the formatting have been changed slightly.

1. Introduction

Humanity is currently facing multiple crises: climate change, dwindling natural resources, and the unjust distribution of wealth and security are threatening the planet and its inhabitants (e.g., Brand and Wissen 2012). The way humans are interfering with life-maintaining Earth system processes has already alarmed scientists long ago (see also Meadows et al. 1972; Meadows et al. 2004). In fact, Rockström and colleagues (Rockström et al. 2009; Rockström et al. 2009) claim that the Earth system has already crossed several thresholds and thus transcended what they term *planetary boundaries*, beyond which safe operating space for humanity can no longer be guaranteed and sustainability is severely compromised (see also Steffen et al. 2015). These interrelated and systemic challenges have been referred to alternatively as *wicked problems* (Blok et al. 2015; Hulme 2009; Rittel and Webber 1973; Von Wehrden et al. 2017, Brown et al. 2010), *persistent problems* (Rotmans and Loorbach 2009; Frantzeskaki et al. 2012), *complex challenges* (Hassan 2014), *grand challenges* (e.g., Von Schornberg 2013; Cagnin et al. 2012; Kuhlmann and Rip 2014), or even *super wicked problems* (Levin et al. 2012) in the sense that their causes are emergent and complex, they are embedded in the social structure, their effects are uncertain, and they are thus extremely difficult to manage. It is rather unsurprising that in the context of this multiplexity of problems sustainability itself becomes a deeply normative issue often involving conflicting worldviews and contested pathways. Consequently, technological solutions will not suffice to fundamentally improve the prospects for our living conditions in the sense of a sustainable future, and an "optimization" of present systems is literally impossible (Frantzeskaki et al. 2012; Schot and Steinmueller 2016; Ostrom 2009). Quite the contrary, tackling wicked problems (and all of the other problems and challenges mentioned above) requires radical systemic changes, i.e., *transformations*, in multiple dimensions (e.g., economic, institutional, technical, cultural, organizational, etc.). This, in turn, necessitates advanced and comprehensive approaches aiming at better understanding and governing these so-called transformations towards sustainability (Frantzeskaki et al. 2012; European Environment Agency 2016; Görg et al. 2017; Patterson et al. 2017; Weber and Hemmelskamp 2005; Weber and Rohracher 2012; Hill et al. 2017)

With this article, we aim to complement research on these transformations towards sustainability in two ways. First, we discuss the (lack of a) normative dimension of *innovation systems* (IS)—a framework deemed suitable for scrutinizing processes of technological and economic change. More specifically, we contribute to the development of an advanced IS framework in which issues of normativity are integrated. Our discussion ties in with recent debates on normative foundations and directionality in IS (e.g., Bryden et al. 2013; Bryden and Gezelius 2017; Daimer et al. 2012; Godin 2015; Lindner et al. 2016; Soete 2013; Weber and Truffer 2017) and with discussions about the need for (more) responsible innovation (e.g., Von Schomberg 2013; Owen et al. 2012; Owen et al. 2013; Stilgoe et al. 2013; Von Schomberg 2012; see also Lubberink et al. 2017; Lubberink et al. 2017; Timmermans 2017 for reviews). Second, we provide a fundamental argument for the difficulties of integrating normativity in IS, which inevitably calls for a paradigm shift in our way of thinking about IS. Based on this theoretical conception, we propose a research agenda to enhance the capacity of the IS framework to assist researchers and policy-makers in tackling transformations towards sustainability beyond technological solutions.

The paper is structured as follows: Section 2 introduces IS as the underlying concept for our argument and points to its limitations for contributing to better understanding and governing sustainability transformations. Section 3 opens a door for adapting the IS concept to the challenge of tackling wicked problems related to transformations towards sustainability: We raise awareness for the complex normativity of sustainability and emphasize the need for a new, dedicated IS paradigm. We contrast the leading assumptions, dominant values, and practices of the current IS paradigm with those of a dedicated IS paradigm and identify three important issues connected to normativity that must be dealt with when a paradigm shift is aimed at. Subsequently, Section 4 introduces recent theoretical and practical approximations towards parts of the questions raised before. These existing strands of research serve as building blocks for a new research agenda that we deem necessary for the future in order to answer the overarching question of how IS can incorporate legitimate goal-orientation for transformative innovation by and for society. Section 5 concludes the article by summarizing key arguments and avenues for further research.

2. Innovation Systems: Merits and Limits in the Light of Transformations

Understanding and governing processes of technological and economic change have been the underlying rationale for the emergence of the framework of IS, building on evolutionary economics and related disciplines (e.g., Freeman 1987; Dosi et al. 1988; Lundvall 1992; Lundvall 1998; Nelson 1993). Notably, the rise of this framework can be seen as a revolution against mainstream economics by radically challenging unsuitable axioms and simplistic presuppositions of neoclassical economics (Moussavi 2017). For the purpose of a working definition, we follow Niosi and colleagues, who propose to understand IS as systems of multiple interacting agents "aiming at the production of science and technology . . . Interaction among these units may be technical, commercial, legal, social, and financial, inasmuch as the goal of the interaction is the development, protection, financing, or regulation of new science and technology" (Niosi et al. 1993, p. 212; for extensive reviews and overviews, see Weber and Truffer 2017; Edquist 2005; Fagerberg and Sapprasert 2011; Gordin 2009; Klein and Sauer 2016; Sharif 2006). IS have since served scientists as a model for understanding the complex systemic nature of innovation, they have equipped policy-makers with a basis for designing innovation policies (e.g., Edler and Fagerberg 2017; Fagerberg 2017), and they have informed firms to formulate innovation strategies (e.g., Edquist 1997; Lundvall 2007). Until today, the IS literature remains the most influential one for the international innovation policy community (Lindner et al. 2016). The framework has been adapted to various levels (Weber and Truffer 2017; Edquist 2005; Klein und Sauer 2016) including *national* (e.g., see Johnson and Lundvall 2013; Teixeira 2014), *regional* (e.g., Doloreux and Gomez 2017), *sectoral* (e.g., Malerba 2002; Malerba 2005), *technological* (e.g., Bergek et al. 2008; Carlsson and Stankiewicz 1991; Hekkert et al. 2007;

Markard et al. 2015), and recently even *global* IS (Binz and Truffer 2017). In summary, it can be said that IS provide a heuristic framework for examining the collective of actors and institutions involved in innovation and their interactions within (more or less) defined boundaries (Gregersen and Johnson 1997; Edquist and Johnson 1997).

The central aim of most research on IS has been to reveal how differences in configurations as well as interactive learning processes of the respective actors and institutions are responsible for particular (knowledge-based) economic outcomes (Lundvall 1992; Edquist 1997; Lundvall 2016). Much of IS research has focused on analyzing how generic innovation capabilities can be strengthened (Weber 2012; Wydra 2015). The long-term goal of these economic outcomes, however, has not been explicated so far but rather regarded as determined by the system's actors and their specific configuration (Patel and Pavitt 1994; Edquist and Lundvall 1993). Remarkably enough, for a long time, the IS literature has fallen victim to the same inherent fallacy as a large part of innovation research has, namely that innovation per se is good (Godin 2015; Soete 2013; Blok and Lemmens 2015; Buenstorf 2013; Schlaile 2017). Therefore, scholars have paid insufficient attention to the ethical acceptability and societal desirability of innovations. With this, we do not want to imply that IS scholars have completely neglected sustainability considerations (e.g., see Weber and Hemmelskamp 2005; Bryden and Gezelius 2017; Freeman 1992; Altenburg 2012; Jacobsson and Bergek 2011; Segura-Bonilla 1999; Segura-Bonilla 2003; Andersen and Johnson 2015; Stamm et al. 2009; Walz and Kuhlmann 2005). Nevertheless, many of the approaches—particularly the so-called *sustainable systems of innovation* (Segura-Bonilla 1999; Segura-Bonilla 2003) or *sustainability-oriented innovation systems* (Altenburg and Pegels 2012; Jacobsson and Bergek 2011; Segura-Bonilla 1999; Segura-Bonilla 2003; Andersen and Johnson 2015; Stamm et al. 2009) - remain focused on technological innovation with the aim of environmental protection. In the face of wicked problems, this is simply insufficient.

Transformations towards sustainability involve, for example, also changing practices, routines, and habits of both producers and consumers (e.g., Schlaile et al. 2016; Schmidt 2016; Davies 2014; Southerton and Ulph 2014) and other types of innovation beyond technological solutions (e.g., Warnke et al. 2016; Avelino et al. 2017; Haxeltine et al. 2016; Olsson et al. 2017; Rao-Nicholson 2017; Steward 2008; Bajmócy and Gébert 2014; Leach et al. 2012). Moreover, in order to achieve systemic changes, multiple sustainability dimensions (e.g., economic, institutional, cultural, organizational, etc.) have to be considered beyond environmental ones.

In summary, it can be said that research on IS enhances our understanding of conditions and actor configurations conducive to innovation (Weber and Truffer 2017; Klein and Sauer 2016; Lundvall 2016; Warnke et al 2016) but so far lacks an explicit debate about the normativity, i.e., desirability and goals of innovation processes (Bryden and Gezelius 2017; Daimer et al. 2012; Lindner et al. 2016). Furthermore, most previous IS approaches that deal with sustainability appear to have neglected its complexity by focusing on solving (only) environmental problems with (only) technological innovations (Bryden and

Gezelius 2017; Green 2005). This gap renders IS frameworks currently insufficient to address wicked problems in the context of sustainability.

3. Exploring the Normative Dimension

Evidently, it is anything but trivial to integrate "sustainability" in the sense of a goal-orientation in IS. Among other things, this is owed to the fact that sustainability can never be perceived as just "a technical optimisation puzzle waiting to be solved" (Hormio 2017, p. 111). Instead, sustainability itself is a deeply complex normative issue that needs to be made explicit. This Section, therefore, explores implications of this normative complexity for IS research aimed at transformations towards sustainability.

3.1 The Complex Normativity of Sustainability and the Need for a New IS Paradigm

It has long been recognized that sustainability per se has a deeply normative nature (Kates 2001; Renn et al. 2009; Swart et al. 2004; Walsh et al. 2017; Wang 2011). The literature on sustainability is not merely *de*scriptive about various problems, but also *pre*scriptive about practices for 'human use of the Earth' (e.g., Kates 2001; Wang 2011; Hahn 2009). Sustainability then provides a vision of a desirable state of what the future should look like, alongside a set of rules that indicate what ought to happen for this state to be reached (Renn 2009). However, it has been criticized that normative or ethical aspects of sustainability have often been misrepresented or even disregarded (Becker 2012). Although conceptions of sustainability share a general normative outlook, they differ on what the desired state should look like and by which means (i.e., practices) it ought to be attained (e.g., Blok et al. 2015; De Witt et al. 2010; De Witt 2015; Franceschini et al. 2016; Hoffman 2012; Hoffman 2015; Hulme 2015; Peterson 2009; Anderson et al. 2015; Miller et al. 2014). In other words, different societal actors have different worldviews and visions with regard to (pathways to) sustainability (Blok 2018; Luederitz et al. 2017; Parodi 2015). For example, the so-called Brundtland Report emphasizes the ability of future generations to fulfil their needs and the conservation of plant and animal species (World Commission on Environment and Development 1987), while the understanding of sustainability held by the report of the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) underlines the need to discern "the earth's carrying capacity and continuity of regenerating enough resources for the sake of future generations and the vulnerable sectors of society" (COMEST 2015, p. 11). Likewise, companies such as Unilever or Shell have a different conception of what a sustainable society ought to look like from non-governmental organizations such as Greenpeace or Friends of the Earth. Against this background, it can be observed that prior research on sustainability transformations has often neglected the complexity of differing worldviews, norms, and value systems by presuming consensus about the scale and importance of sustainability-related visions (Almudi et al. 2017). From this, it follows that the worldviews shaping both current IS frameworks and those dedicated to transformations must be scrutinized. Such an endeavor requires researchers to shift attention to the *paradigm* level.

A paradigm may be regarded as a set of basic beliefs or metaphysics that deals with ultimates or first principles (Denzin and Lincoln 2005). For our current purpose, it can be defined as a complex set of assumptions, concepts, values, and practices that constitute a worldview for the community that shares them (see also Meadows 1999; Meadows 2008; Sanford 2015). Hence, paradigms span a *bounded performative space* within which certain actions or practices are regarded as possible, reasonable, legitimate, and important, while others are excluded as being impossible, illegitimate, unreasonable, and unimportant (Ratcliffe 1983). This performative space actuates but also bounds the emergence and development of practices within IS.

It is important to note, however, that the relationship between paradigms and societal practices is not unidirectional. Quite the contrary, in a co-evolutionary sense, we may contend that there actually are feedback loops between paradigm and practice. Foremost, paradigms are constitutive to legitimizing social activity taking place within IS. Yet, at the same time, certain practices may push paradigms into particular intended or unintended directions as paradigms are also constituted by practices, despite their resilience. This is due to their discursive constitution by the behaviors taking place within a social field and the reflection upon them (cf. Berger and Luckmann 1966; Donmoyer 2008; Morgan 2007; Searle 2010; Searle 1995). As Montuori puts it, "we create knowledge that in turn creates us, our ways of thinking and acting and feeling" (2017, p. 152). Thus, normativity on a practical level cannot be understood independently from a paradigmatic one, but certain practices may also serve as (leverage) points to intervene in a system to facilitate a paradigm shift (Abson et al. 2017). Thus, it is important to contrast the current IS paradigm with an advanced one capable of integrating sustainability as a deeply normative and complex issue.

Advancing IS in such a way actually requires a two-stage process: First, IS actors and researchers must adjust their perspective to scrutinizing the ultimate purpose of innovations. This, in turn, calls for incorporating a dedication to desirable goals and tackling important problems. A dedicated paradigm entails awareness for the necessity of pursuing these goals and the relevance of the problems, thereby affording heuristics and mental frames for exploring alternative innovation avenues. We will, therefore, refer to the advanced framework as "dedicated" IS paradigm or simply *dedicated innovation system* (DIS) as already indicated by Pyka (2017). While dedication can refer to various goals and different problems, a second step is required to concretize its orientation. In the light of wicked problems and the dismal prospects of current global developments, transformations towards sustainability offer a powerful frame of reference. For the remainder of this article, we use DIS in connection to this special case of "IS dedicated to transformations towards sustainability".

Both the conventional and the DIS paradigms share the central assumption that innovation takes place in complex (evolutionary) systems. Yet, as mentioned before, first and foremost they differ in what they assume to be the desirable goal of innovation processes. While in the early days of the (conventional) IS framework (e.g., Freeman 1987), the desirable goal of innovation was economic development (e.g., including national competitiveness and the creation of income and jobs), it can be observed that today, innovation is more and more seen as a panacea and has therefore become akin to an aim in itself (Godin 2015). By contrast, in DIS it is innovations contributing to transformations towards sustainability that are desirable. However, this explicit systemic dedication requires that the complexity of normativity, as well as the wickedness of problems, are adequately considered.

Within the current IS paradigm, it is evident that economic growth, efficiency, and system improvement are regarded as important and technological innovations as per se legitimate. By contrast, the dominant values or norms of a DIS paradigm are not that straightforward in the face of the multiplexity of visions and pathways. One potential value frame has been proposed by Renn and colleagues (Renn et al. 2009), who suggest that sustainability involves the continuity and endurance of human social and ecological systems, inter- and intragenerational justice, and a sustainable quality of life for all. Nevertheless, even this value frame remains ambiguous, particularly in terms of translating the respective norms into transformative (innovation) practices. For example, which qualitative systemic change processes should enable continuity and endurance of which particular (sub-)systems? What is justice and in which context? Who determines what a sufficient and sustainable level of quality of life should look like? Despite these and several other open questions in the context of transformations, the three norms suggested above can be a central guiding principle of DIS (i.e., IS for society), whereas in conventional IS innovation trajectories are usually not aligned with an overall systemic vision (i.e., IS *for* the sake of innovation).

In the conventional paradigm, technological innovation, competition, entrepreneurship, and knowledge creation and its diffusion play a major role (e.g., see Edquist 2005; Hekkert et al. 2007). Innovation processes are determined primarily by the so-called "supply side" (e.g., Warnke et al. 2016), and policy intervention is deemed necessary for correcting *system failures* (e.g., infrastructural, transition, lock-in/path-dependency, institutional, network, and capabilities failure as summarized by Klein Woolthuis and colleagues (2005). These activities and practices will also be important in a DIS paradigm, but they have to be expanded by *transformative innovation* based on alternative, dedicated innovation trajectories. Transformative innovation, as explained by Steward (2008), goes beyond radically new technologies, products, or (production) processes; instead, it "is about the implementation of paradigm-breaking, system-wide novelty" (p. 15). Transformative innovation processes can, thereby, be understood as collective experimentation processes by multiple systemic actors (Joly et al. 2010; Joly 2017) (e.g., citizens, mediators, social and sustainable entrepreneurs, etc.). Policies will be required that go beyond the "traditional" system failures and additionally address what Weber and Rohracher (2012) have called *transformational failures*. A brief summary of the comparison between the conventional and the dedicated IS paradigm is presented in Table 1.

Table 1 Comparison of the conventional and the dedicated paradigm

	Conventional Paradigm/IS	**Dedicated Paradigm/IS**
Concept	Innovation Systems	Dedicated Innovation Systems
Leading assumption	Innovation takes place in complex systems	Innovation takes place in complex systems
	Implicit assumption: innovation per se desirable	Explicit assumption: innovations that contribute to transformations towards sustainability are desirable, but: complexity of normativity and wickedness of problems
Dominant values/norms	Economic growth, efficiency, system improvement	Continuity of ecological systems, inter- and intra-generational justice, quality of life
Key practices	Technological innovation, competition, entrepreneurship, knowledge creation and diffusion	Additionally: transformative innovation based on alternative, dedicated innovation trajectories
	Innovation processes determined primarily by "supply side"	Innovation processes determined by all systemic actors and institutions (e.g., citizens, mediators, social and sustainable entrepreneurs, etc.)
	Policies tackle system failures	Policies tackle transformational failures

To recapitulate, sustainability goals cannot be easily integrated into an IS framework because the current IS paradigm cannot accommodate the complex normativity of sustainability. Instead, this requires a shift towards an IS paradigm dedicated to sustainability transformations. Such dedication, however, inevitably calls for a more rigorous consideration of at least three central questions: transform/sustain (1) what?; (2) why?; (3) by and for whom? (based on Tainter 2014; O´Brien 2012). Other relevant questions may also include "for how long?", "at what cost?", and "at which scale so that it will make a difference?" (Tainter 2014; O´Brien 2012). If these questions have not been posed, any attempt to answer the question of "how" to achieve transformations towards sustainability will remain either window dressing or resemble hope for a silver bullet. Consequently, an IS approach suitable for contributing to sustainability transformations must also be related to these central questions. For the remainder of this article, we focus mainly on the questions of "what", "why", and "by and for whom" in an IS context, as we can argue that other questions will inevitably have to follow but cannot be discussed on the same level in this article.

3.2 Directionality, Legitimacy, and Responsibility: Questions to Be Answered

The first central question "what" to transform or sustain concerns the overarching issue of directionality or goal-orientation of IS (Daimer et al. 2012; Lindner et al. 2016). Directionality primarily involves the question "what is the ultimate goal of an IS?" In the context of sustainability, it is also a question of "the right" transformation pathway(s) for social, economic, ecological, cultural, technological, and other relevant (sub-)systems. Therefore, directionality is not only about challenging the contemporary implicit focus on technological innovation and economic growth but also about opening up the IS approach for a variety of pathways (e.g., Schot and Steinmueller 2016; Luederitz et al. 2017; Stirling 2009; Schot et al.

2009; Turnheim et al. 2015) and actors (Warnke et al. 2016) while closing down other, non-sustainable options.

However, previous discussions about directionality often seem to assume that steering is possible as if we already knew "the right direction", which is questionable in the context of wicked problems. There are several additional problems when we make directionality explicit: First, the consideration of direction is quite contradictory to the evolutionary nature of innovation processes characterized by emergent properties, feedback effects, non-linearity, uncertainty, and a collective of fallible and boundedly rational actors (Berkhout 2005; Smits et al. 2010; Hodgson 1994). In a similar vein, the authors of the flagship report by the German Advisory Council on Global Change (WBGU) stress that "[t]ransformations are usually open-ended processes, the results of a collective steering are never certain, and not clearly foreseeable, despite a defined goal" (WBGU 2011, p. 107). Second, as mentioned above, a consensus on the desired transformation or systemic "goal" will hardly be reached as we are dealing with wicked problems and multiple actors with potentially conflicting interests and expectations (Berkhout 2006). It is, therefore, necessary to ask which (groups of) agents would be in the position and have the power to address matters of directionality and guide societies towards socially desirable outcomes.

This discussion inevitably leads us to the second central question mentioned above: the question of "why" to transform/sustain, which essentially relates to issues of legitimacy. In the context of wicked problems and sustainability, legitimacy is about finding answers to questions along the lines of "why should IS have a particular transformation goal?" and "who decides or determines the respective direction or pathway?" It is futile to rely only on top-down approaches by the government because, in the so-called network society, the monopoly of the state to produce social regulation and judicial norms is no longer self-evident (Castells 2010). Transformations have different initial conditions (e.g., geographically, culturally, economically) (Urmetzer and Pyka 2017) and involve trade-offs. They radically change existing system structures and actors' power relations, which makes compromises and negotiations necessary on various levels and sub-systems. At the same time, bottom-up participatory approaches cannot guarantee that "the right" innovative solutions to wicked problems will be found, even if all actors agreed on pursuing a particular pathway. Our knowledge about future impacts of solution attempts to wicked problems is principally limited (Blok and Lemmens 2015). Moreover, transformative grassroots movements face the additional problem of having to acquire a critical mass to be capable of "creatively destroying" non-sustainable industries and power relations in a truly Schumpeterian sense (Schumpeter 2003). As Gowdy phrases it: "Can the human propensity for cooperation and community building be harnessed sufficiently to scale up and challenge a global system built on competition and accumulation?" (Gowdy 2014, p. 35). One of the major determinants of community building and scaling up human cooperation for sustainability is arguably culture, which is, however, still under-researched in the sustainability context (Parodi 2015; Parodi et al. 2010; Clammer 2016).

It has often been argued that values, goals, norms, and beliefs that make up a paradigm are shaped by cultural evolutionary processes (e.g., Boyd and Richerson 1985; Boyd and Richerson 1994; Henrich 2015; Mokyr

2016; Richerson and Boyd 2005; Waring and Tremblay 2016; Waring et al. 2015; Wuketits 1993), thereby creating barriers and enablers for both the "what" and the "why" questions. For example, through the paradigm, culture shapes also systemic adaptations and responses to wicked problems such as climate change (e.g., Hoffman 2012; Hoffman 2015; Adger et al. 2012). Accordingly, cultural change itself is usually listed among the dimensions of the required sustainability transformations. This is why various authors have recently called for inquiries into how cultural evolution can be influenced to contribute to the emergence of more sustainable practices, institutions, and paradigms (e.g., Beddoe et al. 2009; Brewer 2015; Costanza 2014; Costanza 2016; Buenstorf and Cordes 2008).

However, influencing evolutionary processes is far from facile and also relates to the third central question mentioned above: "by and for whom?", which essentially concerns issues of responsibility. In the context of transformations, responsibility is closely related to agency as it is a matter of who holds the power to bring about change, and who bears the consequences.

Responsibility has probably received even less attention in the IS literature than issues of directionality and legitimacy. While the notion of corporate social responsibility has a long scholarly history and is well-established, it cannot be easily adapted to collective innovation and transformation processes in complex systems involving multiple heterogeneous actors and often fundamentally uncertain outcomes. Some kind of liability for emergent outcomes of complex systemic interactions can hardly be the kind of responsibility we are looking for, although some authors stress the importance of accountability also in the context of transformations towards sustainability (e.g., Patterson et al. 2017; Biermann et al. 2010). As a consequence of this complexity, however, neither individual nor collective responsibility concepts (e.g., French 1991; French 1998) are entirely suitable in the context of IS and transformations. This is owed to unknown causalities, unintended consequences, and the fact that positive or negative systemic impacts are mostly the result of a combination of individual and collective action as well as involuntary feedback effects.

To sum up, we argue that transformative systemic changes towards sustainability can be described and analyzed on the basis of an IS framework. The precondition is a paradigm change which requires engagement with issues of directionality (what future do we want?), legitimacy (why do we want this future, who defines it?), and responsibility (transformation by and for whom?). We have seen, however, that these questions are difficult to answer in a unilateral way in the case of wicked problems that call for transformations towards sustainability in multiple dimensions.

4. Theoretical and Practical Building Blocks for a New Research Agenda

These questions of directionality, legitimacy, and responsibility are already partly dealt with by theoretical and practical endeavors of IS-related research and policy that tackle some isolated aspects that can be used as building blocks for a DIS paradigm.

On the one hand, governments around the world usually do not struggle to provide direction by formulating general policy goals—also related to sustainability aspirations. The orientation of the corresponding innovation journeys is, on the other hand, much harder to achieve. This is particularly well-demonstrated by arguably unsuccessful agreements on the transnational level ranging from the Kyoto Protocol to the Paris Agreement, including so-called Grand Challenges (e.g., Von Schomberg 2013; Cagnin et al. 2012; Kuhlmann and Rip 2014) or the seventeen United Nations Sustainable Development Goals (United Nations 2015), which do not adequately consider the interrelatedness of (wicked) problems and the resulting trade-offs between solution attempts. Moreover, the relative ease with which individual governments such as the Trump administration of the United States of America can withdraw from such transnational agreements points to the importance of entrenching sustainability goals among all IS actors.

The innovation (systems) community has, to some extent, already addressed issues of directionality by investigating how innovation policy has an impact on the quality of the outcomes of structural change (see, e.g., Mazzucato and Perez 2015; Mowery et al. 2010; Nill 2009; Nill and Kemp 2009; Voß et al. 2006). Much of this research is based on evolutionary theorizing and modeling (see also Safarzyńska et al. 2012) and the large body of empirical literature this has given rise to (e.g., Fagerberg 2005; Freeman 1974; Kline and Rosenberg 1986). Traditionally, innovation policies have been classified as either generic, focusing on promoting innovation diffusion, structural change, and economic development in society more generally, or oriented towards coping with more specific challenges that policy-makers care about, so-called "mission-oriented" innovation policies (see, e.g., Eder and Fagerberg 2017; Cantner and Pyka 2001, for an overview). However, innovation policies aiming at transforming an IS towards sustainability are much more ambitious than earlier policies. Recently, so-called *transformative innovation policies* have been suggested (e.g., Schot and Steinmueller 2016; Schot et al. 2017; Chataway et al. 2017; Steward 2012), which aim at "directing socio-technical systems in socially desirable directions and embedding processes of change in society" (Schot and Steinmueller 2016, p. 21). Another way to introduce goal-orientation in IS is *innovation systems foresight*, recently proposed by Andersen and Andersen (2014; 2017). Innovation systems foresight is defined as a "systemic, systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilising joint actions to improve innovation system performance with the ultimate goal of improving desirable socio-economic performance" (Andersen and Andersen 2014, p. 281). This framework has been developed on the basis of foresight and futures studies and has already served as a tool for strategically guiding IS transformations towards desirable directions (Andersen and Andersen 2017).

But why should IS have a particular transformational goal in the first place and who determines the respective direction? Mazzucato (Mazzucato 2016; Mazzucato 2015; Mazzucato 2013) argues, for example, that traditional approaches to innovation policy seriously underestimate the potential for the state to provide clear goals (direction) to a society's technological innovation journey through the systematic use of various policy instruments (an *entrepreneurial state* as she puts it). However, top-down policy-making may not be the most suitable approach to tackling wicked problems such as climate change (Castells 2010; Stirling 2015; Young 2017). Building on earlier work by Evans (Evans 1995), Rodrik (Rodrik 2014) suggests, for example, that a green industrial policy is needed where policy-makers embed policy processes better in society and involve a broader segment of actors in order to increase policy learning. Thereby, the probability of myopic turnarounds by contemporary administrations may also decrease. Due to the simple fact that policy-makers are not perfectly informed social planners, policy-making should be distributed. Furthermore, including key stakeholders becomes a necessary and integral part of innovation policies (Andersen and Andersen 2017). Aside from the substantive value of participation (Sen 1999), mobilizing many actors at multiple scales can create legitimacy in general (Acemoğlu and Robinson 2012; Dingwerth 2007) and for sustainability goals (Schot and Steinmueller 2016; Andersen and Johnson 2015; Ostrom 2010; Van Huijstee et al. 2007) of an IS in particular.

Political economists have stressed the importance of inclusive institutions as vital rules of a system (Acemoğlu and Robinson 2012) that can empower citizens to make politicians pursue the interests of society as a whole. An IS framework incorporating such institutions has been introduced as *inclusive IS*, in which "relatively high levels of inclusion characterize the processes of learning and innovation and in which there is a relatively strong focus on innovation addressing the needs of the lower income strata" (Andersen and Johnson 2015, p. 284). The inclusive IS framework has been used to analyze a set of empirical cases to show how social inclusion impacts the (wicked) challenges of a low-carbon development.

In a similar vein, Bryden and Gezelius (2017) address innovation's legitimate purposes by exploring how institutions for innovation could be designed in order to address sustainability goals. They combine the IS framework with insights from business ethics (especially the influential ideas of Triple Bottom Line accounting (Elkington 1997; Pava 2007; Slaper and Hall 2011) and frame their concept as an IS for *Human Rights-Based Triple Bottom Line* (HRB-TBL) outcomes. Thereby, this novel conception explicitly goes beyond the technological paradigm and environmental dimension of the sustainability-oriented IS approaches mentioned above.

In order to endogenize directionality and thus create legitimacy in IS, Lindner and colleagues (2016) propose to fuse IS with reflexive governance (Voß et al. 2006). They develop ten quality criteria for *reflexive IS* including examples of relevant actors, indicators, and policy implications (Lindner et al. 2016).

Another important insight into how systemic processes of change can be legitimized is provided by the proponents of sustainability transitions research (e.g., see Van den Bergh et al. 2011; Markard et al. 2012; Feola 2015; Loorbach et al. 2017; Kern and Rogge 2017, for reviews). These sustainability transitions have been defined as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (Feola 2015, p. 956). At the operative level, transitions research has developed frameworks such as *transition management* (Kern and Smith 2008; Loorbach 2010; Rotmans et al. 2001), *strategic niche management* (Kemp et al. 1998; Raven and Geels 2010; Smith 2007), and the *multi-level perspective* (e.g., Geels 2002; Geels 2011, Geels

2015; Rip and Kemp 1998) that open up spaces for legitimization processes, including so-called transition arenas (Loorbach 2010) or niche-related actor networks that may include citizens and environmental groups (Kemp et al. 1998) These frameworks have already been implemented in political practice, for example, in the Netherlands and Belgium (Loorbach 2010; Rotmans et al. 2001; De Gooyert et al. 2016).

Finally, to address issues of responsibility in innovation processes, a relatively new strand of literature has been developed around the notion of responsible research and innovation or simply *responsible innovation* (RI) (e.g., Von Schomberg 2013; Owen et al. 2012; Owen et al. 2013; Stilgoe et al. 2013; Von Schomberg 2012; Lubberink et al. 2017; Lubberink et al. 2017; Timmermans 2017; Grunwald 2011; Stahl et al. 2013; Timmermans et al. 2017). RI incorporates a normative outlook into multi-stakeholder innovation practices (e.g., Stilgoe 2013, Geoghegan-Quinn 2012) and aims to achieve (ethically) acceptable, sustainable, and societally desirable outcomes of innovation processes and their marketable products (Von Schomberg 2013; Von Schomberg 2012). Arnaldi and colleagues (2016) even consider responsible research and innovation as the key to "steer[ing] the innovation process from the inside towards societal goals" and thus leaving behind the traditional emphasis of responsibility on fault, punishment, risk, compensation, and coping with "negative externalities" (p. 26). RI includes a wide range of (pre-existing) theories and approaches (see, e.g., Lubberink et al. 2017; Lubberink et al. 2017; Timmermans 2017). Lubberink and colleagues (2017) compile six central dimensions of RI based on a systematic review of the literature, namely anticipation, reflexivity, inclusion, deliberation, responsiveness, and knowledge management, and they suggest operationalization strategies for each of these dimensions.

In summary, there have been many IS-related approaches that address elements relevant for taking the normative dimension seriously: transformative innovation policy, innovation system foresight, the entrepreneurial state, green industrial policy, inclusive IS, the HRB-TBL, reflexive IS, frameworks developed on the basis of transitions research, and RI. However, the questions of transforming/sustaining what, why, and by and for whom are highly interrelated and call for more integrated theoretical and practical approaches that consider directionality, legitimacy, and responsibility in a holistic way. The overarching question for further research will, therefore, be: How can DIS incorporate legitimate goal-orientation for transformative innovation by and for society?

Hence, while these scattered strands of literature and policy endeavors have contributed a lot to solve parts of the issues related to the paradigmatic normativity of IS, various open questions remain to be answered by future research, including the following issues:

1. Although policy-makers can be given an accessible platform and a common language for discussion by drawing upon an IS framework, further investigations are needed on the systemic causes of resistance to change associated with directionality, legitimacy, and responsibility. Examples of research objects may include the paradigmatic "lock-in" in unsustainable value systems and the issue of bounded morality (Schlaile et al. 2016) of systemic actors.
2. Researchers need to shift attention from trying to find "the one" solution to acknowledging that

there are multiple transformation pathways and an epistemic insufficiency to predict "the right" future. This calls for enabling a continuous feedback mechanism between setting goals, formulating normative strategies to reach these goals, while reflecting on the legitimacy of these strategies.

3. Future research must address ways to influence the evolution of complex systems, for example, by drawing upon the literature on so-called leverage points as places to intervene in IS (e.g., Abson et al. 2017).
4. The literature on RI has so far not established sufficient references to the IS literature and vice versa. It is still under-researched what RI would entail in the context of IS. Therefore, further research is needed on how a systemic concept of responsibility can be developed.
5. As it has been stressed by others, one of the important aspects of responsibility in the context of innovation is that it is shared (e.g., Stilgoe et al. 2013). Since responsibility is frequently regarded as a correlate of power (e.g., Jonas 1984; Young 2006), a notion of shared responsibility in an IS context implies that future research is advisable on the role of power and capabilities (e.g., Sen 1999; Nussbaum and Sen 1993) of systemic actors (see also Schlaile et al. 2017; Schlaile et al. 2016).
6. Policy programs are required that tackle transformational failures (Weber and Rohracher 2012) and sustainability-related ecosystem failures (Blok 2018) by means of adaptive and reflexive governance instruments allowing for experimentation and inclusion of relevant stakeholders.
7. Further research is needed on questions of how participatory elements (e.g., stakeholder engagement in innovation) for transformative efforts can be fostered and governed, and how "the right" stakeholders could be selected (because an inclusion of all stakeholders guarantees neither consensus nor selection of adequate solutions).
8. It will also be important to investigate which actors and elements of DIS are universal, which are contingent and depend on geographical or cultural particularities. DIS concern multiple levels (e.g., global, national, regional, sectoral, technological, etc.) and do not aim at developing a "one size fits all" paradigm.
9. In this connection, the differences in temporal structure and dynamics between varieties of DIS should be explored (e.g., co-existence of old and new systems, the role of early adopters, pioneering roles of advanced economies, specific designs of innovation: e.g., engineering vs. frugal).

Notwithstanding the necessity of these research endeavors, we must keep in mind what Sendzimir and colleagues wrote already more than a decade ago: "No system of analysis, policy, or practice will ever eliminate surprise and uncertainty. Innovation and novelty as well as wicked problems incessantly emerge from evolving systems of nature and humanity, and will continue to do so. Our responsibility to address the impacts of evolution through new ways of learning, managing, and discussion must engage uncertainty as a stimulus to explore innovations and not as a basis of apprehension and apathy" (Sendzimir et al. 2006, p. 157).

5. Conclusions

IS offer a widely accepted and broadly used framework to analyze innovation processes. Because of the heterogeneity of involved actors and the dynamics and imponderables of learning processes as well as knowledge diffusion, the analysis of innovation processes generally requires a framework open for complexity. This is even more important when the nature of innovation becomes more fundamental and includes radical systemic changes such as transformations towards sustainability. We argue that the current IS framework is insufficient because it focuses too much on technological solutions and implicitly follows the normative assumption that innovation is per se desirable. Therefore, shifting attention to the paradigm level is the only way to potentially integrate the complex normativity of sustainability in IS. The guiding assumptions, values, norms, and practices of the current IS paradigm must be challenged in order to achieve a systemic dedication to sustainability. A dedicated paradigm or an IS dedicated to transformations towards sustainability can in principle allow for innovation trajectories that are to be subordinated to a sustainability goal. However, wicked problems and conflicting interests, expectations, and visions concerning sustainability require researchers to delve into questions of directionality, legitimacy, and responsibility. Previous IS-related approaches to these issues are scattered but already provide valuable building blocks for a more integrative investigation as proposed above. Future research is needed on how DIS can incorporate legitimate goal-orientation for transformative innovation by and for society. This research agenda covers various avenues. We commence with three rather general proposals: to explore systemic causes of resistance to change, to identify potential places to intervene in IS, and to engage in a stronger fusion of IS with RI. We then move on to the specific research objects of potential policy instruments for reflexive governance and stakeholder inclusion. Finally, we call for a substantiation of the introduced DIS framework, including questions of a spatial and temporal scale.

6. References

Abson, D.J.; Fischer, J.; Leventon, J.; Newig, J.; Schomerus, T.; Vilsmaier, U.; von Wehrden, H.; Abernethy, P.; Ives, C.D.; Jager, N.W.; et al. Leverage points for sustainability transformation. Ambio 2017, 46, 30–39.

Acemoğlu, D.; Robinson, J.A. Why Nations Fail: The Origins of Power, Prosperity, and Poverty; Crown Business: New York, NY, USA, 2012; ISBN 9780307719218.

Adger, W.N.; Barnett, J.; Brown, K.; Marshall, N.; O'Brien, K. Cultural dimensions of climate change impacts and adaptation. Nat. Clim. Chang. 2012, 3, 112–117.

Almudi, I.; Fatas-Villafranca, F.; Potts, J. Utopia competition: A new approach to the micro-foundations of sustainability transitions. J. Bioecon. 2017, 19, 165–185.

Altenburg, T.; Pegels, A. Sustainability-oriented innovation systems—Managing the green transformation. Innov. Dev. 2012, 2, 5–22.

Andersen, A.D.; Andersen, P.D. Foresighting for inclusive development. Technol. Forecast. Soc. Chang. 2017, 119, 227–236.

Andersen, A.D.; Andersen, P.D. Innovation system foresight. Technol. Forecast. Soc. Chang. 2014, 88, 276–286.

Andersen, A.D.; Johnson, B. Low-carbon development and inclusive innovation systems. Innov. Dev. 2015, 5, 279–296.

Anderson, M.W.; Teisl, M.F.; Noblet, C.L. Whose values count: Is a theory of social choice for sustainability science possible? Sustain. Sci. 2015, 11, 373–383.

Arnaldi, S.; Gorgoni, G.; Pariotti, E. RRI as a governance paradigm: What is new? In Navigating towards Shared Responsibility in Research and Innovation. Approach, Process and Results of the Res-AGorA Project; Lindner, R., Kuhlmann, S., Randles, S., Eds.; Fraunhofer ISI: Karlsruhe, Germany, 2016; ISBN 9783000517099.

Avelino, F.; Wittmayer, J.M.; Pel, B.; Weaver, P.; Dumitru, A.; Haxeltine, A.; Kemp, R.; Jørgensen, M.S.; Bauler, T.; Ruijsink, S.; et al. Transformative social innovation and (dis)empowerment. Technol. Forecast. Soc. Chang. 2017, 1–12.

Bajmócy, Z.; Gébert, J. The outlines of innovation policy in the capability approach. Technol. Soc. 2014, 38, 93–102.

Becker, C. Sustainability Ethics and Sustainability Research; Springer: Dordrecht, The Netherlands, 2012; ISBN 9789400722842.

Beddoe, R.; Costanza, R.; Farley, J.; Garza, E.; Kent, J.; Kubiszewski, I.; Martinez, L.; McCowen, T.; Murphy, K.; Myers, N.; et al. Overcoming systemic roadblocks to sustainability: The evolutionary redesign of worldviews, institutions, and technologies. Proc. Natl. Acad. Sci. USA 2009, 106, 2483–2489. [PubMed]

Bergek, A.; Jacobsson, S.; Carlsson, B.; Lindmark, S.; Rickne, A. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res. Policy 2008, 37, 407–429.

Berger, P.L.; Luckmann, T. The Social Construction of Reality: A Treatise in the Sociology of Knowledge; Penguin: London, UK, 1966; ISBN 9780385058988.

Berkhout, F. Normative expectations in systems innovation. Technol. Anal. Strateg. Manag. 2006, 18, 299–311.

Berkhout, F. Technological regimes, environmental performance and innovation systems: Tracing the links. In Towards Environmental Innovation Systems; Weber, M., Hemmelskamp, J., Eds.; Springer: Berlin, Germany, 2005; pp. 57–80. ISBN 9783540272984.

Biermann, F.; Betsill, M.M.; Gupta, J.; Kanie, N.; Lebel, L.; Liverman, D.; Schroeder, H.; Siebenhüner, B.; Zondervan, R. Earth system governance: A research framework. Int. Environ. Agreem. Politics Law Econ. 2010, 10, 277–298.

Binz, C.; Truffer, B. Global innovation systems—A conceptual framework for innovation dynamics in transnational contexts. Res. Policy 2017, 46, 1284–1298.

Blok, V. Information asymmetries and the paradox of sustainable business models: Towards an integrated theory of sustainable entrepreneurship. In Sustainable Business Models: Principles, Promise, and Practice; Idowu, S., Moratis, L., Melissen, F., Eds.; Springer: Berlin, Germany, 2018.

Blok, V.; Gremmen, B.; Wesselink, R. Dealing with the wicked problem of sustainability: The role of individual virtuous competence. Bus. Prof. Ethics J. 2015, 34, 297–327.

Blok, V.; Lemmens, P. The emerging concept of responsible innovation. Three reasons why it is questionable and calls for a radical transformation of the concept of innovation. In Responsible Innovation 2: Concepts, Approaches, and Applications; Koops, B.-J., Oosterlaken, I., Romijn, H., Swierstra, T., van den Hoven, J., Eds.; Springer: Cham, Switzerland, 2015; pp. 19–35. ISBN 9783319173085.

Boyd, R.; Richerson, P. Culture and the Evolutionary Process; The University of Chicago Press: Chigago, IL, USA, 1985; ISBN 9780226069333.

Boyd, R.; Richerson, P.J. The evolution of norms: An anthropological view. J. Inst. Theor. Econ. 1994, 150, 72–87.

Brand, U.; Wissen, M. Global environmental politics and the imperial mode of living: Articulations of state–capital relations in the multiple crisis. Globalizations 2012, 9, 547–560.

Brewer, J. Tools for culture design: Toward a science of social change? Spanda J. 2015, 6, 67–73.

Brown, V.A.; Harris, J.A.; Russell, J.Y. (Eds.) Tackling Wicked Problems through the Transdisciplinary Imagination; Earthscan: London, UK, 2010; ISBN 9781844079247.

Bryden, J.M.; Gezelius, S.S. Innovation as if people mattered: The ethics of innovation for sustainable development. Innov. Dev. 2017, 7, 101–118.

Bryden, J.M.; Gezelius, S.S.; Refsgaard, K. Governing Innovation for Sustainable Development: Designing Creative Institutions; Working Paper 2013-5; Norwegian Agricultural Economics Research Institute: Oslo, Norway, 2013.

Buenstorf, G.; Cantner, U.; Hanusch, H.; Hutter, M.; Lorenz, H.-W.; Rahmeyer, F. Editorial: The two sides of innovation: Creation and destruction in the evolution of capitalist economies. In The Two Sides of Innovation: Creation and Destruction in the Evolution of Capitalist Economies; Buenstorf, G., Cantner, U., Hanusch, H., Hutter, M., Lorenz, H.-W., Rahmeyer, F., Eds.; Springer: Cham, Switzerland, 2013; pp. 1–7. ISBN 9783319014951.

Buenstorf, G.; Cordes, C. Can sustainable consumption be learned? A model of cultural evolution. Ecol. Econ. 2008, 67, 646–657.

Cagnin, C.; Amanatidou, E.; Keenan, M. Orienting European innovation systems towards grand challenges and the roles that FTA can play. Sci. Public Policy 2012, 39, 140–152.

Cantner, U.; Pyka, A. Classifying technology policy from an evolutionary perspective. Res. Policy 2001, 30, 759–775.

Carlsson, B.; Stankiewicz, R. On the nature, function and composition of technological systems. J. Evol. Econ. 1991, 1, 93–118.

Castells, M. The Information Age: Economy, Society, and Culture, 2nd ed.; Wiley: Chichester, UK, 2010; Volume 3.

Chataway, J.; Daniels, C.; Kanger, L.; Ramirez, M.; Schot, J.; Steinmueller, E. Developing and Enacting Transformative Innovation Policy: A Comparative Study. In Proceedings of the 8th International Sustainability Transitions Conference, Gothenburg, Sweden, 18–21 June 2017.

Clammer, J. Cultures of Transition and Sustainability: Culture after Capitalism; Palgrave Macmillan US: New York, NY, USA, 2016; ISBN 9781137520333.

COMEST , World Commission on the Ethics of Scientific Knowledge and Technology. Ethical Principles for Climate Change: Adaptation and Mitigation; UNESCO: Paris, France, 2015.

Costanza, R. A theory of socio-ecological system change. J. Bioecon. 2014, 16, 39–44.

Costanza, R. How do cultures evolve, and can we direct that change to create a better world? Wildl. Aust. 2016, 53, 46–47.

Daimer, S.; Hufnagl, M.; Warnke, P. Challenge-oriented policy-making and innovation systems theory. Reconsidering systemic instruments. In Innovation System Revisited: Experiences from 40 Years of Fraunhofer ISI Research; Koschatzky, K., Ed.; Fraunhofer ISI: Karlsruhe, Germany, 2012; pp. 217–234. ISBN 9783839604434.

Davies, A.R.; Fahy, F.; Rau, H. (Eds.) Challenging Consumption: Pathways to a More Sustainable Future; Routledge: London, UK, 2014; ISBN 9781136734908.

De Gooyert, V.; Rouwette, E.; Van Kranenburg, H.; Freeman, E.; Van Breen, H. Sustainability transition dynamics: Towards overcoming policy resistance. Technol. Forecast. Soc. Chang. 2016, 111, 135–145.

De Wit, B.; Meyer, R. Strategy Synthesis: Resolving Strategy Paradoxes to Create Competitive Advantage; Cengage Learning EMEA: London, UK, 2010; ISBN 9781408018996.

De Witt, A. Climate change and the clash of worldviews: An exploration of how to move forward in a polarized debate. Zygon 2015, 50, 906–921.

Denzin, N.K.; Lincoln, Y.S. Paradigms and perspectives in contention. In The Sage Handbook of Qualitative Research, 3rd ed.; Denzin, N.K., Lincoln, Y.S., Eds.; Sage Publications: Thousand Oaks, CA, USA, 2005; pp. 183–190. ISBN 9780761927570.

Dingwerth, K. The New Transnationalism: Transnational Governance and Democratic Legitimacy; Palgrave Macmillan: Basingstoke, UK, 2007; ISBN 9780230590144.

Doloreux, D.; Porto Gomez, I. A review of (almost) 20 years of regional innovation systems research. Eur. Plan. Stud. 2017, 25, 371–387.

Donmoyer, R. Paradigm. In The Sage Encyclopedia of Qualitative Research Methods; Given, L.M., Ed.; SAGE: Los Angeles, CA, USA, 2008; pp. 591–595. ISBN 9781452265896.

Dosi, G.; Freeman, C.; Nelson, R.; Silverberg, G.; Soete, L. (Eds.) Technical Change and Economic Theory; Pinter: London, UK, 1988; ISBN 9780861879496.

Edler, J.; Fagerberg, J. Innovation policy: What, why, and how. Oxf. Rev. Econ. Policy 2017, 33, 2–23.

Edquist, C. Systems of innovation: Perspectives and challenges. In The Oxford Handbook of Innovation; Fagerberg, J., Mowery, D.C., Nelson, R.R., Eds.; Oxford University Press: Oxford, UK, 2005; pp. 181–208. ISBN 9780199286805.

Edquist, C. Systems of Innovation: Technologies, Institutions, and Organizations; Pinter: London, UK, 1997; ISBN 9781855674523.

Edquist, C.; Johnson, B. Institutions and organizations in systems of innovation. In Systems of Innovation: Technologies, Institutions, and Organizations; Edquist, C., Ed.; Pinter: London, UK, 1997; pp. 41–63.

Edquist, C.; Lundvall, B.-Å. Comparing the Danish and Swedish systems of innovation. In National Innovation Systems: A Comparative Analysis; Nelson, R.R., Ed.; Oxford University Press: London, UK, 1993; pp. 265–298. ISBN 9780195360431.

Elkington, J. Cannibals with Forks: The Triple Bottom Line of 21st Century Business; Capstone: Oxford, UK, 1997; ISBN 9781900961271.

European Environment Agency. Sustainability Transitions: Now for the Long Term; Eionet Report No 1/2016; European Environment Agency: Copenhagen, Denmark, 2016.

Evans, P.B. Embedded Autonomy: States and Industrial Transformation; Princeton University Press: Princeton, NJ, USA, 1995; ISBN 9780691037363.

Fagerberg, J. Innovation policy: Rationales, lessons and challenges. J. Econ. Surv. 2017, 31, 497–512.

Fagerberg, J. Innovation: A guide to the literature. In The Oxford Handbook of Innovation; Fagerberg, J., Mowery, D.C., Nelson, R.R., Eds.; Oxford University Press: Oxford, UK, 2005; pp. 1–27. ISBN 9780199286805.

Fagerberg, J.; Sapprasert, K. National innovation systems: The emergence of a new approach. Sci. Public Policy 2011, 38, 669–679.

Feola, G. Societal transformation in response to global environmental change: A review of emerging concepts. Ambio 2015, 44, 376–390. [PubMed]

Franceschini, S.; Faria, L.G.D.; Jurowetzki, R. Unveiling scientific communities about sustainability and innovation. A bibliometric journey around sustainable terms. J. Clean. Prod. 2016, 127, 72–83.

Frantzeskaki, N.; Loorbach, D.; Meadowcroft, J. Governing societal transitions to sustainability. Int. J. Sustain. Dev. 2012, 15, 19–36.

Freeman, C. Technology Policy and Economic Performance; Lessons from Japan; Pinter: London, UK, 1987; ISBN 9780861879281.

Freeman, C. The Economics of Hope: Essays on Technical Change, Economic Growth, and the Environment; Pinter: London, UK, 1992; ISBN 9781855670839.

Freeman, C. The Economics of Industrial Innovation; Penguin Books: Harmondsworth, UK, 1974; ISBN 9780140809060.

French, P.A. (Ed.) Individual and Collective Responsibility, 2nd ed.; Schenkman Books: Rochester, UK, 1998; ISBN 9780870470707.

French, P.A. The Spectrum of Responsibility; St. Martin's Press: New York, NY, USA, 1991; ISBN 9780312034962.

Geels, F.W. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. Res. Policy 2002, 31, 1257–1274.

Geels, F.W. The arduous transition to low-carbon energy: A multi-level analysis of renewable electricity niches and resilient regimes. In The Triple Challenge for Europe: Economic Development, Climate Change, and Governance; Fagerberg, J., Martin, B.R., Laestadius, S., Eds.; Oxford University Press: Oxford, UK, 2015; pp. 91–118. ISBN 9780198747413.

Geels, F.W. The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environ. Innov. Soc. Transit. 2011, 1, 24–40.

Geoghegan-Quinn, M. Responsible Research and Innovation. Europe's Ability to Respond to Societal Challenges. In Proceedings of the Science in Dialogue–Towards a European Model for Responsible Research and Innovation, Odense, Denmark, 23–25 April 2012; European Union Publication Office: Brussels, Belgium, 2012.

Godin, B. Innovation Contested: The Idea of Innovation over the Centuries; Routledge: New York, NY, USA, 2015; ISBN 9780415727204.

Godin, B. National innovation system: The system approach in historical perspective. Sci. Technol. Hum. Values 2009, 34, 476–501.

Görg, C.; Brand, U.; Haberl, H.; Hummel, D.; Jahn, T.; Liehr, S. Challenges for social-ecological transformations: Contributions from social and political ecology. Sustainability 2017, 9, 1045.

Gowdy, J.M. Governance, sustainability, and evolution. In State of the World 2014: Governing for Sustainability; Worldwatch Institute, Ed.; Island Press: Washington, DC, USA, 2014; pp. 31–40. ISBN 9781610915427.

Green, K. Towards environmental innovation—A policy synthesis. In Towards Environmental Innovation Systems; Weber, M., Hemmelskamp, J., Eds.; Springer: Berlin, Germany, 2005; pp. 319–323. ISBN 9783540272984.

Gregersen, B.; Johnson, B. Learning economies, innovation systems and European integration. Reg. Stud. 1997, 31, 479–490.

Grunwald, A. Responsible innovation: Bringing together technology assessment, applied ethics, and STS research. Enterp. Work Innov. Stud. 2011, 7, 9–31.

Hahn, R. The ethical rational of business for the poor—Integrating the concepts bottom of the pyramid, sustainable development, and corporate citizenship. J. Bus. Ethics 2009, 84, 313–324.

Hassan, Z. The Social Labs Revolution: A New Approach to Solving our most Complex Challenges; Berrett-Koehler Publishers: San Francisco, CA, USA, 2014; ISBN 9781626560734.

Haxeltine, A.; Avelino, F.; Pel, B.; Dumitru, A.; Kemp, R.; Longhurst, N.; Chilvers, J.; Wittmayer, J.M. A Framework for Transformative Social Innovation; TRANSIT Working Paper #5; TRANSformative Social Innovation Theory: Rotterdam, The Netherlands, 2016.

Hekkert, M.P.; Suurs, R.A.A.; Negro, S.O.; Kuhlmann, S.; Smits, R.E.H.M. Functions of innovation systems: A new approach for analysing technological change. Technol. Forecast. Soc. Chang. 2007, 74, 413–432.

Henrich, J. The Secret of Our Success: How Culture Is Driving Human Evolution, Domesticating Our Species, and Making Us Smarter; Princeton University Press: Princeton, NJ, USA, 2015; ISBN 9780691166858.

Hill, R.; Robinson, C.; Pert, P.; Barber, M.; Lyons, I.; Maclean, K.; Talbot, L.; Moran, C. Integration science for impact: Fostering transformations towards sustainability. In Social Science and Sustainability; Schandl, H., Walker, I., Eds.; CSIRO: Clayton, Australia, 2017; pp. 23–50. ISBN 9781486306411.

Hodgson, G.M. Evolution and optimality. In The Elgar Companion to Institutional and Evolutionary Economics A-K; Hodgson, G.M., Samuels, W.J., Tool, M.R., Eds.; Edward Elgar: Cheltenham, UK, 1994; pp. 207–212. ISBN 9781852784393.

Hoffman, A.J. Climate science as culture war. Stanf. Soc. Innov. Rev. 2012, 10, 30–37.

Hoffman, A.J. How Culture Shapes the Climate Change Debate; Stanford University Press: Stanford, CA, USA, 2015; ISBN 9780804794220.

Hormio, S. Climate change mitigation, sustainability and non-sustainability. In The Ethical Underpinnings of Climate Economics; Walsh, A., Hormio, S., Purves, D., Eds.; Routledge: London, UK, 2017; pp. 103–121.

Hulme, M. (Still) disagreeing about climate change: Which way forward? Zygon 2015, 50, 893–905.

Hulme, M. Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity; Cambridge University Press: Cambridge, UK, 2009; ISBN 9780521727327.

Jacobsson, S.; Bergek, A. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environ. Innov. Soc. Transit. 2011, 1, 41–57.

Johnson, B.; Lundvall, B.-Å. National innovation systems (NIS). In Encyclopedia of Creativity, Invention, Innovation and Entrepreneurship; Carayannis, E.G., Ed.; Springer: New York, NY, USA, 2013; pp. 1341–1347. ISBN 9781461438588.

Joly, P.-B. Beyond the competitiveness framework? Models of innovation revisited. J. Innov. Econ. Manag. 2017, 22, 79–96.

Joly, P.-B.; Rip, A.; Callon, M. Re-inventing innovation. In Governance of Innovation: Firms, Clusters and Institutions in a Changing Setting; Arentsen, M.J., van Rossum, W., Steenge, A.E., Eds.; Edward Elgar: Cheltenham, UK, 2010; pp. 19–32. ISBN 9781847207388.

Jonas, H. The Imperative of Responsibility: In Search of an Ethics for the Technological Age; The University of Chicago Press: Chicago, IL, USA, 1984; ISBN 9780226405964.

Kates, R.W. Queries on the human use of the earth. Annu. Rev. Energy Environ. 2001, 26, 1–26.

Kemp, R.; Schot, J.; Hoogma, R. Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Technol. Anal. Strateg. Manag. 1998, 10, 175–198.

Kern, F.; Rogge, K.S. Harnessing theories of the policy process for analysing the politics of sustainability transitions: A critical survey. Environ. Innov. Soc. Transit. 2017, 1–16.

Kern, F.; Smith, A. Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. Energy Policy 2008, 36, 4093–4103.

Klein Woolthuis, R.; Lankhuizen, M.; Gilsing, V. A system failure framework for innovation policy design. Technovation 2005, 25, 609–619.

Klein, M.; Sauer, A. Celebrating 30 Years of Innovation System Research: What You Need to Know about Innovation Systems; Hohenheim Discussion Papers in Business, Economics and Social Sciences 17-2016; Faculty of Business, Economics and Social Sciences, University of Hohenheim: Stuttgart, Germany, 2016.

Kline, S.J.; Rosenberg, N. An overview of innovation. In The Positive Sum Strategy: Harnessing Technology for Economic Growth; Rosenberg, N., Landau, R., Eds.; The National Academy Press: Washington, DC, USA, 1986; pp. 275–299. ISBN 9780309078481.

Kuhlmann, S.; Rip, A. The Challenge of Addressing Grand Challenges: A Think Piece on How Innovation Can Be Driven Towards the "Grand Challenges" as Defined under the Prospective European Union Framework Programme Horizon 2020; European Research and Innovation Area Board (ERIAB): Brussels, Belgium, 2014.

Leach, M.; Rockström, J.; Raskin, P.; Scoones, I.; Stirling, A.C.; Smith, A.; Thompson, J.; Millstone, E.; Ely, A.; Arond, E.; et al. Transforming innovation for sustainability. Ecol. Soc. 2012, 17.

Levin, K.; Cashore, B.; Bernstein, S.; Auld, G. Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. Policy Sci. 2012, 45, 123–152.

Lindner, R.; Daimer, S.; Beckert, B.; Heyen, N.; Koehler, J.; Teufel, B.; Warnke, P.; Wydra, S. Addressing Directionality: Orientation Failure and the Systems of Innovation Heuristic. Towards Reflexive Governance; Fraunhofer ISI Discussion Papers Innovation Systems and Policy Analysis No. 52; Fraunhofer-Institut für System- und Innovationsforschung ISI: Karlsruhe, Germany, 2016.

Loorbach, D. Transition management for sustainable development: A prescriptive, complexity-based governance framework. Governance 2010, 23, 161–183.

Loorbach, D.; Frantzeskaki, N.; Avelino, F. Sustainability transitions research: Transforming science and practice for societal change. Annu. Rev. Environ. Resour. 2017, 42, 599–626.

Lubberink, R.; Blok, V.; van Ophem, J.; Omta, O. A framework for responsible innovation in the business context: Lessons from responsible-, social- and sustainable innovation. In Responsible Innovation 3: A European Agenda? Asveld, L., van Dam-Mieras, R., Swierstra, T., Lavrijssen, S., Linse, K., van den Hoven, J., Eds.; Springer: Cham, Switzerland, 2017; pp. 181–207. ISBN 9783319648347.

Lubberink, R.; Blok, V.; van Ophem, J.; Omta, O. Lessons for responsible innovation in the business context: A systematic literature review of responsible, social and sustainable innovation practices. Sustainability 2017, 9, 721.

Luederitz, C.; Abson, D.J.; Audet, R.; Lang, D.J. Many pathways toward sustainability: Not conflict but co-learning between transition narratives. Sustain. Sci. 2017, 12, 393–407.

Lundvall, B.-Å. (Ed.) National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning; Pinter: London, UK, 1992; ISBN 9781855670631.

Lundvall, B.-Å. National innovation systems—Analytical concept and development tool. Ind. Innov. 2007, 14, 95–119.

Lundvall, B.-Å. The Learning Economy and the Economics of Hope; Anthem Press: London, UK, 2016; ISBN 9781783085965.

Lundvall, B.-Å. Why study national systems and national styles of innovation? Technol. Anal. Strateg. Manag. 1998, 10, 403–422.

Malerba, F. Sectoral systems of innovation and production. Res. Policy 2002, 31, 247–264.

Malerba, F. Sectoral systems: How and why innovation differs across sectors. In The Oxford Handbook of Innovation; Fagerberg, J., Mowery, D.C., Nelson, R.R., Eds.; Oxford University Press: Oxford, UK, 2005; pp. 380–406. ISBN 9780199286805.

Markard, J.; Hekkert, M.; Jacobsson, S. The technological innovation systems framework: Response to six criticisms. Environ. Innov. Soc. Transit. 2015, 16, 76–86.

Markard, J.; Raven, R.; Truffer, B. Sustainability transitions: An emerging field of research and its prospects. Res. Policy 2012, 41, 955–967.

Mazzucato, M. From market fixing to market-creating: A new framework for innovation policy. Ind. Innov. 2016, 23, 140–156.

Mazzucato, M. The Entrepreneurial State: Debunking Private vs. Public Sector Myths; Anthem Press: London, UK, 2013; ISBN 9780857282521.

Mazzucato, M. The green entrepreneurial state. In The Politics of Green Transformations; Scoones, I., Leach, M., Newell, P., Eds.; Earthscan: London, UK, 2015; pp. 134–152. ISBN 9781138792890.

Mazzucato, M.; Perez, C. Innovation as growth policy: The challenge for Europe. In The Triple Challenge for Europe: Economic Development, Climate Change, and Governance; Fagerberg, J., Martin, B.R., Laestadius, S., Eds.; Oxford University Press: Oxford, UK, 2015; pp. 229–264. ISBN 9780198747413.

Meadows, D.H. Leverage Points: Places to Intervene in a System; Sustainability Institute: Hartland, VT, USA, 1999.

Meadows, D.H. Thinking in Systems: A Primer; Earthscan: London, UK, 2008; ISBN 9781603580557.

Meadows, D.H.; Meadows, D.L.; Randers, J.; Behrens, W.W., III. The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind; Universe Books: New York, NY, USA, 1972; ISBN 9780876632222.

Meadows, D.H.; Randers, J.; Meadows, D.L. Limits to Growth: The 30-Year Update; Earthscan: London, UK, 2004; ISBN 9781844071449.

Miller, T.R.; Wiek, A.; Sarewitz, D.; Robinson, J.; Olsson, L.; Kriebel, D.; Loorbach, D. The future of sustainability science: A solutions-oriented research agenda. Sustain. Sci. 2014, 9, 239–246.

Mokyr, J. A Culture of Growth: The Origins of the Modern Economy; Princeton University Press: Princeton, NJ, USA, 2016; ISBN 9780691168883.

Montuori, A. The evolution of creativity and the creativity of evolution. Spanda J. 2017, 7, 147–156.

Morgan, D.L. Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods. J. Mixed Methods Res. 2007, 1, 48–76.

Moussavi, A.; Kermanshah, A. Innovation systems approach: A philosophical appraisal. Philos. Manag. 2017.

Mowery, D.C.; Nelson, R.R.; Martin, B.R. Technology policy and global warming: Why new policy models are needed (or why putting new wine in old bottles won't work). Res. Policy 2010, 39, 1011–1023.

Nelson, R.R. (Ed.) National Innovation Systems: A Comparative Analysis; Oxford University Press: London, UK, 1993; ISBN 9780195360431.

Nill, J. Ökologische Innovationspolitik: Eine Evolutorisch-Ökonomische Perspektive; Metropolis: Marburg, Germany, 2009; ISBN 9783895187285.

Nill, J.; Kemp, R. Evolutionary approaches for sustainable innovation policies: From niche to paradigm? Res. Policy 2009, 38, 668–680.

Niosi, J.; Saviotti, P.; Bellon, B.; Crow, M. National systems of innovation: In search of a workable concept. Technol. Soc. 1993, 15, 207–227.

Nussbaum, M.; Sen, A. (Eds.) The Quality of Life; Clarendon Press: Oxford, UK, 1993; ISBN 9780198287971.

O'Brien, K. Global environmental change II: From adaptation to deliberate transformation. Prog. Hum. Geogr. 2012, 36, 667–676.

Olsson, P.; Moore, M.-L.; Westley, F.R.; McCarthy, D.D.P. The concept of the Anthropocene as a game-changer: A new context for social innovation and transformations to sustainability. Ecol. Soc. 2017, 22, 3114–3131.

Ostrom, E. A general framework for analyzing sustainability of social-ecological systems. Science 2009, 325, 419–422. [PubMed]

Ostrom, E. Polycentric systems for coping with collective action and global environmental change. Glob. Environ. Chang. 2010, 20, 550–557.

Owen, R.; Bessant, J.; Heintz, M. (Eds.) Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society; Wiley: Chichester, UK, 2013a; ISBN 9781119966364.

Owen, R.; Macnaghten, P.; Stilgoe, J. Responsible research and innovation: From science in society to science for society, with society. Sci. Public Policy 2012b, 39, 751–760.

Parodi, O. The missing aspect of culture in sustainability concepts. In Theories of Sustainable Development; Enders, J.C., Remig, M., Eds.; Routledge: London, UK, 2015; pp. 169–187. ISBN 9781138796362.

Parodi, O.; Banse, G.; Schaffer, A. (Eds.) Wechselspiele: Kultur und Nachhaltigkeit: Annäherungen an ein Spannungsfeld; Edition Sigma: Berlin, Germany, 2010; ISBN 9783894045852.

Patel, P.; Pavitt, K. National innovation systems: Why they are important, and how they might be measured and compared. Econ. Innov. New Technol. 1994, 3, 77–95.

Patterson, J.; Schulz, K.; Vervoort, J.; Van der Hel, S.; Widerberg, O.; Adler, C.; Hurlbert, M.; Anderton, K.; Sethi, M.; Barau, A. Exploring the governance and politics of transformations towards sustainability. Environ. Innov. Soc. Transit. 2017, 24, 1–16.

Pava, M.L. A response to "getting to the bottom of 'Triple Bottom Line'". Bus. Ethics Q. 2007, 17, 105–110.

Peterson, H. Transformational supply chains and the 'wicked problem' of sustainability: Aligning knowledge, innovation, entrepreneurship, and leadership. J. Chain Netw. Sci. 2009, 9, 71–82.

Pyka, A. Transformation of economic systems: The bio-economy case. In Knowledge-Driven Developments in the Bioeconomy; Dabbert, S., Lewandowski, I., Weiss, J., Pyka, A., Eds.; Springer: Cham, Switzerland, 2017; pp. 3–36. ISBN 9783319583730.

Rao-Nicholson, R.; Vorley, T.; Khan, Z. Social innovation in emerging economies: A national systems of innovation based approach. Technol. Forecast. Soc. Chang. 2017, 121, 228–237.

Ratcliffe, J.W. Notions of validity in qualitative research methodology. Knowledge 1983, 5, 147–167.

Raven, R.P.J.M.; Geels, F.W. Socio-cognitive evolution in niche development: Comparative analysis of biogas development in Denmark and the Netherlands (1973–2004). Technovation 2010, 30, 87–99.

Renn, O.; Jäger, A.; Deuschle, J.; Weimer-Jehle, W. A normative-functional concept of sustainability and its indicators. Int. J. Glob. Environ. Issues 2009, 9, 291–317.

Richerson, P.J.; Boyd, R. Not by Genes Alone: How Culture Transformed Human Evolution; The University of Chicago Press: Chicago, IL, USA, 2005; ISBN 9780226712123.

Rip, A.; Kemp, R. Technological change. In Human Choice and Climate Change; Rayner, S., Malone, E.L., Eds.; Battelle Press: Washington, DC, USA, 1998; Volume 2, pp. 327–399. ISBN 9781574770476.

Rittel, H.W.J.; Webber, M.M. Dilemmas in a general theory of planning. Policy Sci. 1973, 4, 155–169.

Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. A safe operating space for humanity. Nature 2009, 461, 472–475.

Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. Planetary boundaries: Exploring the safe operating space for humanity. Ecol. Soc. 2009, 14, 32.

Rodrik, D. Green industrial policy. Oxf. Rev. Econ. Policy 2014, 30, 469–491.

Rotmans, J.; Kemp, R.; van Asselt, M. More evolution than revolution: Transition management in public policy. Foresight 2001, 3, 15–31.

Rotmans, J.; Loorbach, D. Complexity and transition management. J. Ind. Ecol. 2009, 13, 184–196.

Safarzyn´ska, K.; Frenken, K.; van den Bergh, J.C.J.M. Evolutionary theorizing and modeling of sustainability transitions. Res. Policy 2012, 41, 1011–1024.

Sanford, C. Language as clue: The effect of paradigms on creating systemic change in business. Spanda J. 2015, 6, 129–135.

Schlaile, M.P.; Klein, K.; Böck, W. From bounded morality to consumer social responsibility: A transdisciplinary approach to socially responsible consumption and its obstacles. J. Bus. Ethics 2016, 1–28.

Schlaile, M.P.; Mueller, M.; Schramm, M.; Pyka, A. Evolutionary economics, responsible innovation and demand: Making a case for the role of consumers. Philos. Manag. 2017, 1–33.

Schmidt, I. Consumer Social Responsibility: Gemeinsame Verantwortung für Nachhaltiges Konsumieren und Produzieren; Springer: Wiesbaden, Germany, 2016; ISBN 9783658108656.

Schot, J.; Daniels, C.; Torrens, J.; Bloomfield, G. Developing a Shared Understanding of Transformative Innovation Policy. Available online: http://www.transformative-innovation-policy.net/publications/developing-a-shared-understanding/ (accessed on 5 December 2017).

Schot, J.; Steinmueller, E. Framing Innovation Policy for Transformative Change: Innovation Policy 3.0. 2016. Available online: http://www.johanschot.com/wordpress/wp-content/uploads/2016/09/SchotSteinmueller_ FramingsWorkingPaperVersionUpdated2018.10.16-New-copy.pdf (accessed on 6 December 2017).

Schumpeter, J.A. Capitalism, Socialism and Democracy; Taylor & Francis: London, UK, 2003; ISBN 0203202058.

Searle, J.R. Making the Social World: The Structure of Human Civilization; Oxford University Press: Oxford, UK, 2010; ISBN 9780195396171.

Searle, J.R. The Construction of Social Reality; Free Press: New York, NY, USA, 1995; ISBN 9780029280454.

Segura-Bonilla, O. Competitiveness, systems of innovation and the learning economy: The forest sector in Costa Rica. For. Policy Econ. 2003, 5, 373–384.

Segura-Bonilla, O. Sustainable Systems of Innovation: The Forest Sector in Central America. Ph.D. Dissertation, Aalborg University, Aalborg, Denmark, 1999.

Sen, A. Commodities and Capabilities; Oxford University Press: Oxford, UK, 1999; ISBN 9780195650389.

Sen, A. Development as Freedom; Oxford University Press: Oxford, UK, 1999; ISBN 9780198297581.

Sendzimir, J.; Magnuszewski, P.; Balogh, P.; Vári, A. Adaptive management to restore ecological and economic resilience in the Tisza river basin. In Reflexive Governance for Sustainable Development; Voß, J.-P., Bauknecht, D., Kemp, R., Eds.; Edward Elgar: Cheltenham, UK, 2006; pp. 131–161. ISBN 9781845425821.

Sharif, N. Emergence and development of the national innovation systems concept. Res. Policy 2006, 35, 745–766.

Slaper, T.F.; Hall, T.J. The Triple Bottom Line: What is it and how does it work? Indiana Bus. Rev. 2011, 86, 4–8.

Smith, A. Translating sustainabilities between green niches and socio-technical regimes. Technol. Anal. Strateg. Manag. 2007, 19, 427–450.

Smits, R.E.; Kuhlmann, S.; Shapira, P. (Eds.) The Theory and Practice of Innovation Policy; Edward Elgar: Cheltenham, UK, 2010; ISBN 9781845428488.

Soete, L. Is innovation always good? In Innovation Studies: Evolution and Future Challenges; Fagerberg, J., Martin, B.R., Andersen, E.S., Eds.; Oxford University Press: Oxford, UK, 2013; pp. 134–144. ISBN 9780199686346.

Southerton, D.; Ulph, A. (Eds.) Sustainable Consumption: Multi-Disciplinary Perspectives in Honour of Professor Sir Partha Dasgupta; Oxford University Press: Oxford, UK, 2014; ISBN 9780199679355.

Stahl, B.C.; Eden, G.; Jirotka, M. Responsible research and innovation in information and communication technology: Identifying and engaging with the ethical implications of ICTs. In Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society; Bessant, J., Owen, R., Heintz, M., Eds.; Wiley: Chichester, UK, 2013; pp. 199–218. ISBN 9781119966364.

Stamm, A., Dantas, E.; Fischer, D.; Ganguly, S.; Rennkamp, B. Sustainability-Oriented Innovation Systems: Towards Decoupling Economic Growth from Environmental Pressures? 2009. Available online: http://edoc.vifapol.de/opus/volltexte/2011/3310/pdf/ DP_20.2009.pdf (accessed on 5 December 2017).

Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; et al. Planetary boundaries: Guiding human development on a changing planet. Science 2015, 347, 1259855. [PubMed]

Steward, F. Breaking the Boundaries: Transformative Innovation for the Global Good; NESTA: London, UK, 2008; ISBN 9781848750135.

Steward, F. Transformative innovation policy to meet the challenge of climate change: Sociotechnical networks aligned with consumption and end-use as new transition arenas for a low-carbon society or green economy. Technol. Anal. Strateg. Manag. 2012, 24, 331–343.

Stilgoe, J.; Owen, R.; Macnaghten, P. Developing a framework for responsible innovation. Res. Policy 2013, 42, 1568–1580.

Stirling, A. Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development; STEPS Working Paper 32; STEPS Centre: Brighton, UK, 2009; ISBN 9781858647916.

Stirling, A. Emancipating transformations. In The Politics of Green Transformations; Scoones, I., Leach, M., Newell, P., Eds.; Earthscan: London, UK, 2015; pp. 54–67. ISBN 9781138792890.

Swart, R.J.; Raskin, P.; Robinson, J. The problem of the future: Sustainability science and scenario analysis. Glob. Environ. Chang. 2004, 14, 137–146.

Tainter, J. What Is Transformation? Presentation; Recorded at the 1st Transformative Knowledge Workshop. November 2014. Available online: https://www.youtube.com/watch?v=T0gFP0zW_qY (accessed on 5 December 2017).

Teixeira, A.A.C. Evolution, roots and influence of the literature on national systems of innovation: A bibliometric account. Camb. J. Econ. 2014, 38, 181–214.

Timmermans, J. Mapping the RRI landscape: An overview of organisations, projects, persons, areas and topics. In Responsible Innovation 3: A European Agenda? Asveld, L., van Dam-Mieras, R., Swierstra, T., Lavrijssen, S., Linse, K., van den Hoven, J., Eds.; Springer: Cham, Switzerland, 2017; pp. 21–47. ISBN 9783319648347.

Timmermans, J.; Yaghmaei, E.; Stahl, B.C.; Brem, A. Research and innovation processes revisited—Networked responsibility in industry. Sustain. Account. Manag. Policy J. 2017, 8, 307–334.

Turnheim, B.; Berkhout, F.; Geels, F.; Hof, A.; McMeekin, A.; Nykvist, B.; van Vuuren, D. Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges. Glob. Environ. Chang. 2015, 35, 239–253.

United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development; United Nations: New York, NY, USA, 2015.

Urmetzer, S.; Pyka, A. Varieties of knowledge-based bioeconomies. In Knowledge-Driven Developments in the Bioeconomy; Dabbert, S., Lewandowski, I., Weiss, J., Pyka, A., Eds.; Springer: Cham, Switzerland, 2017; pp. 57–82. ISBN 9783319583730.

Van den Bergh, J.C.J.M.; Truffer, B.; Kallis, G. Environmental innovation and societal transitions: Introduction and overview. Environ. Innov. Soc. Transit. 2011, 1, 1–23.

Van Huijstee, M.M.; Francken, M.; Leroy, P. Partnerships for sustainable development: A review of current literature. Environ. Sci. 2007, 4, 75–89.

Von Schomberg, R. A vision of responsible research and innovation. In Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society; Bessant, J., Owen, R., Heintz, M., Eds.; Wiley: Chichester, UK, 2013; pp. 51–74. ISBN 9781119966364.

Von Schomberg, R. Prospects for technology assessment in a framework of responsible research and innovation. In Technikfolgen Abschätzen Lehren: Bildungspotenziale Transdisziplinärer Methoden; Dusseldorp, M., Beecroft, R., Eds.; Springer: Wiesbaden, Germany, 2012; pp. 39–61. ISBN 9783531934686.

Von Wehrden, H.; Luederitz, C.; Leventon, J.; Russell, S. Methodological challenges in sustainability science: A call for method plurality, procedural rigor and longitudinal research. Chall. Sustain. 2017, 5, 35–42.

Voß, J.-P.; Bauknecht, D.; Kemp, R. (Eds.) Reflexive Governance for Sustainable Development; Edward Elgar: Cheltenham, UK, 2006; ISBN 9781845425821.

Walsh, A.J.; Hormio, S.; Purves, D. (Eds.) The Ethical Underpinnings of Climate Economics; Routledge: London, UK, 2017; ISBN 9781138122963.

Walz, R.; Kuhlmann, S. Nachhaltigkeitsinnovationen in systemischer Perspektive. In Erde 2.0—Technologische Innovationen als Chance für Eine Nachhaltige Entwicklung? Mappus, S., Ed.; Springer: Berlin, Germany, 2005; pp. 278–310. ISBN 9783540213277.

Wang, L.-S. Causal efficacy and the normative notion of sustainability science. Sustain. Sci. Pract. Policy 2011, 7, 30–40.

Waring, T.M.; Kline, M.A.; Brooks, J.S.; Goff, S.H.; Gowdy, J.; Janssen, M.A.; Smaldino, P.E.; Jacquet, J. A multilevel evolutionary framework for sustainability analysis. Ecol. Soc. 2015, 20, 3415–3431.

Waring, T.M.; Tremblay, E. An evolutionary approach to sustainability science. Cliodyn. J. Quant. Hist. Cult. Evol. 2016, 7, 119–167.

Warnke, P.; Koschatzky, K.; Dönitz, E.; Zenker, A.; Stahlecker, T.; Som, O.; Cuhls, K.; Güth, S. Opening up the Innovation System Framework towards New Actors and Institutions; Fraunhofer ISI Discussion Papers Innovation Systems and Policy Analysis No. 49; Fraunhofer Institute for Systems and Innovation Research: Karlsruhe, Germany, 2016.

WBGU. World in Transition: A Social Contract for Sustainability; Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen: Berlin, Germany, 2011.

Weber, K.M.; Rohracher, H. Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. Res. Policy 2012, 41, 1037–1047.

Weber, K.M.; Truffer, B. Moving innovation systems research to the next level: Towards an integrative agenda. Oxf. Rev. Econ. Policy 2017, 33, 101–121.

Weber, M.; Hemmelskamp, J. (Eds.) Towards Environmental Innovation Systems; Springer: Berlin, Germany, 2005; ISBN 9783540223221.

World Commission on Environment and Development. Report of the World Commission on Environment and Development: Our Common Future; United Nations: Oxford, UK, 1987.

Wuketits, F.M. Moral systems as evolutionary systems: Taking evolutionary ethics seriously. J. Soc. Evol. Syst. 1993, 16, 251–271.

Wydra, S. Challenges for technology diffusion policy to achieve socio-economic goals. Technol. Soc. 2015, 41, 76–90.

Young, I.M. Responsibility and global justice: A social connection model. Soc. Philos. Policy 2006, 23, 102–130.

Young, O.R. Governing Complex Systems: Social Capital for the Anthropocene; The MIT Press: Cambridge, MA, USA, 2017; ISBN 9780262035934.

Chapter III

Exploring the Dedicated Knowledge Base of a Transformation towards a Sustainable Bioeconomy

III. Exploring the Dedicated Knowledge Base of a Transformation towards a Sustainable Bioeconomy

Abstract

The transformation towards a knowledge-based bioeconomy has the potential to serve as a contribution to a more sustainable future. Yet, until now, bioeconomy policies have been only insufficiently linked to concepts of sustainability transformations. This article aims to create such link by combining insights from innovation systems (IS) research and transformative sustainability science. For a knowledge-based bioeconomy to successfully contribute to sustainability transformations, the IS' focus must be broadened beyond techno-economic knowledge. We propose to also include systems knowledge, normative knowledge, and transformative knowledge in research and policy frameworks for a sustainable knowledge-based bioeconomy (SKBBE). An exploration of the characteristics of this extended, "dedicated" knowledge will eventually aid policymakers in formulating more informed transformation strategies.

Keywords

Sustainable knowledge-based bioeconomy; innovation systems; sustainability transformations; dedicated innovation systems; economic knowledge; systems knowledge; normative knowledge; transformative knowledge; bioeconomy policy.

Status of publication

This article has been published. Please cite as follows:

Urmetzer, S., Schlaile, M., Bogner, K., Mueller, M., & Pyka, A. (2018). Exploring the dedicated knowledge base of a transformation towards a sustainable bioeconomy. Sustainability, 10(6), 1694.

The content of the text has not been altered. For reasons of consistency, the language and the formatting have been changed slightly.

1. Introduction

In the light of so-called *wicked problems* (e.g., Rittel and Webber 1973; Pohl et al. 2017) underlying the global challenges that deeply affect *social*, *environmental*, and *economic* systems, fundamental transformations are required in all of these sustainability dimensions. Therefore, solution attempts need to be based on a systemic consideration of the dynamics, complementarities, and interrelatedness of the affected systems (Schlaile et al. 2017).

A relatively new and currently quite popular approach to sustainability transformations addressing at least some of these problems is the establishment of a bio-based economy: the bioeconomy concept relies on novel and future methods of intelligent and efficient utilization of biological resources, processes, and principles with the ultimate aim of substituting fossil resources (e.g., BMBF and BMEL 2015; Dabbert et al. 2017; Lewandowski 2018; Philp 2018; von Braun 2017; The White House 2012; El-Chichakli et al. 2016; Virgin et al. 2017). It is therefore frequently referred to as *knowledge-based bioeconomy* (Virgin et al. 2017; Pyka and Prettner 2018; DECHEMA 2007). Whereas the idea of a bioeconomy is promoted both by academia and in policy circles, it remains unclear what exactly it is comprised of, how to spur the transformation towards a knowledge-based bioeconomy, and how it will affect sustainable development (Staffas et al. 2013; Bugge et al. 2016). While the development and adoption of novel technologies that help to substitute fossil resources by re-growing biological ones certainly is a condition *sine qua non*, a purely technological substitution process will hardly be the means to confront the global challenges (Schlaile et al. 2017; Pyka 2017; Pyka and Buchmann 2017; Patterson et al. 2017; Morone 2016; Westley et al. 2011). It must be kept in mind that a transformation towards a sustainable bioeconomy is only one important contribution to the overall transformation towards sustainability. We explicitly acknowledge that unsustainable forms of bio-based economies are conceivable and even—if left unattended—quite likely (Pfau et al. 2014). All the more, we see the necessity of finding ways to intervene in the already initiated transformation processes to afford their sustainability.

For successful interventions in the transformation towards a more sustainable bioeconomy, a systemic comprehension of the underlying dynamics is necessary. The *innovation system* (IS) perspective developed in the 1980s as a research concept and policy model (Freeman 1987; Freeman 2008; Lundvall 1992; Nelson 1993; Edquist 1997) offers a suitable framework for such systemic comprehension. In the conventional understanding, according to Gregersen and Johnson, an IS "can be thought of as a system which creates and distributes knowledge, utilizes this knowledge by introducing it into the economy in the form of innovations, diffuses it and transforms it into something valuable, for example, international competitiveness and economic growth" (Gregersen and Johnson 1997, p. 482). While welcoming the importance attributed to knowledge by Gregersen and Johnson and other IS researchers (e.g., Lundvall and Johnson 1994; Lundvall 2004; Lundvall 2010; OECD 2000; Edquist 2005), particularly in the context of a *knowledge*-based bioeconomy, in this article, we aim to re-evaluate the role and characteristics of knowledge generated and exploited through IS. We argue that knowledge is not just utilized by and introduced in *economic* systems, but it also shapes (and is shaped by) *societal* and *ecological* systems more generally. Consequently, especially against the backdrop of the required transformation towards a *sustainable knowledge-based bioeconomy* (SKBBE), what is considered as "something valuable" goes beyond an economic meaning (see also Martin 2016, on a related note). For this reason, it is obvious that the knowledge base for an SKBBE cannot be a purely techno-economic one. We rather see a need for exploring additional types of knowledge and their characteristics necessary for fostering the search for truly transformative innovation (Pyka 2017).

From the sustainability literature, we know that at least three types of knowledge are relevant for tackling (wicked) problems related to transformations towards sustainability: *Systems* knowledge, *normative* knowledge, and *transformative* knowledge (ProClim 1997; Abson et al. 2014; Wiek and Lang 2016; von Wehrden et al. 2017; Knierim et al. 2018). Undoubtedly, these knowledge types need to be centrally considered and fostered for a transformation towards an SKBBE.

In the course of this paper, we aim to clarify the meaning and the characteristics of knowledge necessary for sustainability-oriented interventions in the transformation towards a bioeconomy. To reach this aim, we will explore the following research questions:

> Based on a combination of IS research with the sustainability science perspectives, what are the characteristics of knowledge that are instrumental for a transformation towards an SKBBE?
>
> What are the policy-relevant implications of this extended perspective on the characteristics of knowledge?

The article is structured as follows: Section 2 sets the scene by reviewing how knowledge has been conceptualized in economics. Aside from discussing in which way the understanding of the characteristics of economic knowledge has influenced innovation policy, we introduce the three types of knowledge (systems, normative, and transformative) relevant for governing sustainability transformations. Section 3 specifies the general meaning of these three types of knowledge, highlights their relevance and instrumental value for transformations towards an SKBBE, and relates them to the most prevalent characteristics of knowledge. Subsequently, Section 4 presents the policy-relevant implications that can be derived from our previous discussions. The concluding Section 5 summarizes our article and proposes some avenues for further research.

2. Knowledge and Innovation Policy

The understanding of knowledge and its characteristics varies between different disciplines. Following the Oxford Dictionaries, knowledge can be defined as "[f]acts, information, and skills acquired through experience or education" or simply as "theoretical or practical understanding of a subject" (English Oxford Living Dictionaries 2018). The Cambridge Dictionary defines knowledge as the "understanding of or information about a subject that you get by experience or study, either known by one person or by people generally" (Cambridge University Press 2018). A more detailed definition by Zagzebski (Zagzebski 1999, p. 92) states that "[k]nowledge is a highly valued state in which a person is in cognitive contact with reality. It is, therefore, a relation. On one side of the relation is a conscious subject, and on the other side is a portion of reality to which the knower is directly or indirectly related".

Despite this multitude of understandings of knowledge, most researchers and policymakers probably agree with the statement that knowledge "is a crucial economic resource" (Lundvall 1994, p. 27). Therefore, the exact understanding and definition of knowledge and its characteristics strongly affect how researchers and policymakers tackle the question of how to best deal with and make use of this resource. Policymakers intervene in IS to improve the three key processes of knowledge creation, knowledge diffusion, and knowledge use (its transformation into something valuable). Policy recommendations derived from an incomplete understanding and representation of knowledge, however, will not be able to improve the processes of knowledge flow in IS and can even counteract the attempt to turn knowledge into something genuinely valuable.

2.1 Towards a More Comprehensive Conceptualization of Knowledge

A good example that highlights the importance of how we define knowledge is the understanding and treatment of knowledge in mainstream neoclassical economics. Neoclassical economists describe knowledge as an intangible good with public good features (non-excludable, non-rivalrous in consumption). Due to the (alleged) non-excludable nature of knowledge, new knowledge flows freely from one actor to another (spillover) such that other actors can benefit from new knowledge without investing in its creation (free-riding) (Pyka et al. 2009). In this situation, the knowledge-creating actors cannot fully benefit from the value they created, that is, the actors cannot appropriate the returns that resulted from their research activity (appropriability problem) (Arrow 1962). There is no need for learning since knowledge instantly diffuses from one actor to another and the transfer of knowledge is costless. As Solow is often accredited with pointing out, knowledge falls "like manna from heaven" (see, e.g., Audretsch et al. 2013; Acs et al. 2013 with reference to Solow 1956; Solow 1957), and it can instantly be acquired and used by all actors (Nelson 1989).

In contrast to mainstream neoclassical economics, (evolutionary or neo-Schumpeterian) innovation economists and management scholars consider other features of knowledge, thus, providing a much more appropriate analysis of knowledge creation and innovation processes. Innovation economists argue that knowledge can rather be seen as a *latent public good* (Nelson 1989) that exhibits many non-public good characteristics relevant for innovation processes in IS. Since these more realistic knowledge characteristics strongly influence knowledge flows, their consideration improves the understanding of the three key processes of knowledge creation, knowledge diffusion, and knowledge use (transforming knowledge into something valuable) (Gregersen and Johnson 1997). In what follows, we present the latent public good characteristics of knowledge and structure them according to their relevance for these key processes in IS. Note that for the agents creating, diffusing, and using knowledge, we will use the term *knowledge carrier* in a similar sense as Dopfer and Potts (Dopfer and Potts 2008, p. 28), who wrote that "the micro unit in economic analysis is a knowledge carrier . . . acquiring and applying knowledge".

Characteristics of knowledge that are most relevant in the knowledge creation process are the *cumulative* nature of knowledge (e.g., Boschma 2005; Foray and Mairesse 2002), *path dependency* of knowledge (e.g., (Dosi 1982; Rizzello 2004), and knowledge *relatedness* (e.g., Morone and Taylor 2010; Vermeulen and Pyka 2017). As the creation of new knowledge or innovation results from the (re-)combination of previously unconnected knowledge (Arthur 2007; Schumpeter 1911), knowledge has a cumulative character and can only be understood and created if actors already have a knowledge stock they can relate the new knowledge to (Morone and Taylor 2010; Schlaile et al. 2018). The more complex and industry-specific knowledge gets, the higher the importance of prior knowledge and knowledge relatedness (see also the discussions in Vermeulen and Pyka 2017; Frenken et al. 2007).

Characteristics of knowledge that are especially important for the knowledge diffusion process are *tacitness*, *stickiness*, and *dispersion*. Knowledge is not equal to information (Rooney et al. 2003; Adolf and Stehr 2014). In fact, as Morone (2013) also explains, information can be regarded as that part of knowledge that can be easily partitioned and transmitted to someone else; information requires knowledge to become useful. Other parts of knowledge are *tacit* (Polanyi 1966), that is, very difficult to be codified and to be transported (Galunic and Rodan 1998). Tacit knowledge is excludable and, therefore, not a public good (Antonelli 1999). So, even if the knowledge carrier is willing to share, tacitness makes it impossible sometimes to transfer this knowledge (Nonaka 1994). In addition, knowledge and its transfer can be *sticky* (Szulanski 2003; von Hippel 1994), which means that the transfer of this knowledge requires significantly more effort than the transfer of other knowledge. According to Szulanski (2003), both knowledge and the process of knowledge exchange can be sticky. The reasons may be the kind and amount of knowledge itself but also attributes of the knowledge carriers. Finally, the *dispersion* of knowledge also influences the possibility of diffusing knowledge. Galunic and Rodan (1998) explain dispersed knowledge by using the example of a jigsaw puzzle. The authors state that knowledge is distributed if all actors receive a photocopy of the picture of the jigsaw puzzle. In contrast, knowledge is dispersed if every actor receives one piece of the jigsaw puzzle, meaning that everybody only holds pieces of the knowledge but not the 'whole' picture. Dispersed knowledge (or systems-embedded knowledge) is difficult to be transferred from one to the other actor (as detecting dispersed knowledge can be problematic, too (Galunic and Rodan 1998), thus hindering knowledge diffusion.

Characteristics of knowledge (and knowledge carriers) that influence the possibility to use the knowledge within an IS, that is, to transform it into something valuable, are the *context specificity* and *local* characteristics of knowledge. Even if knowledge is freely available in an IS, the public good features of knowledge are not necessarily decisive, and it might be of little or no use to the receiver. We have to keep in mind that knowledge itself has no value; it only becomes valuable to someone if the knowledge can be used, for example, to solve certain problems (Potts 2001). Assuming that knowledge has different values for different actors, more knowledge is not always better. Actors need the right knowledge in the right context at the right time and have to be able to combine this knowledge in the right way to utilize the knowledge. The "resource" knowledge might only be relevant and of use in the narrow context for and in which it was developed (Galunic and Rodan 1998). Moreover, to understand and use new knowledge, agents need *absorptive capacities* (Cohen and Levinthal 1989; Cohen and Levinthal 1990). These capacities vary with the disparity of the actors exchanging knowledge: the larger the *cognitive distance* between them, the more difficult it is to exchange and internalize knowledge. Hence, the cognitive distance can be critical for learning and transforming knowledge into something valuable (Nooteboom et al. 2007; Bogner et al. 2018).

Note that while we have described the creation, diffusion, and use of knowledge in IS as rather distinct processes, this does not imply any linear character or temporal sequence of these processes. Quite the contrary, knowledge creation, diffusion, and use and the respective characteristics of knowledge may overlap and intertwine in a myriad of ways. For example, due to the experimental nature of innovation in general and the fundamental uncertainty involved, there are path dependencies, lock-ins (for example, in terms of stickiness), and feedback that lead to evolutionary cycles of variation/recombination, selection, and transmission or retention of knowledge. Moreover, the vast literature on knowledge *mobilization*, knowledge *translation*, and knowledge *transfer* (e.g., Bennet and Bennet 2007; Jacobson et al. 2003; Szulanski 2000; Mitton et al. 2007) suggests that there can be various obstacles between the creation, diffusion, and use of knowledge, and that so-called *knowledge mediators* or *knowledge brokers* may be required to actively guide these interrelated processes (see also Adomßent 2013, on a related discussion). Consequently, we caution against reading the "trichotomy" of creation, diffusion, and use as connoting that knowledge will be put to good use by the carriers in the end so long as the conditions, such as social network structures, for diffusion are right. In fact, the notion of "optimal" network structures for diffusion may be misguided against the backdrop of the (in-)compatibility of knowledge, cognitive distance, and the dynamics underlying the formation of social networks (Schlaile et al. 2018).

2.2 How Knowledge Concepts Have Inspired Innovation Policy Making

Depending on the underlying concept of knowledge, different schools of thought influenced innovation policies in diverse ways (see also Ronney et al. 2003; Nyholm et al. 2001; Lundvall 2001). Following the mainstream neoclassical definition, the (alleged) public good characteristics of knowledge may result in market failure and the appropriability problem. As a consequence, policies have mainly focused on the mitigation of potential externalities and the elimination of inefficient market structures. This was done, for example, by incentive creation (via subsidies or intellectual property rights), the reduction of market entry barriers, and the production of knowledge by the public sector (Chaminade and Edquist 2010). As Smith also states, "policies of block funding for universities, R&D subsidies, tax credits for R&D etc. [were] the main instruments of post-war science and technology policy in the OECD area" (Smith 1994, p. 8).

Policies changed (at least to a certain extent) when the understanding of knowledge changed. Considering knowledge as a *latent* public good, the main rationale for policy intervention is not market failure, but rather systemic problems (Chaminade and Edquist 2010; Klein Woolthuis et al. 2005). Consequently, it can be argued that the mainstream neoclassical perspective neglects the importance (and difficulty) of facilitating knowledge creation, knowledge diffusion, and knowledge use in IS (see also Nyholm et al. 2001; Lundvall 2001, on a related note). Western innovation policies are often based on the IS approach and inspired by the more comprehensive understanding of knowledge and its implications for innovation. They generally aim at solving inefficiencies in the system (for example, infrastructural, transition, lock-in/path dependency, institutional, network, and capabilities failures as summarized by Klein Woolthuis 2005). These inefficiencies are tackled, for example, by supporting the creation and development of different institutions in the IS as well as fostering networking and knowledge exchange among the system's actors (Chaminade and Edquist 2010). Since "knowledge is created, distributed, and used in social systems as a result of complex sets of interactions and relations rather than by isolated individuals" (Rooney et al. 2005, p. 2), *network science* (Barabási 2016) especially has provided methodological support for policy interventions in innovation networks (Ahrweiler and Keane 2013; Buchmann and Pyka 2012; Scharnhorst and Pyka 2009).

It is safe to state that innovation policies have changed towards a more realistic evaluation of innovation processes over the last decades (Edler and Fagerberg 2017), although in practice, they often still fail to adequately support processes of knowledge creation, diffusion, and use. Even though many policymakers nowadays appreciate the advanced understanding of knowledge and innovation, what Smith wrote more than two decades ago is arguably still valid to some extent, namely that "linear notions remain powerfully present in policy thinking, even in the new innovatory context" (Smith 1994, p. 8). Such a non-systemic way of thinking is also reflected by the strongly disciplinary modus operandi which is most obviously demonstrated by the remarkable difficulties still present in concerted actions at the level of political departments.

2.3 Knowledge Concepts in Transformative Sustainability Science

Policy adherence to the specific knowledge characteristics identified by economists has proven invaluable for supporting IS to produce innovations. However, to what end? So far, innovation has frequently been implicitly regarded as desirable per se (Schlaile et al. 2017; Soete 2013; Engelbrecht 2017) and, by default, creating something valuable. However, if IS research shall be aimed at contributing to developing solution strategies to global sustainability challenges, a mere increase in innovative performance by improving the flow of economically relevant knowledge will not suffice (Schlaile et al. 2017). In times of globally effective wicked problems challenging our current production and consumption patterns, it is evident that research into knowledge creation and innovation cannot be a task for economists or any other isolated discipline alone (see also Lahnsen 2010, on a related discussion). Additional types of knowledge particularly relevant for addressing wicked problems have been proposed by sustainability science in general and *transformational* sustainability research in particular (Wiek and Lang 2016). Solution options for the puzzle of reconciling economic development with sustainability goals have been found to require three kinds of knowledge: First, *systems knowledge*, which relates to the understanding of the dynamics and processes of ecological and social systems (including IS); second, *normative knowledge*, which determines the desired (target) states of a system; and third, *transformative knowledge*, which builds on systems and normative knowledge to inform the development of strategies for changing systems towards the desired state (ProClim 1997; Abson et al. 2014; Wiek and Lang 2016; von Wehrden 2017; Knierim et al. 2018). Although there are alternative terms for these three types of knowledge (such as *explanatory* knowledge, *orientation* knowledge, and *action-guiding* knowledge, as used in Grunwald 2007), for the sake of terminological consistency with most recent publications, we adopt the terms systems knowledge, normative knowledge, and transformative knowledge.

The fundamental significance of these three kinds of knowledge (systems, normative, and transformative) for sustainability transformations has been put forward by a variety of research strands from theoretical (ProClim 1997; Abson et al. 2014) to applied planning perspectives (Wiek and Binder 2005; Rydin 2007). Explorations into the specific characteristics in terms of how such knowledge is created, diffused, and used within IS, however, are missing so far. For the particular case of a dedicated transformation towards an SKBBE, we seek to provide some clarification as a basis for an improved governance towards desired ends.

3. Dedicated Knowledge for an SKBBE Transformation

A dedicated transformation towards an SKBBE can be framed with the help of the newly introduced concept of *dedicated innovation system* (DIS) (Schlaile et al. 2017; Pyka 2017a; Pyka 2017b), which goes beyond the predominant focus on technological innovation and economic growth. DIS are dedicated to *transformative* innovation (Steward 2008; Steward 2012), which calls for experimentation and (co-)creation of solution strategies to overcome systemic inertia and the resistance of incumbents. In the following, we specify in what ways the IS knowledge needs to be complemented to turn into *dedicated knowledge* instrumental for a transformation towards an SKBBE. Such dedicated knowledge will thus have to comprise economically relevant knowledge as regarded in IS as well as systems knowledge, normative knowledge, and transformative knowledge. Since little is known regarding the meaning and the nature of the latter three knowledge types, we need to detail them and illuminate their central characteristics. This will help to fathom the processes of knowledge creation, diffusion, and use, which will be the basis for deriving policy-relevant implications in the subsequent Section 4.

3.1 Systems Knowledge

Once the complexity and interdependence of transformation processes on multiple scales is acknowledged, systemic boundaries become quite irrelevant. In the context of an SKBBE, systems knowledge must comprise more than the conventional understanding of IS in terms of actor configurations, institutions, and interrelations. As already stressed by Grunwald (2004, p. 154), "sufficient insight into natural and societal systems, as well as knowledge of the interactions between society and the natural environment, are necessary prerequisites for successful action in the direction of sustainable development". Although the IS literature has contributed much to systems knowledge about several levels of economic systems, including technological, sectoral, regional, national, and global IS, the interplay between IS, the Earth system (e.g., Schellnhuber et al. 2004; Biermann et al. 2010) and other relevant (sub-)systems (e.g., Boulding 1985; Schramm 1994; Seidler and Bawa 2009; Colander and Kupers 2014; Almudi and Fatas-Villafranca 2018) must also be regarded as a vital part of systems knowledge in the context of sustainability and the bioeconomy. On that note, various authors have emphasized the importance of understanding systemic thresholds and tipping points (e.g., Young 2017; Lamberson 2012; Wassmann and Lenton 2012; Gladwell 2000) and network structures (e.g., Morone 2015; Scheiterle et. al 2018), which can thus be considered important elements of systems knowledge. In this regard, it may also be important to stress that systems knowledge is (and must be) subject to constant revision and change, because, as Boulding (1966, p. 9) already emphasized, "we are not simply acquiring knowledge about a static system which stays put, but acquiring knowledge about a whole dynamic process in which the acquisition of the knowledge itself is a part of the process".

To give a prominent example which suggests a lack of systems knowledge in bioeconomy policies, we may use the case of biofuels and their adverse effects on land-use and food supply in some of the least developed countries (Leemans et al. 1996; Searchinger et al. 2008). In this case, the wicked problem addressed was climate change due to excessive CO_2 emissions, and the solution attempt was the introduction of bio-based fuel for carbon-reduced mobility. However, after the first boom of biofuel promotion, emissions savings were at best underwhelming or negative since the initial models calculating greenhouse gas savings had insufficiently considered the effects of the biofuel policies on markets and production: whereas the carbon intensity of biofuel crop cultivation was taken into account, the overall expansion of the agricultural area and the conversion of former grasslands and forests into agricultural land was not (Leemans et al. 1996; Searchinger et al. 2008). These indirect land-use change (ILUC) effects are estimated to render the positive effects of biofuel usage more than void, which represents a vivid example for how (a lack of) comprehensive systems knowledge can influence the (un)sustainability of bioeconomy transformations.

In accordance with much of the IS literature's focus on knowledge and the common intellectual history of IS and evolutionary economics (e.g., Freeman 2008), it becomes clear that an economic system, in general, and a (knowledge-based) bioeconomy, in particular, may also be regarded as "a coordinated system of distributed knowledge" (Potts 2001, p. 413). Potts posits that "[k]nowledge is the solution to problems. A solution will consist of a *rule*, which is a generative system of connected components" (2001, p. 418f.). The importance of rules is particularly emphasized by the so-called *rule-based approach* (RBA) to evolutionary economics developed by Dopfer and colleagues (e.g., Dopfer and Potts 2008; Dopfer 2005; Dopfer 2011; Dopfer 2016; Dopfer and Potts 2009; Dopfer 2004; Dopfer et al. 2004). According to the RBA, a "rule is defined as the idea that organizes actions or resources into operations. It is the element of knowledge in the knowledge-based economy and the locus of evolution in economic evolution" (Dopfer and Potts 2008, p. 6). As Blind and Pyka also elucidate, "a rule represents knowledge that enables its carrier to perform economic operations, i.e., production, consumption and transactions. The distinction between generic rules and operations based on these rules is essential for the RBA" (Blind and Pyka 2014, p. 1086). According to the RBA, these generic rules may be further distinguished into subject and object rules: subject rules are the cognitive and behavioral rules of an economic agent, whereas object rules are social and technical rules that represent the organizing principles for social and technological systems (Dopfer and Potts 2008; Dopfer 2016). The latter include, for example, *Nelson-Winter organizational routines* (Nelson and Winter 1982) and *Ostrom social rules* (e.g., Ostrom 2005; Ostrom 2006; Ostrom and Basurto 2011). From this brief summary of the RBA, it already becomes clear that an understanding of the bioeconomic systems' rules and their interrelations is an instrumental element of systems knowledge. Or, as Meadows puts it, "[p]ower over the rules is real power" (Meadwos 2008, p. 158).

Since it can be argued that the creation, diffusion, and use of systems knowledge is the classical task of the sciences (Grunwald 2007; Grunwald 2004), most of the characteristics of latent public goods (as outlined above) can be expected to also hold for systems knowledge in terms of its relatedness, cumulative properties, and codifiability. Special features to be considered when dealing with systems knowledge in the context of a transformation towards an SKBBE will be twofold: First, systems knowledge may be quite sticky, that is, it may require much effort to be transferred. This is owed to the fact that departing from linear cause-and-effect thinking and starting to think in systems still requires quite some intellectual effort on the side of the knowledge carrier (see also Capra and Luisi 2014, on a related note). Second, systems knowledge can be expected to be strongly dispersed among different disciplines and knowledge bases of great cognitive distances, such as—with recourse to the example of ILUC—economics, agricultural sciences, complexity science, and other (social and natural) sciences.

3.2 Normative Knowledge

According to Abson and colleagues (2014, p. 32), "[n]ormative knowledge encompasses both knowledge on desired system states (normative goals or target knowledge...) and knowledge related to the rationalization of value judgements associated with evaluating alternative potential states of the world (as informed by systems knowledge...)". In the context of an SKBBE, it becomes clear that normative knowledge must refer not only to directionality, responsibility, and legitimacy issues in IS (as discussed in Schlaile et al. 2017) but also to the targets of the interconnected physical, biological, social, political, and other systems (e.g., Boulding 1985). Thereby, for the transformation of knowledge into "something valuable" within IS (cf. Gregersen and Johnson 1997), the dedication of IS to an SKBBE also implies that the goals of "international competitiveness and economic growth" (cf. Gregersen and Johnson 1997) must be adjusted and re-aligned with what is considered something valuable in conjunction with the other interconnected (sub-)systems (for example, social and ecological ones) (see also Daimer et al. 2012; Lindner et al. 2016 on the related discussion about orientation failure in IS).

Yet, one of the major issues with prior systemic approaches to sustainability transformations, in general, seems to be that they tend to oversimplify the complexity of normative knowledge and value systems by presuming a consensus about the scale and importance of sustainability-related goals and visions (Almudi et al. 2017). As, for instance, Miller and colleagues claim, "[i]nquiries into values are largely absent from the mainstream sustainability science agenda" (Miller et al. 2014, p. 241). However, sustainability is a genuinely normative phenomenon (Grunwald 2007) and knowledge related to norms, values, and desired goals that indicate the necessity for and direction of change is essential for the successful systemic change towards a *sustainable* bioeconomy (and not just any bioeconomy for the sake of endowing the biotechnology sector). Norms, values, and narratives of sustainability are regularly contested and contingent on diverse and often conflicting and (co-)evolving worldviews (Schlaile et al. 2017; Almudi et al.2017; Miller et al. 2014; Beddoe et al. 2009; Matutinoović 2007; Brewer and Karafiath 2013; Leach et al. 2010; Van Opstal and Hugé 2013; Breslin 2014).

Similar ambiguity can be observed in the context of the bioeconomy (e.g., Bugge et al. 2016; Zwier et al. 2015). When taking the complexity of normative knowledge seriously, it may even be impossible to define globally effective rules, norms, or values (in terms of a universal paradigm for an SKBBE) (Pfau et al. 2014). Arguably, it may be more important to empower actors within IS to "apply, negotiate and reconcile norms and principles based on the judgements of multiple stakeholders" (Blok et al. 2016, p. 12). The creation of normative knowledge for an SKBBE can thus be expected to depend on different initial conditions such as the cultural context, whereas the diffusion of a globally effective canon of practices for an SKBBE is highly unlikely (see also Urmetzer and Pyka 2017). Normative knowledge for an SKBBE is, therefore, intrinsically local in character despite the fact that sustainable development is a global endeavor.

Moreover, the creation of normative knowledge is shaped by *cultural evolutionary processes* (e.g., Breslin 2014; Hodgson 2014; Wuketits 1993; Boyd and Richerson 1985; Boyd and Richerson 1994; Boyd and Richerson 2005; Richerson and Boyd 2005; Ayala 1987; Waring et al. 2015). This means, for example, that both subject rules that shape the sustainability goals of the individual carriers (for example, what they consider good or bad) and object rules that determine what is legitimate and important within a social system or IS are subject to path dependence, competition, and feedback at the level of the underlying ideas (e.g., Schlaile et al. 2018; Almudi et al. 2017; Markey-Towler 2018; Almudi et al. 2017). The diffusion of normative knowledge about the desired states of a system is therefore always contingent on its context specificity and dependent on cultural evolution. In Boyd and Richerson's words, "people acquire beliefs, attitudes, and values both by teaching and by observing the behavior of others. Culture is not behavior; culture is information . . . that, together with individuals' genes and their environments, determines their behavior" (Boyd and Richerson 1994, p. 74). While many object rules are codifiable as laws and formal institutions, most subject rules can be assumed to remain tacit so that normative knowledge consists of a combination of tacit and codified knowledge. Of course, "people are not simply rule bound robots who carry out the dictates of their culture" (Boyd and Richerson 1994, p. 72), but rules can often work subconsciously to evolve institutions (e.g., Johnson 2010) and shared paradigms that span the "bounded performative space" of an IS (see, e.g., Schlaile et al. 2017, on a related note).

Consequently, when referring to normative knowledge and the constituting values and belief systems, we are not only dealing with the competition and evolution of knowledge at the level of rules and ideas driven by (co-)evolutionary processes across the societal sub-systems of individuals, the market, the state, civil society, and nature (Almudi and Fatas-Villafranca 2018). To a great extent, the cognitive distances of competing carriers *within* sub-systems and their conflicting strategies can also pose serious impediments to normative knowledge creation, diffusion, and use. This complex interrelation may, thus, be understood from a multilevel perspective with feedback between worldviews, visions, paradigms, the Earth system, regimes, and niches (Göpel 2016).

3.3 Transformative Knowledge

Transformative knowledge can, in the context of this article, be understood as knowledge about how to accelerate and influence the ongoing transformation towards an SKBBE. As, for instance, Abson and colleagues (2014) explain, this type of knowledge is necessary for the development of tangible strategies to transform systems (based on systems knowledge) towards the goals derived from normative knowledge. Theoretical and practical understanding must be attained to afford transitions from the current to the desired states of the respective system(s), which will require a mix of codified and tacit elements. Creating transformative knowledge will encompass the acquisition of skills and knowledge about how to effect systemic changes, or, as Almudi and Fatas-Villafranca put it, how to deliberately shape the evolutionary processes in other sub-systems (a mechanism referred to as *promotion* by Almudi and Fatas-Villafranca 2018). Although wicked problems that necessitate these changes are most often global in nature, their solution strategies will have to be adapted to the local conditions (Steward 2008). While global concepts and goals for a bioeconomy may be relatively easy to agree upon, the concrete measures and resource allocation will be negotiated and disputed at the regional and local scales (Schaper-Rinkel 2012). This renders transformative knowledge in IS exceptionally local.

In line with the necessity for a change of goals and values, scholars of the educational sciences argue that effective transformative knowledge will also require a revision of inherited *individual* value frames and assumptions on the side of the knowledge carriers themselves (Banks 1993). This process of fundamentally challenging personal worldviews inherent in the absorption of truly transformative knowledge makes this type of knowledge extremely sticky and inhibited by lock-ins and path dependence. For a transformation from a fossil to a bio-based economy, the collective habituation to a seemingly endless and cheap supply of fossil resources and the ostensibly infinite capacity of ecosystems to absorb emissions and waste must be overcome. In line with findings from cultural evolution and the RBA, sustainability education research has also pointed to the importance of acknowledging that human action is driven not only by cognitive knowledge but also unconsciously by “deeper” levels of knowing such as norms, assumptions, values, or beliefs (Sterling 2011). Consequently, only when being effective on these different levels of consciousness can transformative knowledge unfold its full potential to enable its carriers to induce behavioral change in themselves, a community, or the society. Put differently, the agents of sub-systems will only influence the replication and selection processes according to sustainable values in other sub-systems (via promotion) if they expect advantages in individual and social well-being (Almudi and Fatas-Villafranca 2018).

Besides systems and normative knowledge, transformative knowledge thus requires the skills to affect deeper levels of knowing and meaning, thereby influencing more immediate and conscious levels of (cognitive and behavioral) rules, ideas, theories, and action (Mezirow 1991; Dirkx 1998). Against this backdrop, it may come as no surprise that the prime minister of the German state of Baden-Wuerttemberg, member of the green party, has so far failed to push state policies towards a mobility transformation away from individual transport on the basis of combustion technology. In an interview, he made it quite clear that although he has his chauffeur drive him in a hybrid car on official trips, in his private life he "does what he considers right" by driving "a proper car"—namely a Diesel (Focus 2015).

From what we have elaborated regarding the characteristics of transformative knowledge, we must conclude that its creation requires a learning process on multiple levels. It must be kept in mind that it can only be absorbed if the systemic understanding of the problem and a vision regarding the desired state are present, that is, if a certain level of capacity to absorb transformative knowledge is given. Furthermore, Grunwald (2007) argues that the creation of transformative knowledge must be reflexive. In a similar vein, Lindner and colleagues stress the need for reflexivity in IS, and they propose various quality criteria for reflexive IS (Lindner et al. 2016). In terms of its diffusion and use, transformative knowledge is thought to become effective only if it is specific to the context and if its carriers have internalized the necessity for transformation by challenging their personal assumptions and values. Consequently, since values and norms have evolved via cultural evolution, transformative knowledge also needs to include knowledge about how to influence the cultural evolutionary processes (e.g., Beddoe et al. 2009; Brewer 2015; Wilson 2016; Wilson et al. 2014; Biglan and Barnes-Holmes 2015). To take up Brewer's *culture design* approach, "change processes can only be guided if their evolutionary underpinnings are adequately understood. This is the role for approaches and insights from cultural evolution" (Brewer 2015, p. 69).

4. Policy-Relevant Implications

4.1 Knowledge-Related Gaps in Current Bioeconomy Policies

The transformation towards an SKBBE must obviously be guided by strategies derived from using transformative knowledge which is, by definition, based on the other relevant types comprising dedicated knowledge. We suspect that the knowledge which guided political decision-makers in developing and implementing current bioeconomy policies so far has, in some respect, not been truly transformative. Important processes of creating, diffusing, and using systems and, especially normative knowledge, have not sufficiently been facilitated. We propose how more detailed insights into the characteristics of dedicated knowledge can be used to inform policymakers in improving their transformative capacities. Based on the example of two common issues of critique in the current bioeconomy policy approaches, we will substantiate our knowledge-based argument. Bioeconomy policies have been identified (i) to be biased towards economic goals and, therefore, take an unequal account of all three dimensions of sustainability (Pfau et al. 2014; Ramcilovic-Suominen and Pülzl 2018; Schmid et al. 2012; Hilgartner 2007; Birch et al. 2010; McCormick and Kautto 2013); and, to some extent related to it; (ii) to only superficially integrate all relevant stakeholders into policy making (Pfau et al. 2014; Schmid et al. 2012; Fatheuer 2015; Albrecht et al. 2012; Raghu et al. 2011; ten Bros and van Dam 2013; Schütte 2018).

Bioeconomy policies brought forward by the European Union (EU) and several nations have been criticized for a rather narrow techno-economic emphasis. While using the term sustainable as an attribute to a range of goals and principles frequently, the EU bioeconomy framework, for example, still overemphasizes the economic dimension. This is reflected by the main priority areas of various political bioeconomy agendas which remain quite technocratic: keywords include biotechnology, eco-efficiency, competitiveness, innovation, economic output, and industry in general (Staffas et al. 2013; Ramcilovic-Suominen and Pülzl 2018). The EU's proposed policy action along the three large areas (i) the investment in research, innovation and skills; (ii) the reinforcement of policy interaction and stakeholder engagement; and (iii) the enhancement of markets and competitiveness in bioeconomy sectors (European Commission 2012, p. 22), reveals a strong focus on fostering *economically relevant* and technological knowledge creation. In a recent review (European Commission 2017) of its 2012 Bioeconomy Strategy (European Commission 2012) the European Commission (EC) did indeed observe some room for improvement with regard to more comprehensive bioeconomy policies by acknowledging that "the achievement of the interlinked bioeconomy objectives requires an integrated (i.e., cross-sectoral and cross-policy) approach within the EC and beyond. This is needed in order to adequately address the issue of multiple trade-offs but also of synergies and interconnected objectives related to bioeconomy policy (e.g., sustainability and protection of natural capital, mitigating climate change, food security)" (European Commission 2017, p. 25).

An overemphasis on economic aspects of the bioeconomy in implementation strategies is likely to be rooted in an insufficient stock of systems knowledge. If the bioeconomy is meant to "radically change [Europe's] approach to production, consumption, processing, storage, recycling and disposal of biological resources" (European Commission 2012, p. 8) and to "assure over the long term the prosperity of modern societies" (BMBF and BMEL 2015, p. 2), the social and the ecological dimension have to play equal roles. Furthermore, the systemic interplay between all three dimensions of sustainability must be understood and must find its way into policy making via systems knowledge. While the creation of systems knowledge within the individual disciplines does not seem to be the issue (considering, for example, advances in Earth system sciences, agriculture, and political sciences), its interdisciplinary diffusion and use seem to lag behind (see also Brewer 2015, on a related note). The prevalent characteristics of this knowledge relevant for its diffusion have been found to be stickiness and dispersal (see Section 3.1 above). To reduce the stickiness of systems knowledge and, thus, improve its diffusion and transfer, long-term policies need to challenge the fundamental principles still dominating in education across disciplines and across school levels: linear cause-and-effect thinking must be abandoned in favor of systemic ways of thinking. To overcome the wide dispersal of bioeconomically relevant knowledge across academic disciplines and industrial sectors, policies must encourage inter- and transdisciplinary research even more and coordinate knowledge diffusion across mental borders. This, in turn, calls for strategies that facilitate connecting researchers across disciplines and with practitioners as well as translating systems knowledge for the target audience (e.g., Bennet and Bennet 2007). Only then can systems knowledge ultimately be used for informing the creation processes of transformative knowledge.

This brings us to the second issue of bioeconomy policies mentioned above: the failure of bioeconomy strategies to involve all stakeholders in a sincere and open dialogue on goals and paths towards (a sustainable) bioeconomy (Fatheuer et al. 2015; Albrecht et al. 2012; Schütte 2018). Their involvement in the early stages of a bioeconomy transformation is not only necessary for receiving sufficient acceptance of new technologies and the approval of new products (McCormick and Kautto 2013; Albrecht et al. 2012). These aspects—which, again, mainly affect the short-term *economic* success of the bioeconomy—are addressed well across various bioeconomy strategies. However, "[a]s there are so many issues, trade-offs and decisions to be made on the design and development of the bioeconomy, a commitment to participatory governance that engages the general public and key stakeholders in an *open* and *informed dialogue* appears vital" (McCormick and Kautto 2013, p. 2603; italics added). From the perspective of dedicated knowledge, there is a reason why failing to integrate the knowledge, values, and worldviews of the people affected will seriously impede the desired transformation: the processes of creation, diffusion, and use of normative knowledge and transformative knowledge are contingent on the input of a broad range of stakeholders—basically, of everyone who will eventually be affected by the transformation. The use of normative knowledge (that is, the agreement upon common goals), as well as the use of transformative knowledge (that is, the definition of transformation strategies), have both been identified to be intrinsically local and context-specific (see Sections 3.2 and 3.3). A policy taking account of these characteristics will adopt mechanisms to enable citizens to take part in societal dialogue which must comprise three tasks: offering suitable participatory formats, educating people to become responsible citizens, and training transdisciplinary capabilities to overcome cognitive distances between different mindsets as well as to reconcile global goals with local requirements. In this respect, there has been a remarkable development at the European level: while the German government is still relying on the advice of a Bioeconomy Council representing only the industry and academia for developing the bioeconomy policy (Schaper-Rinkel 2012), the recently reconstituted delegates of the European Bioeconomy Panel represent a variety of societal groups: "business and primary producers, policymakers, researchers, and civil society organisations" (European Commission 2017, p. 13). Unsurprisingly, their latest publication, the bioeconomy stakeholders' *manifesto*, gives some recommendations that clearly reflect the broad basis of stakeholders involved, especially concerning education, skills, and training (The European Bioeconomy Stakeholders Panel 2018).

For a structured overview of the elements of dedicated knowledge and their consideration by current bioeconomy policy approaches, see Table 2.

Table 2 The elements of dedicated knowledge in the context of SKBBE policies.

Central Knowledge Types as Elements of Dedicated Knowledge	**General Meaning**	**Sustainability and Bioeconomy-Related Instrumental Value**	**Most Prevalent Characteristics Regarding Creation, Diffusion and Use**	**Consideration by Current Bioeconomy Policy Approaches**
Economically relevant knowledge	Knowledge necessary to create economic value.	Knowledge necessary to create economic value in line with the resources, processes, and principles of biological systems.	Latent public good, depending on the technology in question.	Adequately considered.
Systems knowledge	Descriptive, interdisciplinary understanding of relevant systems.	Understanding of the dynamics and interactions between biological, economic, and social systems.	Sticky and strongly dispersed between disciplines.	Insufficiently considered.
Normative knowledge	Knowledge about desired system states to formulate systemic goals.	(Knowledge of) Collectively developed goals for sustainable bioeconomies.	Intrinsically local, path-dependent, and context-specific; but sustainability as a global endeavor.	Partially considered.
Transformative knowledge	Know-how for challenging worldviews and developing tangible strategies to facilitate the transformation from current system to target system.	Knowledge about strategies to govern the transformation towards an SKBBE.	Local and context-specific, strongly sticky, and path-dependent.	Partially considered.

4.2 Promising (But Fragmented) Building Blocks for Improved SKBBE Policies

Although participatory approaches neither automatically decrease the cognitive distances between stakeholders nor guarantee that the solution strategies agreed upon are based on the most appropriate (systems and normative) knowledge (Rydin 2007), an SKBBE cannot be achieved in a top-down manner. Consequently, the involvement of stakeholders confronts policymakers with the roles of coordinating agents and knowledge brokers (Bennet and Bennet 2007; Jacobson 2003; Mitton et al. 2007; Meyer 2010). Once a truly systemic perspective is taken up, the traditional roles of different actors (for example, the state, non-governmental organizations, private companies, consumers) become blurred (see also Castells 2010a; Castells 2010b; Castells 2010c), which has already been recognized in the context of environmental governance and prompted Western democracies to adopt more participatory policy approaches (Copagnon 2012). A variety of governance approaches exist, ranging from *adaptive governance* (e.g., Wyborn 2015; Folke et al. 2005; Boyd and Folke 2012) and *reflexive governance* (e.g., Lindner et al. 2016;

Voß et al. 2006) to *Earth system governance* (e.g., Patterson 2017; Biermann et al. 2010; Biermann 2014) and various other concepts (e.g., Young 2017; von Schomberg 2013; Scoones et al. 2015; Milkoreit 2017; Bugge 2018). Without digressing too much into debates about the differences and similarities of systemic governance approaches, we can already contend that the societal roots of many of the sustainability-related wicked problems clearly imply that social actors are not only part of the problem but must also be part of the solution. Against this background, transdisciplinary research and participatory approaches such as co-design and co-production of knowledge have recently gained momentum with good reason (e.g., von Wehrden et al. 2017; Evans et al. 2015; Frantzeskaki 2016; Kahane 2012; Luederitz et al. 2017; Mauser et al. 2013; Moser 2016; Wiek 2007; Wiek et al. 2012) and are also promising in the context of the transformation towards an SKBBE. Yet, the question remains why only very few, if any, bioeconomy policies have taken participatory approaches and stakeholder engagement seriously (see, e.g., Albrecht et al. 2012a; Albrecht et al. 2012b, on a related discussion).

To better acknowledge the characteristics of dedicated knowledge, we can propose a combination of four hitherto rather fragmented but arguably central frameworks that may be built on to improve bioeconomy policy agendas in terms of creating, diffusing, and using dedicated knowledge (note that the proposed list is non-exhaustive but may serve as a starting point for developing more adequate knowledge-based bioeconomy policies):

- Consider the roles of policymakers and policy making from a co-evolutionary perspective (see also Breslin 2014), where the "state" is conceived as one of several sub-systems (for example, next to the individuals, civil society, the market, and nature) shaping contemporary capitalist societies (Almudi and Fatas-Villafranca 2018). Through the special co-evolutionary mechanism of *promotion*, political entities are able to deliberately influence the propagation (or retention) of certain knowledge, skills, ideas, values, or habits within other sub-systems and, thereby, trigger change in the whole system (Almudi and Fatas-Villafranca 2018).
- Take up insights from *culture design* (e.g., Beddoe et al. 2009; Brewer 2015; Wilson 2016; Wilson et al. 2014; Biglan and Barnes-Holmes 2015; Costanza 2016) and findings on transmission and learning biases in cultural evolution (e.g., Mesoudi 2016; Mesoudi 2017a; Mesoudi 2017b) that may help to explain and eventually overcome the stickiness and locality of both systems and normative knowledge and thereby increase the absorptive capacities of DIS actors for dedicated knowledge.
- Use suggestions from the literature on *adaptive governance* such as the combination of indigenous knowledge with scientific knowledge (to overcome path dependencies), continuous adaptation of transformative knowledge to new systems knowledge (to avoid lock-ins), embracing uncertainty (accepting that the behavior of systems can never be completely understood and anticipated), and the facilitation of self-organization (e.g., Folke et al. 2005; Boyd and Folke 2012) by empowering citizens to participate in the responsible co-creation, diffusion, and use of dedicated knowledge.

- Apply *reflexive governance* instruments as guideposts for DIS, including principles of transdisciplinary knowledge production, experimentation, and anticipation (creating systems knowledge), participatory goal formulation (creating and diffusing normative knowledge), and interactive strategy development (using transformative knowledge) (Lindner et al. 2016; Voß and Kemp 2006) for the bioeconomy transformation.

In summary, we postulate that for more sustainable bioeconomy policies, we need more adequate knowledge policies.

5. Conclusions

Bioeconomy policies have not effectively been linked to findings and approved methods of sustainability sciences. The transformation towards a bioeconomy, thus, runs into the danger of becoming an unsustainable and purely techno-economic endeavor. Effective public policies that take due account of the knowledge dynamics underlying transformation processes are required. In the context of sustainability, it is not enough to just improve the capacity of an IS for creating, diffusing, and using economically relevant knowledge. Instead, the IS must become more goal-oriented and dedicated to tackling wicked problems (Schlaile et al. 2017; Fagerberg 2017). Accordingly, for affording such systemic dedication to the transformation towards an SKBBE, it is central to consider dedicated knowledge (that is, a combination of the understanding of economically relevant knowledge with systems knowledge, normative knowledge, and transformative knowledge).

Drawing upon our insights into such dedicated knowledge, we can better understand why current policies have not been able to steer the bioeconomy transformation onto a sustainable path. We admit that recent policy revision processes (e.g., Schütte 2018; European Commission 2017; The European Bioeconomy Stakeholders Panel 2018; German Bioeconomy Council 2016; BMEL 2016; Imbert et al. 2017)—especially in terms of viewing the transition to a bioeconomy as a societal transformation, a focus on participatory approaches, and a better coordination of policies and sectors—are headed in the right direction. However, we suggest that an even stronger focus on the characteristics of *dedicated* knowledge and its creation, diffusion, and use in DIS is necessary for the knowledge-based bioeconomy to become truly sustainable. These characteristics include stickiness, locality, context specificity, dispersal, and path dependence. Taking dedicated knowledge more seriously entails that the currently most influential players in bioeconomy governance (that is, the industry and academia) need to display a serious willingness to learn and acknowledge the value of opening up the agenda-setting discourse and allow true participation of all actors within the respective DIS. Although in this article, we focus on the role of knowledge, we are fully aware of the fact that in the context of an SKBBE, other points of systemic intervention exist and must also receive appropriate attention in future research and policy endeavors (Meadows 2008; Abson et al. 2017).

While many avenues for future inter- and transdisciplinary research exist, the next steps may include

- enhancing systems knowledge by analyzing which actors and network dynamics are universally important for a successful transformation towards an SKBBE and which are contingent on the respective variety of a bioeconomy,
- an inquiry into knowledge mobilization and, especially the role(s) of knowledge brokers for the creation, diffusion, and use of dedicated knowledge (for example, installing regional bioeconomy hubs),
- researching the implications of extending the theory of knowledge to other relevant disciplines,
- assessing the necessary content of academic and vocational bioeconomy curricula for creating bioeconomy literacy beyond techno-economic systems knowledge,
- applying and refining the RBA to study which subject rules and which object rules are most important for supporting sustainability transformations,
- and many more.

6. References

Abson, D.J.; Fischer, J.; Leventon, J.; Newig, J.; Schomerus, T.; Vilsmaier, U.; von Wehrden, H.; Abernethy, P.; Ives, C.D.; Jager, N.W.; et al. Leverage points for sustainability transformation. Ambio 2017, 46, 30–39.

Abson, D.J.; von Wehrden, H.; Baumgärtner, S.; Fischer, J.; Hanspach, J.; Härdtle, W.; Heinrichs, H.; Klein, A.M.; Lang, D.J.; Martens, P.; et al. Ecosystem services as a boundary object for sustainability. Ecol. Econ. 2014, 103, 29–37.

Acs, Z.J.; Audretsch, D.B.; Lehmann, E.E. The knowledge spillover theory of entrepreneurship. Small Bus. Econ. 2013, 41, 757–774.

Adolf, M.; Stehr, N. Knowledge; Routledge: London, UK, 2014.

Adomßent, M. Exploring universities' transformative potential for sustainability-bound learning in changing landscapes of knowledge communication. J. Clean. Prod. 2013, 49, 11–24.

Ahrweiler, P.; Keane, M.T. Innovation networks. Mind Soc. 2013, 12, 73–90.

Albrecht, S.; Gottschick, M.; Schorling, M.; Stirn, S. Bio-Ökonomie—Gesellschaftliche Transformation ohne Verständigung über Ziele und Wege? Biogum Univ: Hamburg, Germany, 2012a.

Albrecht, S.; Gottschick, M.; Schorling, M.; Stirn, S. Bioökonomie am Scheideweg: Industrialisierung von Biomasse oder nachhaltige Produktion? GAIA 2012b, 21, 33–37.

Almudi, I.; Fatas-Villafranca, F. Promotion and coevolutionary dynamics in contemporary capitalism. J. Econ. Issues 2018, 52, 80–102.

Almudi, I.; Fatas-Villafranca, F.; Izquierdo, L.R.; Potts, J. The economics of utopia: A co-evolutionary model of ideas, citizenship and socio-political change. J. Evol. Econ. 2017, 27, 629–662.

Almudi, I.; Fatas-Villafranca, F.; Potts, J. Utopia competition: A new approach to the micro-foundations of sustainability transitions. J. Bioecon. 2017, 19, 165–185.

Antonelli, C. The evolution of the industrial organisation of the production of knowledge. Camb. J. Econ. 1999, 23, 243–260.

Arrow, K. Economic welfare and the allocation of resources for invention. In The Rate and Direction of Inventive Activity: Economic and Social Factors; Nelson, R.R., Ed.; Princeton University Press: Princeton, NJ, USA, 1962; pp. 609–626.

Arthur, W.B. The structure of invention. Res. Policy 2007, 36, 274–287.

Audretsch, D.B.; Leyden, D.P.; Link, A.N. Regional appropriation of university-based knowledge and technology for economic development. Econ. Dev. Q. 2013, 27, 56–61.

Ayala, F.J. The biological roots of morality. Biol. Philos. 1987, 2, 235–252.

Banks, J.A. The canon debate, knowledge construction, and multicultural education. Educ. Res. 1993, 22, 4–14.

Barabási, A.-L. Network Science; Cambridge University Press: Cambridge, UK, 2016.

Beddoe, R.; Costanza, R.; Farley, J.; Garza, E.; Kent, J.; Kubiszewski, I.; Martinez, L.; McCowen, T.; Murphy, K.; Myers, N.; et al. Overcoming systemic roadblocks to sustainability: The evolutionary redesign of worldviews, institutions, and technologies. Proc. Natl. Acad. Sci. USA 2009, 106, 2483–2489.

Bennet, A.; Bennet, D. Knowledge Mobilization in the Social Sciences and Humanities: Moving from Research to Action; MQI Press: Marlinton, VI, USA, 2007.

Biermann, F. Earth System Governance: World Politics in the Anthropocene; The MIT Press: Cambridge, MA, USA, 2014.

Biermann, F.; Betsill, M.M.; Gupta, J.; Kanie, N.; Lebel, L.; Liverman, D.; Schroeder, H.; Siebenhüner, B.; Zondervan, R. Earth system governance: A research framework. Int. Environ. Agreem. 2010, 10, 277–298.

Biglan, A.; Barnes-Holmes, Y. Acting in light of the future: How do future-oriented cultural practices evolve and how can we accelerate their evolution? J. Context. Behav. Sci. 2015, 4, 184–195.

Birch, K.; Levidow, L.; Papaioannou, T. Sustainable capital? The neoliberalization of nature and knowledge in the European "knowledge-based bio-economy". Sustainability 2010, 2, 2898–2918.

Blind, G.; Pyka, A. The rule approach in evolutionary economics: A methodological template for empirical research. J. Evol. Econ. 2014, 24, 1085–1105.

Blok, V.; Gremmen, B.; Wesselink, R. Dealing with the wicked problem of sustainability in advance. Bus. Prof. Ethics J. 2016.

BMBF; BMEL. Bioeconomy in Germany: Opportunities for a Bio-Based and Sustainable Future; Federal Ministry of Education and Research & Federal Ministry of Food and Agriculture: Berlin/Bonn, Germany, 2015.

BMEL. Fortschrittsbericht zur Nationalen Politikstrategie Bioökonomie; Bundesministerium für Ernährung und Landwirtschaft: Berlin, Germany, 2016.

Bogner, K.; Mueller, M.; Schlaile, M.P. Knowledge diffusion in formal networks: The roles of degree distribution and cognitive distance. Int. J. Comput. Econ. Econom. 2018, in press.

Boschma, R. Proximity and innovation: A critical assessment. Reg. Stud. 2005, 39, 61–74.

Boulding, K.E. The economics of knowledge and the knowledge of economics. Am. Econ. Rev. 1966, 56, 1–13.

Boulding, K.E. The World as a Total System; SAGE: Beverly Hills, CA, USA, 1985.

Boyd, E.; Folke, C. (Eds.) Adapting Institutions: Governance, Complexity and Social-Ecological Resilience; Cambridge University Press: Cambridge, UK, 2012.

Boyd, R.; Richerson, P.J. Culture and the Evolutionary Process; University of Chicago Press: Chicago, IL, USA, 1985.

Boyd, R.; Richerson, P.J. The evolution of norms: An anthropological view. J. Inst. Theor. Econ. 1994, 150, 72–87.

Boyd, R.; Richerson, P.J. The Origin and Evolution of Cultures; Oxford University Press: Oxford, UK; New York, NY, USA, 2005.

Breslin, D. Towards a generalized Darwinist view of sustainability. In Beyond Sustainability; Scholz, C., Zentes, J., Eds.; Nomos: Baden-Baden, Germany, 2014; pp. 13–35.

Brewer, J. Tools for culture design: Toward a science of social change? Spanda J. 2015, 6, 67–73.

Brewer, J.; Karafiath, L. Why Global Warming Won't Go Viral: A Research Report Prepared by DarwinSF 2013. Available online: https://www.slideshare.net/joebrewer31/why-global-warming-wont-go-viral (accessed on 14 April 2018).

Buchmann, T.; Pyka, A. Innovation networks. In Handbook on the Economics and Theory of the Firm; Dietrich, M., Krafft, J., Eds.; Edward Elgar: Cheltenham, UK, 2012; pp. 466–482.

Bugge, M.; Hansen, T.; Klitkou, A. What is the bioeconomy? A review of the literature. Sustainability 2016, 8, 691.

Bugge, M.M.; Coenen, L.; Branstad, A. Governing socio-technical change: Orchestrating demand for assisted living in ageing societies. Sci. Public Policy 2018, 38, 1235.

Cambridge University Press. Meaning of "Knowledge" in the English Dictionary. 2018. Available online: https://dictionary.cambridge.org/dictionary/english/knowledge (accessed on 16 April 2018).

Capra, F.; Luisi, P.L. The Systems View of Life: A Unifying Vision; Cambridge University Press: Cambridge, UK, 2014.

Castells, M. The Rise of the Network Society, 2nd ed.; Wiley-Blackwell: Chichester, UK, 2010a.

Castells, M. The Power of Identity, 2nd ed.; Wiley-Blackwell: Chichester, UK, 2010b.

Castells, M. End of Millennium, 2nd ed.; Wiley-Blackwell: Chichester, UK, 2010c.

Chaminade, C.; Edquist, C. Rationales for public policy intervention in the innovation process: A systems of innovation approach. In The Theory and Practice of Innovation Policy: An International Research Handbook; Smits, R.E., Kuhlmann, S., Shapira, P., Eds.; Edward Elgar: Cheltenham, UK, 2010; pp. 95–114.

Cohen, W.M.; Levinthal, D.A. Absorptive capacity: A new perspective on learning and innovation. Admin. Sci. Q. 1990, 35, 128–152.

Cohen, W.M.; Levinthal, D.A. Innovation and learning: The two faces of R & D. Econ. J. 1989, 99, 569–596.

Colander, D.C.; Kupers, R. Complexity and the Art of Public Policy: Solving Society's Problems from the Bottom Up; Princeton University Press: Princeton, NJ, USA, 2014.

Copagnon, D.; Chan, S.; Mert, A. The changing role of the state. In Global Environmental Governance Reconsidered; Biermann, F., Pattberg, P., Eds.; MIT Press: Cambridge, MA, USA, 2012; pp. 237–264.

Costanza, R. How do cultures evolve, and can we direct that change to create a better world? Wildl. Aust. 2016, 53, 46–47.

Dabbert, S.; Lewandowski, I.; Weiss, J.; Pyka, A. (Eds.) Knowledge-Driven Developments in the Bioeconomy; Springer: Cham, Switzerland, 2017.

Daimer, S.; Hufnagl, M.; Warnke, P. Challenge-oriented policy-making and innovation systems theory: Reconsidering systemic instruments. In Innovation System Revisited: Experiences from 40 Years of Fraunhofer ISI Research; Koschatzky, K., Ed.; Fraunhofer Verlag: Stuttgart, Germany, 2012; pp. 217–234.

DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V. on behalf of the German Presidency of the Council of the European Union. En Route to the Knowledge-Based Bio-Economy—Cologne Paper. 2007. Available online: http://dechema.de/dechema_media/Cologne_Paper-p-20000945.pdf (accessed on 1 April 2018).

Dirkx, J.M. Transformative learning theory in the practice of adult education: An overview. PAACE J. Lifelong Learn. 1998, 7, 1–14.

Dopfer, K. Economics in a cultural key: Complexity and evolution revisited. In The Elgar Companion to Recent Economic Methodology; Davis, J.B., Hands, D.W., Eds.; Edward Elgar: Cheltenham, UK, 2011; pp. 319–340.

Dopfer, K. Evolutionary economics. In Handbook on the History of Economic Analysis; Faccarello, G., Kurz, H.-D., Eds.; Edward Elgar: Cheltenham, UK; Northampton, MA, USA, 2016; pp. 175–193.

Dopfer, K. Evolutionary economics: A theoretical framework. In The Evolutionary Foundations of Economics; Dopfer, K., Ed.; Cambridge University Press: Cambridge, UK, 2005; pp. 3–55.

Dopfer, K. The economic agent as rule maker and rule user: Homo Sapiens Oeconomicus. J. Evol. Econ. 2004, 14, 177–195.

Dopfer, K.; Foster, J.; Potts, J. Micro-meso-macro. J. Evol. Econ. 2004, 14, 263–279.

Dopfer, K.; Potts, J. On the theory of economic evolution. Evol. Inst. Econ. Rev. 2009, 6, 23–44.

Dopfer, K.; Potts, J. The General Theory of Economic Evolution; Routledge: London, UK, 2008.

Dosi, G. Technological paradigms and technological trajectories. Res. Policy 1982, 11, 147–162.

Edler, J.; Fagerberg, J. Innovation policy: What, why, and how. Oxf. Rev. Econ. Policy 2017, 33, 2–23.

Edquist, C. (Ed.) Systems of Innovation; Routledge: London, UK, 1997.

Edquist, C. Systems of innovation: Perspectives and challenges. In The Oxford Handbook of Innovation; Fagerberg, J., Mowery, D.C., Nelson, R.R., Eds.; Oxford University Press: Oxford, UK, 2005; pp. 181–208.

El-Chichakli, B.; von Braun, J.; Lang, C.; Barben, D.; Philp, J. Five cornerstones of a global bioeconomy. Nature 2016, 535, 221–223.

Engelbrecht, H.-J. A proposal for a 'national innovation system plus subjective well-being' approach and an evolutionary systemic normative theory of innovation. In Foundations of Economic Change; Pyka, A., Cantner, U., Eds.; Springer: Cham, Switzerland, 2017; pp. 207–231.

English Oxford Living Dictionaries. Definition of Knowledge in English. Available online: https://en.oxforddictionaries.com/definition/knowledge (accessed on 13 April 2018).

European Commission. Innovating for Sustainable Growth: A Bioeconomy for Europe; European Commission: Brussels, Belgium, 2012.

European Commission. Review of the 2012 European Bioeconomy Strategy; European Commission: Brussels, Belgium, 2017.

Evans, J.; Jones, R.; Karvonen, A.; Millard, L.; Wendler, J. Living labs and co-production: University campuses as platforms for sustainability science. Curr. Opin. Environ. Sustain. 2015, 16, 1–6.

Fagerberg, J. Mission (Im)possible? The Role of Innovation (and Innovation Policy) in Supporting Structural Change & Sustainability Transitions; Centre for Technology, Innovation and Culture, University of Oslo, Oslo, Norway, 2017. Available online: https://www.sv.uio.no/tik/InnoWP/tik_working_paper_20180216.pdf (accessed on 16 April 2018).

Fatheuer, T.; Fuhr, L.; Unmüßig, B. Kritik der Grünen Ökonomie; Oekom Verlag: München, Germany, 2015.

Focus. Kretschmann kauft sich neues Dieselauto—Fahrverbote für alte Diesel bleiben. Focus. 21 May 2017. Available online: https://www.focus.de/auto/news/abgas-skandal/mache-was-ich-fuer-richtig-halte-gruener-ministerpraesidentin-kauft-sich-neues-dieselauto-fahrverbote-fuer-alte-diesel-bleiben_id_7160275.html (accessed on 7 April 2018).

Folke, C.; Hahn, T.; Olsson, P.; Norberg, J. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour. 2005, 30, 441–473.

Foray, D.; Mairesse, J. The knowledge dilemma in the geography of innovation. In Institutions and Systems in the Geography of Innovation; Feldman, M.P., Massard, N., Eds.; Springer: New York, NY, USA, 2002; pp. 35–54.

Frantzeskaki, N.; Kabisch, N. Designing a knowledge co-production operating space for urban environmental governance—Lessons from Rotterdam, Netherlands and Berlin, Germany. Environ. Sci. Policy 2016, 62, 90–98.

Freeman, C. Systems of Innovation: Selected Essays in Evolutionary Economics; Edward Elgar: Cheltenham, UK, 2008.

Freeman, C. Technology Policy and Economic Performance: Lessons from Japan; Pinter: London, UK, 1987.

Frenken, K.; van Oort, F.; Verburg, T. Related variety, unrelated variety and regional economic growth. Reg. Stud. 2007, 41, 685–697.

Galunic, D.C.; Rodan, S. Resource recombinations in the firm: Knowledge structures and the potential for Schumpeterian innovation. Strat. Mgmt. J. 1998.

German Bioeconomy Council. Empfehlungen des Bioökonomierates: Weiterentwicklung der "Nationalen Forschungsstrategie Bioökonomie 2030"; Bioökonomierat: Berlin, Germany, 2016.

Gladwell, M. The Tipping Point: How Little Things Can Make a Big Difference; Little, Brown and Company: Boston, MA, USA, 2000.

Göpel, M. The Great Mindshift; Springer International Publishing: Cham, Switzerland, 2016.

Gregersen, B.; Johnson, B. Learning economies, innovation systems and European integration. Reg. Stud. 1997, 31, 479–490.

Grunwald, A. Strategic knowledge for sustainable development: The need for reflexivity and learning at the interface between science and society. IJFIP 2004, 1, 150–167.

Grunwald, A. Working towards sustainable development in the face of uncertainty and incomplete knowledge. J. Environ. Policy Plan. 2007, 9, 245–262.

Hilgartner, S. Making the bioeconomy measurable: Politics of an emerging anticipatory machinery. BioSocieties 2007, 2, 382–386.

Hodgson, G.M. The evolution of morality and the end of economic man. J. Evol. Econ. 2014, 24, 83–106.

Imbert, E.; Ladu, L.; Morone, P.; Quitzow, R. Comparing policy strategies for a transition to a bioeconomy in Europe: The case of Italy and Germany. Energy Res. Soc. Sci. 2017, 33, 70–81.

Jacobson, N.; Butterill, D.; Goering, P. Development of a framework for knowledge translation: Understanding user context. J. Health Serv. Res. Policy 2003, 8, 94–99.

Johnson, B. Institutional learning. In National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning; Lundvall, B.-Å., Ed.; Anthem Press: London, UK, 2010; pp. 23–45.

Kahane, A. Transformative Scenario Planning: Working Together to Change the Future; Berrett-Koehler Publishers: San Francisco, CA, USA, 2012.

Klein Woolthuis, R.; Lankhuizen, M.; Gilsing, V. A system failure framework for innovation policy design. Technovation 2005, 25, 609–619.

Knierim, A.; Laschewski, L.; Boyarintseva, O. Inter- and transdisciplinarity in bioeconomy. In Bioeconomy; Lewandowski, I., Ed.; Springer International Publishing: Cham, Switzerland, 2018; pp. 39–72.

Lahsen, M. The social status of climate change knowledge: An editorial essay. WIREs Clim. Chang. 2010, 1, 162–171.

Lamberson, P.J.; Page, S.E. Tipping points. QJPS 2012, 7, 175–208.

Leach, M.; Stirling, A.; Scoones, I. Dynamic Sustainabilities: Technology, Environment, Social Justice; Earthscan: Abingdon, UK; New York, NY, USA, 2010.

Leemans, R.; van Amstel, A.; Battjes, C.; Kreileman, E.; Toet, S. The land cover and carbon cycle consequences of large-scale utilizations of biomass as an energy source. Glob. Environ. Chang. 1996, 6, 335–357.

Lewandowski, I. (Ed.) Bioeconomy; Springer International Publishing: Cham, Switzerland, 2018.

Lindner, R.; Daimer, S.; Beckert, B.; Heyen, N.; Koehler, J.; Teufel, B.; Warnke, P.; Wydra, S. Addressing Directionality: Orientation Failure and the Systems of Innovation Heuristic. Towards Reflexive Governance. In Fraunhofer ISI Discussion Papers Innovation and Policy Analysis; Fraunhofer Institute for Systems and Innovation Research: Karlsruhe, Germany, 2016; Volume 52.

Luederitz, C.; Schäpke, N.; Wiek, A.; Lang, D.J.; Bergmann, M.; Bos, J.J.; Burch, S.; Davies, A.; Evans, J.; König, A.; et al. Learning through evaluation—A tentative evaluative scheme for sustainability transition experiments. J. Clean. Prod. 2017, 169, 61–76.

Lundvall, B.-Å. (Ed.) National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning; Pinter: London, UK, 1992.

Lundvall, B.-Å. Innovation policy in the globalizing learning economy. In The Globalizing Learning Economy; Archibugi, D., Lundvall, B.-Å., Eds.; Oxford University Press: Oxford, UK, 2001; pp. 273–291.

Lundvall, B.-Å. Post script: Innovation system research—Where it came from and where it might go. In National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning; Lundvall, B.-Å., Ed.; Anthem Press: London, UK, 2010; pp. 317–349.

Lundvall, B.-Å. The economics of knowledge and learning. In Product Innovation, Interactive Learning and Economic Performance; Christensen, J.L., Lundvall, B.-Å., Eds.; Elsevier JAI: Amsterdam, The Netherlands, 2004; pp. 21–42.

Lundvall, B.-Å.; Johnson, B. The learning economy. J. Ind. Stud. 1994, 1, 23–42.

Markey-Towler, B. The competition and evolution of ideas in the public sphere: A new foundation for institutional theory. J. Inst. Econ. 2018, 43, 1–22.

Martin, B.R. Twenty challenges for innovation studies. Sci. Public Policy 2016, 43, 432–450.

Matutinovic´, I. Worldviews, institutions and sustainability: An introduction to a co-evolutionary perspective. Int. J. Sustain. Dev. World Ecol. 2007, 14, 92–102.

Mauser, W.; Klepper, G.; Rice, M.; Schmalzbauer, B.S.; Hackmann, H.; Leemans, R.; Moore, H. Transdisciplinary global change research: The co-creation of knowledge for sustainability. Curr. Opin. Environ. Sustain. 2013, 5, 420–431.

McCormick, K.; Kautto, N. The bioeconomy in Europe: An overview. Sustainability 2013, 5, 2589–2608.

Meadows, D.H. Thinking in Systems: A Primer; Wright, D., Ed.; Earthscan: London, UK, 2008.

Mesoudi, A. Cultural evolution: Integrating psychology, evolution and culture. Curr. Opin. Psychol. 2016a, 7, 17–22.]

Mesoudi, A. Cultural evolution: A review of theory, findings and controversies. Evol. Biol. 2016b, 43, 481–497.

Mesoudi, A. Pursuing Darwin's curious parallel: Prospects for a science of cultural evolution. Proc. Natl. Acad. Sci. USA 2017.

Meyer, M. The rise of the knowledge broker. Sci. Commun. 2010, 32, 118–127.

Mezirow, J. Transformative Dimensions of Adult Learning; Jossey-Bass: San Francisco, CA, USA, 1991.

Milkoreit, M. Mindmade Politics: The Cognitive Roots of International Climate Governance; The MIT Press: Cambridge, MA, USA, 2017.

Miller, T.R.; Wiek, A.; Sarewitz, D.; Robinson, J.; Olsson, L.; Kriebel, D.; Loorbach, D. The future of sustainability science: A solutions-oriented research agenda. Sustain. Sci. 2014, 9, 239–246.

Mitton, C.; Adair, C.E.; McKenzie, E.; Patten, S.B.; Waye Perry, B. Knowledge transfer and exchange: Review and synthesis of the literature. Milbank Q. 2007, 85, 729–768.

Morone, P. Knowledge, innovation and internationalisation: A roadmap. In Knowledge, Innovation and Internationalization; Morone, P., Ed.; Taylor and Francis: Hoboken, NJ, USA, 2013; pp. 1–13.

Morone, P. The times they are a-changing: Making the transition toward a sustainable economy. Biofuels Bioprod. Biorefin. 2016, 10, 369–377.

Morone, P.; Tartiu, V.E.; Falcone, P. Assessing the potential of biowaste for bioplastics production through social network analysis. J. Clean. Prod. 2015, 90, 43–54.

Morone, P.; Taylor, R. Knowledge Diffusion and Innovation: Modelling Complex Entrepreneurial Behaviours; Edward Elgar: Cheltenham, UK, 2010.

Moser, S.C. Can science on transformation transform science? Lessons from co-design. Curr. Opin. Environ. Sustain. 2016, 20, 106–115.

Nelson, R.R. (Ed.) National Innovation Systems: A Comparative Study; Oxford University Press: New York, NY, USA, 1993.

Nelson, R.R. What is private and what is public about technology? Sci. Technol. Hum. Values 1989, 14, 229–241.

Nelson, R.R.; Winter, S.G. An Evolutionary Theory of Economic Change; The Belknap Press of Harvard University Press: Cambridge, MA, USA, 1982.

Nonaka, I. A dynamic theory of organizational knowledge creation. Organ. Sci. 1994, 5, 14–37.

Nooteboom, B.; van Haverbeke, W.; Duysters, G.; Gilsing, V.; van den Oord, A. Optimal cognitive distance and absorptive capacity. Res. Policy 2007, 36, 1016–1034.

Nyholm, J.; Normann, L.; Frelle-Petersen, C.; Riis, M.; Torstensen, P. Innovation policy in the knowledge-based economy: Can theory guide policy making? In The Globalizing Learning Economy; Archibugi, D., Lundvall, B.-Å., Eds.; Oxford University Press: Oxford, UK, 2001; pp. 239–272.

OECD. Knowledge Management in the Learning Society: Education and Skills; OECD: Paris, France, 2000.

Ostrom, E. The complexity of rules and how they may evolve over time. In Evolution and Design of Institutions; Schubert, C., von Wangenheim, G., Eds.; Routledge: London, UK; New York, NY, USA, 2006; pp. 100–122.

Ostrom, E. Understanding Institutional Diversity; Princeton University Press: Princeton, NJ, USA, 2005.

Ostrom, E.; Basurto, X. Crafting analytical tools to study institutional change. J. Inst. Econ. 2011, 7, 317–343.

Patterson, J.; Schulz, K.; Vervoort, J.; van der Hel, S.; Widerberg, O.; Adler, C.; Hurlbert, M.; Anderton, K.; Sethi, M.; Barau, A. Exploring the governance and politics of transformations towards sustainability. Environ. Innov. Soc. Trans. 2017, 24, 1–16.

Pfau, S.; Hagens, J.; Dankbaar, B.; Smits, A. Visions of sustainability in bioeconomy research. Sustainability 2014, 6, 1222–1249.

Philp, J. The bioeconomy, the challenge of the century for policy makers. New Biotechnol. 2018, 40, 11–19.

Pohl, C.; Truffer, B.; Hirsch Hadorn, G. Addressing wicked problems through transdisciplinary research. In The Oxford Handbook of Interdisciplinarity; Frodeman, R., Klein, J.T., Pacheco, R.C.S., Eds.; Oxford University Press: Oxford, UK, 2017; pp. 319–331.

Polanyi, M. The Tacit Dimension; University of Chicago Press: Chicago, IL, USA, 1966.

Potts, J. Knowledge and markets. J. Evol. Econ. 2001, 11, 413–431.

ProClim. Research on Sustainability and Global Change—Visions in Science Policy by Swiss Researchers; ProClim: Berne, Switzerland, 1997.

Pyka, A. Dedicated innovation systems to support the transformation towards sustainability: Creating income opportunities and employment in the knowledge-based digital bioeconomy. J. Open Innov. 2017a, 3, 385.

Pyka, A. Transformation of economic systems: The bio-economy case. In Knowledge-Driven Developments in the Bioeconomy; Dabbert, S., Lewandowski, I., Weiss, J., Pyka, A., Eds.; Springer: Cham, Switzerland, 2017b; pp. 3–16.

Pyka, A.; Buchmann, T. Die Transformation zur wissensbasierten Bioökonomie. In Technologie, Strategie und Organisation; Burr, W., Stephan, M., Eds.; Springer: Wiesbaden, Germany, 2017; pp. 333–361.

Pyka, A.; Gilbert, N.; Ahrweiler, P. Agent-based modelling of innovation networks: The fairytale of spillover. In Innovation Networks: New Approaches in Modelling and Analyzing; Pyka, A., Scharnhorst, A., Eds.; Springer: Heidelberg, Germany, 2009; pp. 101–126.

Pyka, A.; Prettner, K. Economic growth, development, and innovation: The transformation towards a knowledge-based bioeconomy. In Bioeconomy; Lewandowski, I., Ed.; Springer International Publishing: Cham, Switzerland, 2018; pp. 331–342.

Raghu, S.; Spencer, J.L.; Davis, A.S.; Wiedenmann, R.N. Ecological considerations in the sustainable development of terrestrial biofuel crops. Curr. Opin. Environ. Sustain. 2011, 3, 15–23.

Ramcilovic-Suominen, S.; Pülzl, H. Sustainable development—A 'selling point' of the emerging EU bioeconomy policy framework? J. Clean. Prod. 2018, 172, 4170–4180.

Richerson, P.J.; Boyd, R. Not by Genes Alone: How Culture Transformed Human Evolution; University of Chicago Press: Chicago, IL, USA, 2005.

Rittel, H.W.J.; Webber, M.M. Dilemmas in a general theory of planning. Policy Sci. 1973, 4, 155–169.

Rizzello, S. Knowledge as a path-dependence process. J. Bioecon. 2004, 6, 255–274.

Rooney, D.; Hearn, G.; Mandeville, T.; Joseph, R. Public Policy in Knowledge-Based Economies: Foundations and Frameworks; Edward Elgar: Cheltenham, UK, 2003.

Rooney, D.; Hearn, G.; Ninan, A. Knowledge: Concepts, policy, implementation. In Handbook on the Knowledge Economy; Rooney, D., Hearn, G., Ninan, A., Eds.; Edward Elgar: Cheltenham, UK, 2005; pp. 1–16.

Rydin, Y. Re-examining the role of knowledge within planning theory. Plan. Theory 2007, 6, 52–68.

Schaper-Rinkel, P. Bio-politische Ökonomie: Zur Zukunft des Regierens von Biotechnologien. In Bioökonomie: Die Lebenswissenschaften und die Bewirtschaftung der Körper; Lettow, S., Ed.; Transcript: Bielefeld, Germany, 2012; pp. 155–179.

Scharnhorst, A.; Pyka, A. (Eds.) Innovation Networks: New Approaches in Modelling and Analyzing; Springer: Berlin/Heidelberg, Germany, 2009.

Scheiterle, L.; Ulmer, A.; Birner, R.; Pyka, A. From commodity-based value chains to biomass-based value webs: The case of sugarcane in Brazil's bioeconomy. J. Clean. Prod. 2018, 172, 3851–3863.

Schellnhuber, H.-J.; Crutzen, P.J.; Clark, W.C.; Claussen, M.; Held, H. (Eds.) Earth System Analysis for Sustainability; MIT Press in Cooperation with Dahlem University Press: Cambridge, MA, USA, 2004.

Schlaile, M.P.; Urmetzer, S.; Blok, V.; Andersen, A.; Timmermans, J.; Mueller, M.; Fagerberg, J.; Pyka, A. Innovation systems for transformations towards sustainability? Taking the normative dimension seriously. Sustainability 2017, 9, 2253.

Schlaile, M. P., Zeman, J., & Mueller, M. It'sa match! Simulating compatibility-based learning in a network of networks. Journal of evolutionary economics, 28(5), 1111-1150. J. Evol. Econ. 2018.

Schmid, O.; Padel, S.; Levidov, L. The bio-economy concept and knowledge base in a public goods and farmer perspective. Bio-Based Appl. Econ. 2012, 1, 47–63.

Schramm, M. Der Geldwert der Schöpfung: Theologie, Ökologie, Ökonomie; Schöningh: Paderborn, Germany, 1994.

Schumpeter, J.A. Theorie der wirtschaftlichen Entwicklung; Duncker & Humblot: Leipzig, Germany, 1911.

Schütte, G. What kind of innovation policy does the bioeconomy need? New Biotechnol. 2018, 40, 82–86.

Scoones, I.; Leach, M.; Newell, P. (Eds.) The Politics of Green Transformations; Earthscan: London, UK, 2015.

Searchinger, T.; Heimlich, R.; Houghton, R.A.; Dong, F.; Elobeid, A.; Fabiosa, J.; Tokgoz, S.; Hayes, D.; Yu, T.-H. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 2008, 319, 1238–1240.

Seidler, R.; Bawa, K.S. Dimensions of sustainable development. In Dimensions of Sustainable Development; Bawa, K.S., Seidler, R., Eds.; Eolss Publishers Co Ltd.: Oxford, UK, 2009; Volume 1, pp. 1–20.

Smith, K. Interactions in Knowledge Systems: Foundations, Policy Implications and Empirical Methods, STEP Report R-10. 1994. Available online: https://brage.bibsys.no/xmlui/bitstream/handle/11250/226741/STEPrapport10-1994.pdf?sequence=1 (accessed on 16 April 2018).

Soete, L. Is innovation always good? In Innovation Studies: Evolution and Future Challenges; Fagerberg, J., Martin, B.R., Andersen, E.S., Eds.; Oxford Univ. Press: Oxford, UK, 2013; pp. 134–144.

Solow, R.M. A Contribution to the theory of economic growth. Q. J. Econ. 1956, 70, 65.

Solow, R.M. Technical change and the aggregate production function. Rev. Econ. Stat. 1957, 39, 312.

Staffas, L.; Gustavsson, M.; McCormick, K. Strategies and policies for the bioeconomy and bio-based bconomy: An analysis of official national approaches. Sustainability 2013, 5, 2751–2769.

Sterling, S. Transformative learning and sustainability: Sketching the conceptual ground. Learn. Teach. High. Educ. 2011, 17–33.

Steward, F. Breaking the Boundaries: Transformative Innovation for the Global Good, NESTA Provocation 07. 2008. Available online: http://www.nesta.org.uk/publications/breaking-boundaries (accessed on 16 April 2018).

Steward, F. Transformative innovation policy to meet the challenge of climate change: Sociotechnical networks aligned with consumption and end-use as new transition arenas for a low-carbon society or green economy. Technol. Anal. Strat. Manag. 2012, 24, 331–343.

Szulanski, G. Sticky Knowledge: Barriers to Knowing in the Firm; SAGE: London, UK, 2003.

Szulanski, G. The process of knowledge transfer: A diachronic analysis of stickiness. Organ. Behav. Hum. Dec. Process. 2000, 82, 9–27.

ten Bos, R.; van Dam, J.E.G. Sustainability, polysaccharide science, and bio-economy. Carbohydr. Polym. 2013, 93, 3–8. [PubMed]

The European Bioeconomy Stakeholders Panel. European Bioeconomy Stakeholders Manifesto. Available online: https://ec.europa.eu/research/bioeconomy/pdf/european_bioeconomy_stakeholders_manifesto.pdf (accessed on 16 April 2018).

The White House. National Bioeconomy Blueprint; The White House: Washington, DC, USA, 2012.

Urmetzer, S.; Pyka, A. Varieties of knowledge-based bioeconomies. In Knowledge-Driven Developments in the Bioeconomy; Dabbert, S., Lewandowski, I., Weiss, J., Pyka, A., Eds.; Springer: Cham, Switzerland, 2017; pp. 57–82.

Van Opstal, M.; Hugé, J. Knowledge for sustainable development: A worldviews perspective. Environ. Dev. Sustain. 2013, 15, 687–709.

Vermeulen, B.; Pyka, A. The role of network topology and the spatial distribution and structure of knowledge in regional innovation policy: A calibrated agent-based model study. Comput. Econ. 2017, 11, 23.

Virgin, I.; Fielding, M.; Fones Sundell, M.; Hoff, H.; Granit, J. Benefits and challenges of a new knowledge-based bioeconomy. In Creating Sustainable Bioeconomies: The Bioscience Revolution in Europe and Africa; Virgin, I., Morris, E.J., Eds.; Routledge: Abingdon, UK, 2017; pp. 11–25.

von Braun, J. Bioeconomy: The New Transformation of Agriculture, Food, and Bio-Based Industries, Implications for Emerging Economies. 2017. Available online: http://www.ifpri.org/event/bioeconomy-%E2%80%93-new-transformation-agriculture-food-and-bio-based-industries-%E2%80%93-implications (accessed on 15 April 2018).

von Hippel, E. "Sticky information" and the locus of problem solving: Implications for innovation. Manag. Sci. 1994, 40, 429–439.

von Schomberg, R. A vision of responsible research and innovation. In Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society; Owen, R., Bessant, J.R., Heintz, M., Eds.; John Wiley & Sons Inc.: Chichester, UK, 2013; pp. 51–74.

von Wehrden, H.; Luederitz, C.; Leventon, J.; Russell, S. Methodological challenges in sustainability science: A call for method plurality, procedural rigor and longitudinal research. Chall. Sustain. 2017, 5.

Voß, J.-P.; Bauknecht, D.; Kemp, R. (Eds.) Reflexive Governance for Sustainable Development; Edward Elgar: Cheltenham, UK, 2006.

Voß, J.-P.; Kemp, R. Sustainability and reflexive governance: Introduction. In Reflexive Governance for Sustainable Development; Voß, J.-P., Bauknecht, D., Kemp, R., Eds.; Edward Elgar: Cheltenham, UK, 2006; pp. 3–28.

Waring, T.M.; Kline, M.A.; Brooks, J.S.; Goff, S.H.; Gowdy, J.; Janssen, M.A.; Smaldino, P.E.; Jacquet, J. A multilevel evolutionary framework for sustainability analysis. E&S 2015, 20.

Wassmann, P.; Lenton, T.M. Arctic tipping points in an Earth system perspective. Ambio 2012, 41, 1–9.

Westley, F.; Olsson, P.; Folke, C.; Homer-Dixon, T.; Vredenburg, H.; Loorbach, D.; Thompson, J.; Nilsson, M.; Lambin, E.; Sendzimir, J.; et al. Tipping toward sustainability: Emerging pathways of transformation. Ambio 2011, 40, 762–780.

Wiek, A. Challenges of transdisciplinary research as interactive knowledge generation: Experiences from transdisciplinary case study research. GAIA 2007, 16, 52–57.

Wiek, A.; Binder, C. Solution spaces for decision-making—A sustainability assessment tool for city-regions. Environ. Impact Assess. Rev. 2005, 25, 589–608.

Wiek, A.; Lang, D.J. Transformational sustainability research methodology. In Sustainability Science; Heinrichs, H., Martens, P., Michelsen, G., Wiek, A., Eds.; Springer: Dordrecht, The Netherlands, 2016; pp. 31–41.

Wiek, A.; Ness, B.; Schweizer-Ries, P.; Brand, F.S.; Farioli, F. From complex systems analysis to transformational change: A comparative appraisal of sustainability science projects. Sustain. Sci. 2012, 7, 5–24.

Wilson, D.S. Intentional cultural change. Curr. Opin. Psychol. 2016, 8, 190–193.

Wilson, D.S.; Hayes, S.C.; Biglan, A.; Embry, D.D. Evolving the future: Toward a science of intentional change. Behav. Brain Sci. 2014, 37, 395–416.

Wuketits, F.M. Moral systems as evolutionary systems: Taking evolutionary ethics seriously. J. Soc. Evol. Syst. 1993, 16, 251–271.

Wyborn, C.A. Connecting knowledge with action through coproductive capacities: Adaptive governance and connectivity conservation. E&S 2015, 20.

Young, O.R. Governing Complex Systems: Social Capital for the Anthropocene; The MIT Press: Cambridge, MA, USA, 2017.

Zagzebski, L. What is knowledge? In The Blackwell Guide to Epistemology; Greco, J., Sosa, E., Eds.; Blackwell Publishing Ltd.: Malden, MA, USA, 1999; pp. 92–116.

Zwier, J.; Blok, V.; Lemmens, P.; Geerts, R.-J. The ideal of a zero-waste humanity: Philosophical reflections on the demand for a bio-based economy. J. Agric. Environ. Ethics 2015, 28, 353–374.

Chapter IV

Learning to change: Transformative knowledge for building a sustainable bioeconomy

IV. Learning to change: Transformative knowledge for building a sustainable bioeconomy

Abstract

The transition towards a bioeconomy is considered a powerful approach to combating current trends of unsustainability. To date, the concept has been widely perceived as a predominantly technical endeavor. This is, however, not sufficient and will not really tackle the global sustainability challenges. Therefore, the imparting of technological knowledge must be accompanied by instruction in other types of knowledge, particularly transformative knowledge. The authors explore the various elements of transformative knowledge necessary to equip the protagonists of a bioeconomy transformation. On this basis, four academic bioeconomy programs across Europe are analyzed using a hybrid methodological approach, combining a keyword-based content analysis of the module descriptions with semi-structured interviews of key representatives of the programs. It is shown that the syllabi of all four programs include important elements of transformative knowledge, such as communication, participation, and decision making skills. Skills related to the ability to revise and reflect personal values, in contrast, are mainly only an implicit part of the program. The study applies insights into education for sustainable development to the requirements of a fundamental transformation towards a sustainable bioeconomy. It offers a first appraisal of the consideration transformative knowledge is given in the design of European academic bioeconomy curricula.

Keywords

Sustainable bioeconomy; wicked problems; transformation; education; transformative knowledge; module description

Status of publication

This article has been published. Please cite as follows:

Urmetzer, S., Lask, J., Vargas-Carpintero, R., & Pyka, A. (2020). Learning to change: Transformative knowledge for building a sustainable bioeconomy. *Ecological Economics*, *167*, 106435.

1. Introduction

Around the world, governments are developing strategies to confront current global challenges – climate change, the over-exploitation of natural resources associated with the depletion of the natural environment, or issues of malnutrition and poverty. Continuing our current modes of consumption and production will lead to a situation in which the stability of the Earth System can no longer be guaranteed (Steffen et al. 2015). It has been repeatedly argued that "business as usual" is no longer an option (Leach et al. 2012). A relatively novel and currently strongly endorsed approach to overcoming some of the imminent challenges is the establishment of a bioeconomy - an economy based on innovative methods to substitute fossil resources with the intelligent and efficient use of bio-based materials and processes. Policies and strategies to foster the bioeconomy are being given priority on a number of political levels (EC 2012; BMEL 2014; MWK 2013; Rönnlund et al. 2014). The aim of the European bioeconomy strategy is „to pave the way to a more innovative, resource efficient and competitive society that reconciles food security with the sustainable use of biotic renewable resources for industrial purposes, while ensuring environmental protection" (EC 2012, p. 2). In a similar vein, the German government claims that the bioeconomy is a tool to overcome the challenges of the future (Federal Ministry of Education and Research, 2017), while Finland expects their bioeconomy to reduce their "dependence on fossil natural resources, prevent biodiversity loss and create new economic growth and jobs in line with the principles of sustainable development" (Finnish Ministry of Employment and the Economy 2014, p. 3).

None of these framings leaves a doubt that the bioeconomy is an important means to combatting global challenges such as climate change, food security, and the depletion of natural resources. The logic appears to be quite simple: substituting fossil resources with renewable resources and biological processes and optimizing their cultivation by means of technological innovation will reduce CO_2 emissions and at the same time guarantee a sufficient supply of resources for food, energy and material production. Yet for a bioeconomy to contribute to overcoming currently unsustainable practices, relevant innovations must involve more than alternative raw materials and new technologies.

Instead, systemic innovations on multiple levels are required (Federal Ministry of Education and Research 2014; MWK 2013): We need a pervasive transformation encompassing the dynamics and complementarities of technological, organizational, economic, institutional, socio-cultural, political, and environmental systems (Leach et al. 2010; Schlaile et al. 2017). These change processes necessary to tackle global problems have been referred to in their entirety as the great transformation in the sense of a "worldwide remodeling of economy and society towards sustainability" (WBGU 2011, p. 5). The sustainable bioeconomy must be regarded as one building block of this great transformation.

Such profound societal change requires each and every individual to reconsider his/her practices and attitudes. This necessarily involves learning. In the context of transformations towards the fundamentally new socio-economic practices envisioned by a sustainable bioeconomy, learning encompasses more than the acquisition of knowledge. According to one of the targets set for reaching the Sustainable Development Goal (SDG) 4 on inclusive and equitable quality education and the promotion of lifelong learning opportunities for all, education shall activate sustainable lifestyles, human rights, non-violence, and global citizenship (UN 2015). This postulation considers learning as part of an education which "must not just be the communication of purely cognitive knowledge, but must also encompass, on the one hand, practical aspects which can be applied to actions and, on the other hand, competence building to enable those learning to reflect on their actions, and empowering them to shape their future" (de Haan 2003; WBGU 2011, p. 354).

The article at hand aims at inspecting academic bioeconomy education for its practical, reflexive, and empowering capacities. More concretely, we analyze to what extent the curricula of European bioeconomy programs consider the conveyance of what we refer to as transformative knowledge. Although, as emphasized by the SDG's, it is important to involve society as a whole in the learning process for the envisaged transformation to a bioeconomy, this paper focuses on academic education only. This is motivated by the assumption that academics play a central role as multipliers in processes of systems change in a knowledge society (Adomßent 2013; Fadeeva et al. 2014; Sipos et al. 2008; Steuer and Marks 2008). Based on the argument that a transition to a sustainable bioeconomy requires transformative knowledge, the authors pose the following research question:

> Are the curricula of European bioeconomy graduate programs designed in a way that they account for the conveyance of transformative knowledge?

To answer this question, the argument is made that our current global challenges are to be regarded as *wicked problems* whose solution approaches must place an emphasis on knowledge and learning (Section 2). Section 3 spotlights transformative knowledge and explores its role in a comprehensive education dedicated to the bioeconomy. The data and analytical framework for the subsequent empirical study are presented in Section 4. The results of the analysis (Section 5) and their discussion (Section 6) are followed by concluding remarks and an outlook in Section 7.

2. The nature of global challenges and the need for knowledge

The development of innovative technologies that help substitute fossil by bio-based resources, certainly is a sine qua non for a transformation process towards sustainability. However, the nature of the grand challenges humanity is currently confronted with has been found to be of a complex nature and technological substitution processes alone will hardly suffice to confront them (Pyka 2017b; Schlaile et al. 2017). Global challenges like climate change, food security, and resource depletion have been referred to as wicked problems (Hulme 2009; Wehrden et al. 2017) in the sense that their causes are emergent and complex, they are immanent in the social structure, their effects are uncertain, and consequently it is extremely difficult to manage them (Rittel and Webber 1973). Conventional thinking, approaches, and methods of problem solving have proven inappropriate for tackling wicked problems. Such approaches generally feature linear top-down processes that start by analyzing the problem, then design and finally implement a solution (Conklin 2006). In the case of wickedness, the isolated analysis of the problem itself will be futile since "one cannot first understand, then solve" (Rittel and Webber 1973, p. 162).

Alternative approaches become necessary that emphasize proactive consideration of the interconnectedness, interrelatedness, and interdependence of elements responsible for the problem (Conklin 2006; Waddock et al. 2015), as opposed to curing the symptoms without affecting the problematic architecture of the system. Such approaches will need to deviate from linear thinking and instead focus right from the start on the entirety of actors and processes involved (McCormick and Kautto 2013). It is debatable and indeed currently debated, whether ostensibly technocratic solution approaches such as the bioeconomy offer adequate answers to the type of challenges we are facing (Bugge et al. 2016; Hausknost et al. 2017; Heimann 2019). Ultimately, the whole system needs to be taken on board to explore, understand, and eventually manipulate the interrelations between causes and effects, mediating between winners and losers, and complementing reactions with actions. Technological bio-innovation must thus be flanked by social innovation and progress must not be defined in techno-economic terms alone (Schlaile et al. 2017).

The resistance of social systems to fundamental behavioral and technical change has been explained by path dependencies of economic, social and political development (Barnes et al. 2004). Very often, existing infrastructures and inherited experiences determine the direction of progress, as well as established, often institutionalized, knowledge (Abson et al. 2017). This knowledge allows for orientation in a complex world, but at the same time includes the risk of sticking to certain traditions for too long and ruling out promising alternatives too early. One prominent example for society's reliance on established knowledge and practices is the so-called carbon lock-in (Unruh 2000): Despite their obvious environmental and (long-term) economic advantages over fossil resources (Stern 2008), bio-based alternatives are still struggling with the perpetuation of their fossil competitors (Narodoslawsky et al. 2008). In addition to infrastructural, institutional, and economic causes (e.g., Kandaramath Hari et al. 2015), the carbon lock-in is a result of prevailing knowledge and value frameworks legitimizing and guiding public, private, and scientific endeavors to search for new solutions to technical problems. This forms the cornerstone of the underlying technological paradigm (Dosi 1982) or techno-economic paradigm (Perez 1985).

So far, fundamental changes in socio-economic paradigms (or great surge as Perez 2003 puts it) have been explained by technological revolutions following radical advancements in technological knowledge and their first applications (Beniger 1989; Perez 2016). Consequently, the heuristics of these (evolutionary) innovation models and policy strategic planning based thereon have generally targeted the creation, diffusion, and exploitation of technological knowledge. This obviously also applies to policies related to the bioeconomy. However, the exclusive focus on the accumulation of technological knowledge is insufficient in the face of wicked problems which are not purely technological mysteries waiting to be solved. Instead, we need to expand our concept of knowledge necessary to understand the entirety of the problems' causes. This involves search heuristics for innovation processes incorporating a direction of change negotiated by all stakeholders towards a dedicated – as opposed to random - transformation (Schlaile et al. 2017).

Against the backdrop of this novel demand on the conception of innovation, Pyka (2017a) coined the notion of dedicated innovation systems (DIS) that target "radical transformations of existing institutions and routines (…) to overcome the inertia of the oil-based paradigm" (Pyka 2017a, p. 3). Within DIS, knowledge types other than technological knowledge come into focus since they are expected to act as both, important catalysts for the development of new technologies and a selection mechanism among these technologies during the emergence of new paradigms (Beniger 1989). In the context of a transformation to a sustainable bioeconomy, such knowledge must encompass an understanding of biogeochemical cycles and social interaction, a conception of equitable and environmentally friendly bio-based value chains along with skills to implement them, and the awareness that some of the underlying assumptions and perceptions of current processes of production and consumption need to be seriously revised (Urmetzer et al. 2018). Ideally, this results in the emergence of a completely novel set of search heuristics, development instructions, and self-commitment on the part of industry with the aim of improving the supply responses to sustainable and bio-based demand requirements. In other words, and with reference to Dosi and Nelson (2010), such knowledge could be the basis for more sustainable and bio-based trajectories.

It is crucial to understand the characteristics and the levers for the creation and diffusion of such knowledge and skills regarding norms and values, but also regarding techniques to induce a system change towards desirable ends (Abson et al. 2017). Three types of knowledge necessary to induce transformative change in the face of wicked problems have been identified: systems knowledge, normative knowledge, and transformative knowledge (Abson et al. 2014; ProClim 1997; Wehrden et al. 2017). These three cognitive spaces are certainly required for an effective confrontation of the wicked problems addressed by the bioeconomy concept, too[2]:

- Systems knowledge: Actors need to understand the systemic embeddedness of the problem, separate symptoms from causes, and scrutinize the interdependent mechanisms that cause the identified problem. For example, the emergence of unforeseen side-effects of land-use change (referred to as *indirect land-use change*) revealed an impressive lack of systemic understanding of the carbon emission problem. In this case, the effects of the well-intentioned policies to increase plant supply for biofuel actually more than nullified the positive effects of biofuel use (Leemans et al. 1996; Searchinger et al. 2008). Likewise, the various causes of malnutrition around the globe and their interdependencies with issues of conflict, corruption, and education

[2] With reference to what has been stated above it is important to note that the following enumeration shall not imply a chronological order as the knowledge is usually acquired in an unstructured non-linear process where problem statement and solution strategy design co-evolve during an iterative process Rittel and Webber (1973).

will have to be understood for its sustained and sustainable eradication to become possible (Cohen and Reeves 1995).

- Normative knowledge: Normative issues must be put up for discussion to enable a debate on visions and objectives of how the world should be. A globally agreed canon of normative knowledge, for instance, has been compiled by the United Nations as the Sustainable Development Goals (UN 2015). Likewise, numerous political strategies and initiatives suggest that the visions and objectives of the bioeconomy are obvious and agreed upon in industrialized countries. The normative bases of the various imaginaries, however, have been found to be utterly diverse (Pfau et al. 2014). Consequently, there is still room for discourse on a common understanding of what a sustainable bioeconomy is and what it is not.
- Transformative knowledge: Based on these two types of knowledge, competences must be acquired to effect a transgression from the status quo to the desired state. This requires a revision of inherited values and assumptions as well as the acquisition of skills to effect the desired societal change (Urmetzer et al. 2018). For example, evolving from a fossil to a bio-based economy, the society needs to get rid of the believe in endless and cheap fossil energy as well as the infinite capacity of our ecosystems to absorb emissions and waste. Only then can societal change be instigated on a deep and long lasting basis.

But how will these three types of knowledge enter societal systems? Since a direct "indoctrination" of apparently important new worldviews must be rejected for ethical considerations, the key to legitimate transformations of personal values can only be education (O'Brien and Sygna 2013; Schlitz et al. 2010).

Through the UN Decade of Education for Sustainable Development (2005–2014) (UNESCO 2006), the global community acknowledges the absolute centrality of education in a transformation towards sustainability. However, it has been criticized that the initiatives kick-started during the decade did not embrace a genuinely transformative approach and did not encourage thorough reflection on the values and thinking that led to today's problems (Huckle and Wals 2015). Without this cognitive space however, a comprehensive transformative education will remain incomplete. The notions of sustainability literacy (Stibbe 2009) and transformative literacy (Schneidewind 2013) explicitly emphasize what has been introduced above as transformative knowledge. It is argued that sustainability education already has much to offer in imparting knowledge about sustainability (i.e., systems and normative knowledge). An education truly aiming at promoting the ability to transform oneself, a community or society as a whole towards more sustainability, however, additionally requires conveyance of the skills, attitudes, and values necessary to put society on a more sustainable track (Singer-Brodowski 2016a; Stibbe 2009; WBGU 2011) (i.e. transformative knowledge) - an educational goal that has been termed by Fadeeva et al. (2014) as fit for transformation. This is thought to involve participatory learning to provide students with the opportunity to become active paradigm changers (Disterheft et al. 2016). It must be assumed that this also holds true for education aiming at a bioeconomy transformation (Urmetzer et al. 2018). A deeper understanding of the elements and objectives of transformative knowledge in the context of a transformation to a sustainable bioeconomy is needed in order to assess the requirements for formal curricula to effectively convey it.

3. Transformative knowledge

The (largely interchangeable) terms transformation knowledge or transformative knowledge (TK) are used throughout the literature in two different senses, depending on the context: In the educational field, TK has been defined as "the facts, concepts, paradigms, themes, and explanations that challenge mainstream academic knowledge and expand and substantially revise established canons, paradigms, theories, explanations, and research methods" (Banks 1993, p. 7). In the context of sustainability transformations, TK is defined as "knowledge on how to shape and implement the transition from the existing to the target situation" (ProClim 1997, p. 15). The latter includes the competences required to develop effective policies and to apply strategies such as participation, empowerment, education, and communication (Abson et al. 2014, p. 32; Rauschmayer et al. 2015) in order to collectively achieve societal goals. It is this type of "knowledge for action" that sustainability transformation scholars consider the scientific basis for guiding politics and society to design coherent and integrative strategies that induce the combat against sustainability problems (Grunwald 2004).

At first glance, the two meanings of transformative knowledge – from the educational science and sustainability science perspective - may seem rather unrelated. However, the first dimension of TK can be considered to constitute the required *personal* prerequisite for the acquisition of the second, more *practical* dimension of TK. In fact, the connection of such different *spheres of transformation* (O'Brien and Sygna 2013) has been found to be essential for a more comprehensive approach to deliberate transformation towards sustainability, since a regime shift requires a change in "worldviews, institutions, and technologies together as an integrated system" (Beddoe et al. 2009, p. 2484). In other words, "there can be no societal transformation without individual transformation" (Balsiger et al. 2017. P. 358). The relationship between the personal and the practical sphere of TK can be best understood against the background of different levels of knowing (Sterling 2011) as shown in Figure 3.

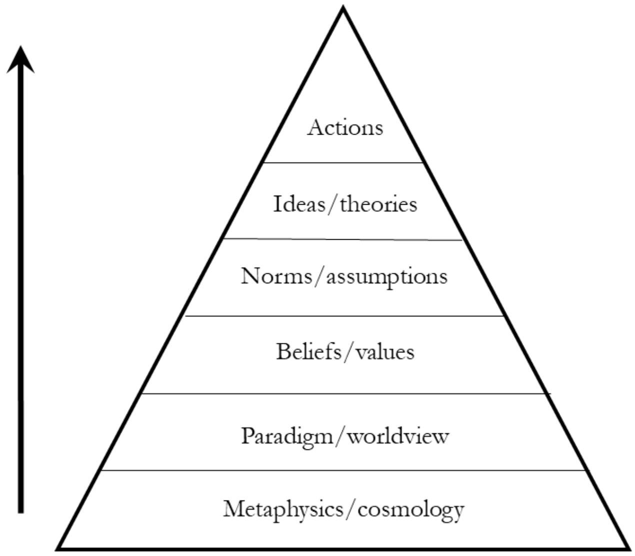

Figure 3 Levels of knowing adapted from Sterling (2011) based on Bohm (1994).

The pyramid illustrates that the ideas and theories that determine our actions emerge as products of our deeper beliefs and values (arrow on the left). To fully understand the characteristics of TK operational towards tackling a certain problem, it is important to acknowledge that the impact of our deeper assumptions on our actions may not be consciously recognized. Only by reaching the different levels of knowing can TK unfold its full potential to enable people to effect behavioral change in themselves, a community or the society as a whole. TK, thus involves the skills to revise deeper levels of knowing and meaning (personal sphere), thereby influencing more immediate and concrete levels of ideas, theories, and action (practical sphere) (Dirkx 1998; Mezirow 1991; Sterling 2011). Translated into the vocabulary of transformation scholars (Abson et al. 2014), a comprehensive canon of TK necessarily involves elements of motivation to cover skills on the personal level, as well as elements of communication and education, participation, and policy and decision making to contribute to the practical transformative abilities of the learner. This terminology helps to operationalize the theoretical deliberations when evidence for TK is sought in bioeconomy curricula in the following Section.

While, to date, these elements of TK have been conceptualized exclusively for knowledge relevant for sustainability transitions, they must be considered equally important in the context of a transformation to a sustainable bioeconomy. Elements of the practical sphere of TK in particular can be found among the strategic objectives of several political bioeconomy-related documents. The importance of capabilities for successful communication and education with regard to the contents and aims of the bioeconomy is stressed in the European bioeconomy strategy (EC 2012) and by the German government (Federal Ministry of Education and Research and Federal Ministry for Food and Agriculture 2015). The closely related element of participation is also found to be essential for a successful transformation to a bioeconomy (EC 2012, 2018; BMBF & BMEL 2015; Knierim et al. 2018; The European Bioeconomy Stakeholders Panel 2017). Yet, the required distribution of power over a number of affected parties requires particular policy and decision making skills across societal stakeholders which has also been called for by, for instance, the European Commission (EC 2018). Several countries evaluate their bioeconomy strategies and install feedback-cycles to ensure policy learning and improve policy and decision making in the long run (German Bioeconomy Council 2018). The TK element relating to the personal sphere, motivation, is only touched upon in European bioeconomy publications. However, the German position is hinted at in the statement that for a bioeconomy transformation "successful structural change must take place throughout society" (BMBF & BMEL 2015, p. 5) and in the call for "comprehensive industrial structural [bioeconomy] transformation toward sustainability" (BMBF & BMEL 2015, foreword). These phrases can be interpreted as reflecting the will to change paradigms behind production and consumption processes. At the level of the individual, the transformation towards a sustainable bioeconomy is seen to require the personal element of TK, too, by postulating critical involvement "with one's own consumer behaviour" (BMBF & BMEL 2015, p. 96).

Although a detailed analysis of policy documents would go beyond the scope of this article, the sample of papers screened point to a perceived demand for TK in a transformation towards a sustainable bioeconomy. Following the discussion regarding the nature of wicked problems (Section 2) and the theoretical foundation of TK (this Section), it must be concluded, that TK constitutes a fundamental component of the knowledge base for future decision makers in their contribution to the transformation to a sustainable bioeconomy.

The following empirical Section focuses on the transformative knowledge base of one particular group, namely future academic bioeconomy experts. It was already mentioned that university graduates play an essential role in instigating societal change. As multipliers within societies, e.g. as future politicians, business leaders, and scientists, the academic elites generally play a major role in transformation processes (Adomßent 2013; Fadeeva et al. 2014; Steuer and Marks 2008).

Several universities in Europe have recently established programs for the training of such bioeconomy experts (Lask et al. 2018). These international and interdisciplinary programs can be expected to provide profound technical and scientific knowledge based on the high-level academic expertise of the respective institutions. However, it is not clear how well their design accounts for the conveyance of transformative knowledge required for future decision makers to contribute to the transformation to a sustainable bioeconomy. For this reason, the compulsory course content as well as the key conceptions of four bioeconomy programs (master's level) were searched for the various elements of TK.

4. Data and methods

4.1 Selection of programs

Our sample of study programs was selected from the European master programs on bioeconomy according to two criteria. In order to ensure comparability, only (1) full-time graduate programs were selected that (2) displayed the interdisciplinary approach to bioeconomy in line with the current

European understanding of the topic (EC 2018). Fulfilment of the second criterion was achieved by those programs that explicitly target the admission of students from diverse academic backgrounds and that explicitly advertise their interdisciplinary training (see Table 3, *Formal admission requirements* and *General aims of the program*). The sampling resulted in the following four programs:

(1) Master Biobased Sciences (Wageningen University & Research, Netherlands; WUR)
(2) Master in Management of Bioeconomy, Innovation and Governance (The University of Edinburgh, UK; EDI)
(3) Master Bioeconomy (University of Hohenheim, Germany; HOH)
(4) Master Degree in Wood Materials Science (University of Eastern Finland, Finland; UEF)

Table 3 Selection of European bioeconomy-related study courses

Program	M.Sc. Biobased Sciences	M.Sc. in Management of Bioeconomy, Innovation and Governance	M.Sc. Bioeconomy	M.Sc. Wood Materials Science
University	Wageningen University & Research, NED	The University of Edinburgh, GBR	University of Hohenheim, GER	University of Eastern Finland, FIN
Year of establishment	2018	2013	2014	2013
Formal admission requirements	Bachelor´s degree or equivalent with profile in natural sciences, engineering, or quantitatively-orientated social sciences	Bachelor's degree or equivalent with a technological or social sciences profile	Bachelor's degree or equivalent with a technological, economic or social profile	Bachelor's degree or equivalent with a profile in forestry, chemistry, material science, biology, physics, engineering or related field.
Program structure	2-year program	1-/2-year program	2-years program	2-years program
General aim of the program	The program focuses on the transition from a petrochemical to a biobased society. Graduates are able to assess opportunities/challenges from an interdisciplinary perspective and to design production chains including biomass production, bioconversion, biorefinery and societal, logistic and economic transition processes.	The program responds to the central challenges of the bioeconomy, including: developing sustainable innovation in a responsible manner; identifying and exploiting value throughout innovation ecosystems; and bringing new technologies to existing and emerging markets. Graduates are able to assess how innovation in the life sciences is changing production methods, industrial structures, market dynamics and strategic decision making.	The interdisciplinary program looks at entire biobased value chains and networks. Graduates are able to examine the ecological, social, and economic dimensions of the bioeconomy on a micro and macro-level. They have the ability to assess the requirements for innovations in the bio-based economy and the corresponding political framework conditions.	The MSc program trains experts who create links between wood and the final products in order to move the forest bioeconomy agenda forward. Graduates understand the entire chain from wood biomass production to product development and innovation management.

Due to the diversity in academic culture and research profiles, each of the universities has a unique perspective on the bioeconomy and the corresponding graduate programs. Obviously, the nature of the contributing institutes influences the contents of the curricula, which are also constantly evolving due to the plasticity of the bioeconomy as such. Nevertheless, all programs span a number of disciplines and are open to graduates from various backgrounds (e.g., engineering, economics, agricultural and natural sciences). Table 3 presents a brief overview of the selected study programs.

4.2 Methodology

To investigate the extent to which TK elements are conceptually considered in European bioeconomy programs, a hybrid methodology was applied. The approach combined a keyword-based content analysis of the compulsory modules' learning outcomes and semi-structured interviews with key representatives of each program. The use of a hybrid methodology allowed to complement "hard" results codified in the curricula (based on the identification of key-words) with rather "soft" and more tacit elements of the key conception behind the respective programs (obtained from the interviews) (see Figure 4).

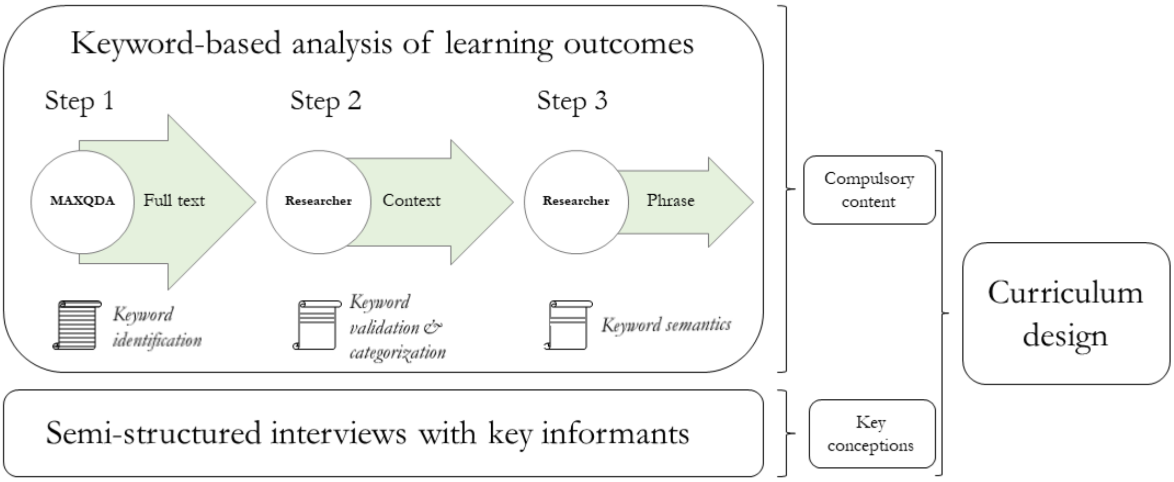

Figure 4 Overview of the hybrid research approach combining the key-word based content analysis with the semi-structured interviews.

The keywords that guided the content analysis as well as the structuration of the interviews were taken from the compilation derived by Abson et al. (2014). Originally, this list was used to analyze the coverage of the diverse knowledge types relating to sustainability in scientific papers. The keywords are categorized according to the three types of knowledge (systems knowledge, normative knowledge, and transformative knowledge) required to solve wicked problems (Wehrden et al. 2017), i.e. to effect transformative change towards sustainability (Urmetzer et al. 2018). The compilation thus provides a solid fundament for the present analysis of TK imparted in higher education, too. The analytical framework for this study (Table 4) combines the suggested keywords with the theoretical foundations of TK for a transformation towards bioeconomy as deliberated above. Following Abson et al. (2014) the keywords identified are clustered according to the following four elements of TK:

(1) Communication & Education

Given the interdisciplinary nature of the bioeconomy, integrative communication abilities are of major relevance and contribute to the development of skills necessary to involve diverse societal actors - a key issue in any kind of societal transition (Frantzeskaki et al. 2012). This involves the relevant communication skills and competences to inform and involve society (Cörvers et al. 2016).

(2) Participation

In order to support and drive a transition towards a sustainable bioeconomy it is essential to (a) acquire the skills to identify and include all relevant stakeholders for a certain project, as well as (b) to handle dispute and dynamics in collaboration processes among these stakeholders. For knowledge-based transition processes such as the bioeconomy, a particular challenge arises where non-academic, societal stakeholders are involved in so-called transdisciplinary research projects (Knierim et al. 2018).

(3) Policy & Decision making

The relevance of processes of governance and policy within societal transitions is taken account for by this element. Fundamental knowledge of governance mechanisms and the political framework is necessary for understanding and driving governance processes in transformation processes.

(4) Motivation

As emphasized above, motivational aspects (personal sphere of TK) are indispensable for "comprehensive transformative" knowledge. This necessarily involves the identification and revision of individual assumptions and values (Banks 1993). In this respect, the keywords identified by Abson et al. (2014) to track down phrases indicating an affiliation with the element motivation cannot be considered exhaustive, as these authors take a rather practical stance on TK. Therefore, further motivational terms were added to the keyword list. These include terms that the authors came across in the course of the analysis which struck them as relevant but were not included in the original keyword list. The reasons are twofold: (1) the broader understanding of TK based on the duality of dimensions (personal and practical); (2) the different foci of the two studies. While Abson et al. (2014) analyzed scientific papers, module descriptions of academic curricula were the research object of the present keyword-based content analysis.

Table 4 illustrates the relation of these four elements (second column) to the two spheres of TK (first column) and substantiates them with relevant skills and competences (third column). The keywords expected to indicate coverage of the respective elements are listed in the fourth column.

Table 4 Analytical framework for the structuration of keywords and interviews.

Transformative knowledge sphere	Elements of transformative knowledge	Relevant skills and competences	Keywords, as suggested by Abson et al. 2014
Practical	• Communication & Education	• Communication skills to inform and involve society (Cörvers et al. 2016)	Communicable, communicate, communicating, communication, communications, communicative, education, educational, learn, learned, learning
	• Participation	• Strategic skills to plan and implement general participatory processes within which credible, shared and feasible strategies are developed (Wiek and Kay 2015).	Democracy, democratic, empower, empowerment, inclusive, inclusivity, institution, institutional, institutions, participant, participants, participate, institutions, participant, participants, participate, participated, participating, participation, participatory, pluralism, pluralistic, practitioners, stakeholder, stakeholders, transdisciplinary, engage, engaged, engagement, team[a], collaborative[a], collaborate[a], cooperation[a], cooperate[a]
	• Policy & Decision making	• An understanding of the processes and governance mechanisms at work in transformations from the current state (systems knowledge) to the desired state (normative knowledge) of the system (Abson et al. 2014).	Decision, decision(-)makers, decision(-)making, decisions, deliberation, deliberative, enforcing, govern, governance, governed, governing, legislation, legislative, multicriteria, policies, policy, policymaker,policymakers, policymaking, facilitate, facilitated, facilitates, facilitating, facilitation, facilitative
Personal	• Motivation	• Ability to revise individual assumptions and values (Banks 1993).	Activists, advocacy, aspiration, attitude, attitudes, attitudinal, belief, beliefs, idealism, idealistic, ideals, incentive, incentives, inspiration, leadership, legitimacy, legitimate, motivate, motivated, motivation, motivations, motives, encourage, encourages, transformability, reflection[a], reflect[a], reflexive[a], reflective[a]

[a] Added by the authors to the original keyword list of Abson and colleagues.

Keyword based content analysis of the bioeconomy curricula

International comparability of European qualifications and course contents has been greatly improved in the course of the Bologna Process (Bologna Working Group 2005). A major achievement of this standardization process is the broad availability of module descriptions for courses taught at universities in Europe. These descriptions summarize contents and learning outcomes, including knowledge, skills and competencies, and can thus be considered useful proxies for the analysis of knowledge types aimed for by the programs in question.

As a first approximation to the course contents, the selected study programs were screened for the presence of TK elements by means of a keyword-based content analysis. The unit of analysis was the module descriptions collected from publicly accessible sources (university homepages, module catalogues). Only compulsory modules were looked at, since they represent the fundament of the program in question and can be expected to contain those contents that are considered relevant to be taken up by all graduates.

By means of the program MAXQDA (VERBI Software GmbH 2018), indicator words within the module descriptions were identified in a first step (see Figure 4). In a second step, keywords were condensed by validation according to the adjacent context or phrase(s) as these text segments are referred to in the following. This step lead to a first reduction of the stock of material to be analyzed. Phrases containing one of the listed keywords were attributed to one of the four TK elements according to the analytical framework shown in Table 4. In the third and final step, some of the phrases were assessed to evaluate their concrete semantics and relevance for the corresponding skills and competences leading to a further reduction in number.

In-depth interviews with key representatives

With the aim to back-up the rather technical keyword-based analysis, additionally four in-depth interviews were conducted with key representatives of each program. The interviews followed a predefined selection of questions loosely structured along the different elements of transformative knowledge, as outlined above. This way, the interviewees were guided towards relevant conceptual foundations of the programs, and at the same time they were offered enough room for bringing in new aspects. A qualitative analysis of the responses was performed in order to systematize the data and deduct the consideration of TK elements in the conceptualization of the programs.

5. Results

In total, 190 TK-related keywords were identified in the module descriptions of the master programs analyzed (step 1, Figure 4) by means of the keyword-based content analysis. This corresponded to 2.36, 2.33, 2.61 and 1.18% of the total number of words in the module descriptions for WUR, EDI, HOH and UEF, respectively. To the authors' knowledge, there is no guideline for the ideal number of words in the assessment of an adequate inclusion of TK. Nevertheless, with view on our research question it is evident that certain aspects of TK are incorporated in the programs. The further analysis in step 2 led to the exclusion of a number of originally positive results. This applied to terms such as *learn* (HOH), *communication* (EDI), *participant* (WUR) used in relatively generic contexts that were assumed not to be related to the TK space. The results from the keyword-based content analysis were complemented with the insights from the in-depth interviews. In the following, the combined results are presented for each of the four TK elements.

5.1 Communication & education

Both the keyword-based search and the interviews revealed the relevance of skills to effectively communicate with diverse audiences in regard of future bioeconomy experts. For the interviewees from WUR, EDI and HOH, one of the major learning goals was the graduates' ability to understand and use a wide range of vocabularies common to the diverse set of bioeconomy-relevant disciplines and stakeholders. This is also in line with the keyword-based search, in which the identified phrases often referred to communication with(in) different audiences and inter- or even transdisciplinary environments. This included "audiences within food production system[s]" (EDI) and "partners from industry" (HOH). Accordingly, students learn to apply "a variety of communication tools" (UEF) and use an "appropriate style and language for different audiences" (EDI). All the curricula imparted different aspects of communication and the relevant communication skills and competences to inform and involve society were covered. However, as elucidated from the interviews, concrete approaches varied substantially. While some relied on "learning-by-doing in a culturally diverse and interdisciplinary environment" (HOH), others have installed supporting facilitators accompanying the compulsory modules (EDI) or process coordinators in dedicated modules (WUR). At UEF, the required skills were regarded more relevant on a PhD level than for master graduates. Therefore, communication skills play a lesser role compared to the other programs.

5.2 Participation

Concerning the two major participation aspects, stakeholder identification and involvement as well as collaboration, the interviewees agreed on the importance of these aspects for bioeconomy education and confirmed their consideration during the conceptualization of the programs.

Dedicated modules (HOH) or the use of leitmotifs throughout fundamental modules (WUR) were established in order to emphasize the systemic nature of the bioeconomy and the importance of stakeholder considerations. This was also reflected by the keyword-based search which identified relevant phrases. For instance, the recognition of "different stakeholder perspectives" (WUR) and their "role […] in the governance of […] innovation" (EDI) processes in the curricula as well as by "concepts such as participation" (HOH) and necessary methods were featured in the WUR, EDI and HOH curricula. Moreover, the HOH curriculum was unique in that it explicitly included transdisciplinary research. The second major aspect of participation, namely collaboration, was present in all analyzed programs. This includes in particular "teamwork practices" and group assignments in "interdisciplinary team [s]" (UHOH), which ideally take place "within complex collaborative environments" (WUR). By that, the curricula aim to ensure that graduates are able to implement participatory processes considering credible strategies based on consensus. All interviewees considered lectures by and projects with external experts from industry or non-governmental organizations helpful for this purpose, as students are exposed to a wide range of roles and perceptions of stakeholders in this way. However, the interviewees stated that the practical implementation and training of such aspects is challenging, as the contact to extra-university partners is difficult to establish and to maintain. For these reasons, these aspects are often only considered on a theoretical level.

5.3 Policy & decision making

A few phrases relating to the TK element *policy & decision making* were identified in the program module descriptions of HOH, WUR and UEF based on the keyword analysis. By contrast, EDI frequently referred to management and government of risk and policies underlying innovation processes. For instance, the EDI descriptions explicitly covered aspects of setting up an innovation policy conducive to the bioeconomy, taking into consideration "its policy and strategic foundations" (EDI). The interviewee pointed out that students are fostered to understand these dynamics in the bioeconomy through case studies and writing policy briefs. HOH and UEF emphasized the role of policies related to the use and management of "scarce resources" (HOH) and the governance of "biomass reserve[s]". Particularly, in the HOH curriculum policy and decision making aspects referred to the regulatory role of the government in natural resources management. In the WUR curriculum, there was no mention of similar aspects in the compulsory modules, however the "design of [...] policy papers" (WUR) was part of the module description. Interviewees from UEF and WUR highlighted regulation as top-down instruments and fundamental enablers. Diverse governance, policy, and decision making issues are conceptually and implicitly covered along the value chain, a common framework shared by the core modules in HOH and WUR, as claimed during the interviews. The role of consumers as drivers of transition was pointed out by interviewees from WUR and EDI, which is reflected only at a general level in the curriculum. According to the interviewees, the unavoidable trade-offs arising from the alignment of the bioeconomy with the requirements of sustainability are considered important political issues for decision-making (EDI, UEF, WUR).

5.4 Motivation

The keyword-based search relating to the motivational aspects of TK yielded very diverse phrases, that covered for instance the understanding of "innovation incentives" (EDI) and their "structures" (WUR) as well as the comprehension of "academic" (WUR) and "social attitudes" (EDI). Based on this selection, the authors followed step 3 of the keyword condensation procedure by interpreting their respective semantics (see Figure 4). Three of the identified phrases were considered adequate to stimulate reconsideration of individual attitudes. These were found in the WUR and EDI curricula, where the reflection on "incentive structures of stakeholders" (WUR) and the recognition that "innovation processes are shaped by [...] social attitudes and perceptions" (EDI) were part of the compulsory modules of the curriculum.

Throughout the interviews, important insights related to the personal experience and transformational stimulation of students were identified in all four programs. For instance, due to the diverse background of lecturers and the different approaches to bioeconomy, students are confronted with a plurality of visions and perspectives (HOH). This partly alleviates the risk for students to assume the perceptions of the individual lecturers as undebatable (UEF). To support students in reflecting on the ideas and knowledge perceived in relation to their own interpretation, EDI has created dedicated spaces to appropriately moderate such processes. In the same vein, UEF and WUR actively encourage students in special modules to question and critically assess statements and exchange ideas in special modules and also try to provide the respective space in other core modules (UEF, WUR). Additional approaches such as de-construction and co-creation contribute to criticize and understand key concepts like sustainability or value (EDI). As a result, students' personal attitude towards the bioeconomy is likely to change during their studies (UEF, EDI). Ethical aspects were highlighted by the interviewee from WUR as principally covered in undergraduate programs rather than at the master's level.

6. Discussion

The literature clearly demonstrates the relevance of TK as a complement to systems and normative knowledge in transition processes (WBGU 2011; Stibbe 2009; Singer-Brodowski 2016a) (see Section 2). While the latter two cognitive spaces form the fundament, TK is required in order to induce a transition from the current to a desired state. The transformation to a sustainable bioeconomy is expected to involve systemic shifts and thus requires the adoption of desired habits, practices, and values in the society. For this reason, bioeconomy-related study programs in higher education need to convey TK. The keyword- based content analysis of curricula of four European bioeconomy graduate programs complemented by in-depth interviews with key representatives of each program yielded valuable insights into this topic.

Before the results are discussed in detail, we want to highlight some of the limitations our research approach displays. Neither the presence of transformation vocabulary in a given curriculum (as derived from our keyword-based analysis) nor its consideration in the conceptualization phase (as derived from the interviews) is a guarantee that it explicitly provides students with comprehensive knowledge on the related concepts. Although it can be assumed that both in combination provide an indication of a general engagement with TK in bioeconomy education, the factual learning outcomes have not been measured. Our results thus only provide evidence for an initial overview of bioeconomy program contents with regard to the inclusion of TK elements. Similar approaches have been applied in previous studies for the assessment of sustainability-related knowledge in scientific publications (e.g., Abson et al. 2014) and in the identification of sustainable development contents in higher education (Singer-Brodowski et al. 2018a).

With these limitations in mind, we are safe to assume that the program curricula assessed hold the potential to contribute to the transformative knowledge base of students. Remarkably, all courses highlight the importance of participatory processes in the bioeconomy transition and emphasize aspects that allow graduates to reach out to a wide range of actors from various disciplines and societal groups. For this purpose, communication across disciplinary and sectoral boundaries is necessary, which partially explains the focus on inter- and transdisciplinary communication approaches in the curricula (esp. WUR, HOH, and UEF). In addition to the interdisciplinary focus of the course contents, the diverse cultural and academic composition of the course participants themselves (found in all the study programs analyzed) is also expected to contribute to the training of the required communication skills.

Considerable variation between the programs is observed with regard to the extent and scope of the element policy & decision making. The strong emphasis on this element in EDI can be attributed to the management orientation of the program and its special focus on the governance of risk. The keywords relating to this TK element are generally used here in the context of economic and innovation policies. In contrast, the curricula of WUR and HOH focus more on public and social policy aspects such as the governance of resources. Against the expectation of several scholars that "the development and impact of the bioeconomy will depend on how it is governed" (Devaney et al. 2017, p. 41, see also Besi and McCormick 2015; Bosman and Rotmans 2016), this rather selective consideration of political skills across the programs seems inadequate. A comprehensive integration of all principles of good governance for a future bioeconomy (Devaney et al. 2017) at different levels (e.g., organizations, markets, legislation) is largely missing.

Overall, the keyword-based analysis suggests that only little attention is currently given to the personal sphere of TK (i.e., the element of motivation). At first glance, this may be interpreted simply as an inadequacy, disregard, or reluctance of the analyzed programs to deliberately trigger a change in personal perceptions. Only few module descriptions do involve a reflection on personal or peer attitudes (WUR) and approaches (EDI). This is in line with statements by interviewees who see the development of curricula mainly content-driven. Usually, the program curricula do not offer space for or support reflection. As argued by HOH and WUR, these aspects are rather implicitly included, as students are constantly confronted with diverse and controversial perspectives from their peers or the lecturers. The interdisciplinary and intercultural studentship as well as the diversity of teaching personnel naturally trigger reflection processes on individual perceptions of aspects related to bioeconomy and sustainability. Consequently, the motivational element of TK is incidentally conveyed at a general level, transversally and throughout the whole learning experience in the sense that these are not primarily and purely covered by any specific module. However, it should be kept in mind that the explicit integration of individual reflection processes may often not be possible to stipulate in formal curricula. It has been shown by education scientists that a change in a student's perspective can only be facilitated, never steered (Singer-Brodowski 2016b), and the reflection process is expected to be ongoing without ever being completed (Dirkx 1998). These characteristics render respective learning contents and outcomes impossible to codify. In addition, open-ended learning objectives seem to be at odds with the traditional self-conception of teachers, who aim at fulfilling a syllabus imposed upon them by the university or their respective disciplines.

While the reconsideration of individual assumptions and worldviews may be too personal and its aim too vague to be formally described, let alone measured, educational scientists have given much thought to the conceptualization of the initiation of such reflection processes in adults (Dirkx 1998; Singer-

Brodowski 2016b). They have framed such perspective change of personal believe systems using the theory of transformative learning (Mezirow 1978, 2000). Transformative learning "refers to transforming a problematic frame of reference to make it more dependable … by generating opinions and interactions that are more justified. We become critically reflective of those beliefs that become problematic." (Mezirow 2000, p. 20). According to the model of progressive change (Hicks 2002; Rogers 1994), the process of transformative learning is one important step towards the development of informed choices for action at personal, social, and political levels. In other words, transformative learning can be understood as one important step towards attaining TK.

While the scope of the present study does not allow for an analysis of the teaching methods and assessment practices, the authors acknowledge the importance of such components, especially for the development of the personal sphere of TK. Fortunately, educational settings to encourage reflection and critical thinking for a future-oriented academic training are not expected to be overly subject-specific. Programs dedicated to train transformative bioeconomists are thus well advised to draw on experiences documented, for instance, within the context of education for sustainable development (Singer-Brodowski et al. 2018b).

7. Conclusion

In times of unprecedented global challenges that seriously threaten the Earth's capacity to further sustain humanity's existence, society must pursue equally unprecedented future strategies. Since "we can't solve problems by using the same kind of thinking we used when we created them" (quote attributed to Albert Einstein), such strategies fundamentally require a reconsideration of established mindsets to design and follow more sustainable pathways. High expectations currently rest on the idea of superseding the fossil-based by a bio-based economy. It aims at relieving some of the global wicked problems connected with the excessive use of non-renewable resources, including climate change and the irreversible depletion of the Earth's natural resources.

The protagonists of a transformation to a sustainable bioeconomy will be in charge to acquire and apply alternative types of knowledge. Traditionally, economic transformations have been attributed to an accumulation of cutting-edge scientific and technological skills. In the case of sustainability transitions however, additional competences have been identified as relevant. Transformative actors need to understand the interdependent nature of current systems, establish a normative vision of alternative scenarios, and be able to effect a transgression from the current to the desired state. This article has reviewed the latter of these three cognitive spaces: transformative knowledge. It involves skills for successful communication and education, the ability to plan and conduct participatory processes, policy and decision-making competences, as well as the capacity to reconsider inherited values and assumptions. All of these elements have been shown to be of utmost importance for a successful transformation to a sustainable bioeconomy by paying tribute to the necessity of "new thinking" for fundamentally new solution strategies.

The analysis of four European graduate programs dedicated to training future bioeconomy experts revealed that they are principally well designed to account for the conveyance of TK. Many aspects of TK are generally well represented in the module descriptions, while other aspects have at least been considered during the conceptualization of the programs. Communication skills and participation approaches in particular form part of all curricula analyzed. Syllabus components identified for the training of policy- and decision-making competences lack a common understanding of bioeconomy governance. Different programs address different governance levels – from enterprise management to global politics, thus neglecting the central role governance must play *at all levels* in normative transitions like the bioeconomy venture. Motivational aspects relating to the reflective capability required to promote change and to overcome structural and social inertia were hardly considered in the module descriptions or during the conceptualization of the programs. Tacitly and unintentionally, however, they have found their way into the curriculum design process, especially in EDI.

Our findings may well serve as a baseline for further development of curricula and pedagogic strategies in bioeconomy education. While we cannot make any qualitative statements on the capacity of the analyzed study programs to educate transformative bioeconomy experts, we do claim that the following aspects should be considered in general when (re-)designing truly transformative bioeconomy programs in the future:

1. The role of governance in the transformation to a sustainable bioeconomy must become clear. Graduated bioeconomists must comprehensively understand the importance of adequate governance at all levels and be trained in shaping political processes.
2. The personal sphere of TK, also referred to as the element of motivation, must be promoted more strongly. The fact that in all four programs deep personal reflection seemed to resonate within the curriculum, shows that there is an awareness of its necessity which deserves more attention in the future. New pedagogical approaches drawing on transformative learning or education for sustainable development could support the education of change makers and experts for a future European bioeconomy, who break unprecedented ground and promote a successful transformation.

Our research is clearly limited by the explanatory power of our analysis. This is, firstly, due to the fact that the set of keywords based on Abson et al. (2014) may be neither exhaustive nor entirely adequate in an educational context. Secondly, the huge discrepancy between the very subjective and personal nature of TK and the rather technical keyword-based approach could only partially be alleviated by the additional in-depth interviews. Future research has to further advance this field of inquiry in at least two directions: the set of keywords should be developed further by employing more sophisticated methods of keyword construction and subsequent content analysis. Also, the conveyance of desired kinds of knowledge (also including systems knowledge and normative knowledge) in study programs could be analyzed in more depth, e.g. by including surveys among graduates and teaching personnel.

8. References

Abson, D.J., Wehrden, H. von, Baumgärtner, S., Fischer, J., Hanspach, J., Härdtle, W., et al., 2014. Ecosystem services as a boundary object for sustainability. Ecol. Econ. 103, 29–37. https://doi.org/10.1016/j.ecolecon.2014.04.012.

Abson, D.J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., et al., 2017. Leverage points for sustainability transformation. Ambio 46, 30–39. https://doi.org/ 10.1007/s13280-016-0800-y.

Adomßent, M., 2013. Exploring universities' transformative potential for sustainability-bound learning in changing landscapes of knowledge communication. J. Clean. Prod. 49, 11–24. https://doi.org/10.1016/j.jclepro.2012.08.021.

Balsiger, J., Förster, R., Mader, C., Nagel, U., Sironi, H., Wilhelm, S., et al., 2017. Transformative learning and education for sustainable development. GAIA - Ecological Perspectives for Science and Society 26, 357–359. https://doi.org/10. 14512/gaia.26.4.15.

Banks, J.A., 1993. The canon debate, knowledge construction, and multicultural education. Educ. Res. 22, 4–14. https://doi.org/10.3102/0013189X022005004.

Barnes, W., Gartland, M., Stack, M., 2004. Old habits die hard: Path dependency and behavioral lock-in. Journal of Economic Issues 38 (2), 371–377.

Beddoe, R., Costanza, R., Farley, J., Garza, E., Kent, J., Kubiszewski, I., et al., 2009. Overcoming systemic roadblocks to sustainability: the evolutionary redesign of worldviews, institutions, and technologies. In: Proceedings of the National Academy of Sciences of the United States of America. 106. pp. 2483–2489. https://doi.org/10. 1073/pnas.0812570106.

Beniger, J.R., 1989. The Control Revolution: Technological and Economic Origins of the Information Society. Harvard University Press, Cambridge.

Besi, M. de, McCormick, K., 2015. Towards a bioeconomy in Europe: national, regional and industrial strategies. Sustainability 7, 10461–10478. https://doi.org/10.3390/ su70810461.

BMBF, Federal Ministry of Education and Research, 2014. Wegweiser Bioökonomie: Forschung für biobasiertes und nachhaltiges Wirtschaftswachstum. Berlin. https://www.ufz.de/ export/data/2/134696_wegweiser-biooekonomie.pdf, Accessed date: 22 July 2019.

BMBF, Federal Ministry of Education and Research, 2017. Bioökonomie - neue Konzepte zur Nutzung natürlicher Ressourcen. https://www.bmbf.de/de/biooekonomie-neue- konzepte-zur-nutzung-natuerlicher-ressourcen-726.html, Accessed date: 25 July 2019.

BMBF & BMEL, Federal Ministry of Education and Research, & Federal Ministry for Food and Agriculture, 2015. Bioeconomy in Germany: Opportunities for a Bio-based and Sustainable Future. Federal Ministry of Education and Research & Federal Ministry of Food and Agriculture, Germany, Berlin, Bonn.

BMEL, Federal Ministry for Food and Agriculture, 2014. Nationale Politikstrategie Bioökonomie: Nachwachsende Ressourcen und biotechnologische Verfahren als Basis für Ernährung, Industrie und Energie. Berlin. https://www.bmel.de/SharedDocs/ Downloads/Broschueren/BioOekonomiestrategie.pdf? blob=publicationFile, Accessed date: 22 July 2019.

Bohm, D., 1994. Thought as a System. Routledge, London.

Bologna Working Group, 2005. A Framework for Qualifications of the European Higher Education Area. Copenhagen. http://www.ecahe.eu/w/images/7/76/A_Framework_ for_Qualifications_for_the_European_Higher_Education_Area.pdf, Accessed date: 17 August 2018.

Bosman, R., Rotmans, J., 2016. Transition governance towards a bioeconomy: a comparison of Finland and The Netherlands. Sustainability 8, 1017. https://doi.org/10. 3390/su8101017.

Bugge, M., Hansen, T., Klitkou, A., 2016. What is the bioeconomy? A review of the lit- erature. Sustainability 8, 691. https://doi.org/10.3390/su8070691.

Cohen, M.J., Reeves, D., 1995. Causes of Hunger. International Food Policy Research Institute 2020 Brief, pp. 19.

Conklin, J., 2006. Wicked problems and social complexity. In: Conklin, J. (Ed.), Dialogue Mapping: Building Shared Understanding of Wicked Problems, 1st ed. John Wiley & Sons, Chichester, pp. 3–40.

Cörvers, R., Wiek, A., Kraker, J. de, & Lang, D.J. and Martens, P. (2016). Problem-based and project-based learning for sustainable development. In H. Heinrichs, W. J. M. Martens, G. Michelsen, & A. Wiek (Eds.), Sustainability Science: An Introduction (pp. 349–358). Dordrecht: Springer.

Devaney, L., Henchion, M., Regan, Á., 2017. Good governance in the bioeconomy. EuroChoices 16, 41–46. https://doi.org/10.1111/1746-692X.12141.

Dirkx, J.M., 1998. Transformative learning theory in the practice of adult education: an overview. PAACE J. Lifelong Learn. 7, 1–14.

Disterheft, A., Caeiro, S.S., Leal Filho, W., Azeiteiro, U.M., 2016. The INDICARE-model – measuring and caring about participation in higher education's sustainability as- sessment. Ecol. Indic. 63, 172–186. https://doi.org/10.1016/j.ecolind.2015.11.057.

Dosi, G., 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Res. Policy 11, 147–162. https://doi.org/10.1016/0048-7333(82)90016-6.

Dosi, G., Nelson, R.R., 2010. Technical change and industrial dynamics as evolutionary processes. In: Bronwyn, H.H., Rosenberg, N. (Eds.), Handbook of the Economics of Innovation, 1st ed. North-Holland, Amsterdam, pp. 51–127.

EC, 2012. Innovating for sustainable growth: a bioeconomy for Europe. Brussels. https://publications.europa.eu/de/publication-detail/-/publication/1f0d8515-8dc0-4435- ba53-9570e47dbd51/language-en, Accessed date: 24 November 2017.

EC, 2018. A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment: updated bioeconomy strategy. Luxembourg. https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf#view=fit&pagemode=none, Accessed date: 17 December 2018.

Fadeeva, Z., Galkute, L., Mader, C., Scott, G., 2014. Assessment for transformation — higher education thrives in redefining quality systems. In: Fadeeva, Z. (Ed.), Sustainable Development and Quality Assurance in Higher Education: Transformation of Learning and Society. 6. Palgrave Macmillan, Houndmills, Basingstoke, Hampshire, pp. 1–22.

Finnish Ministry of Employment and the Economy, 2014. Sustainable growth from bioeconomy: the Finnish bioeconomy strategy. https://biotalous.fi/wp-content/uploads/2014/08/The_Finnish_Bioeconomy_Strategy_110620141.pdf, Accessed date: 18 January 2019.

Frantzeskaki, N., Loorbach, D., Meadowcroft, J., 2012. Governing societal transitions to sustainability. Int. J. Sustain. Dev. 15, 19–36. https://doi.org/10.1504/ijsd.2012. 044032.

German Bioeconomy Council, 2018. Bioeconomy policy (part III): update report of national strategies around the world. Berlin. https://biooekonomierat.de/fileadmin/Publikationen/berichte/GBS_2018_Bioeconomy-Strategies-around-the_World_Part- III.pdf, Accessed date: 17 December 2018.

Grunwald, A., 2004. Strategic knowledge for sustainable development: the need for reflexivity and learning at the interface between science and society. Int. J. Foresight Innov. Policy 1, 150. https://doi.org/10.1504/IJFIP.2004.004619.

de Haan, G., 2003. Bildung als Voraussetzung für eine nachhaltige Entwicklung - Kriterien, Inhalte, Strukturen, Forschungsperspektiven. In: Kopfmüller, J. (Ed.), Den globalen Wandel gestalten: Forschung und Politik für einen nachhaltigen globalen Wandel. Edition Sigma, Berlin, pp. 93–112.

Hausknost, D., Schriefl, E., Lauk, C., Kalt, G., 2017. A transition to which bioeconomy? An exploration of diverging techno-political choices. Sustainability 9, 669. https://doi. org/10.3390/su9040669.

Heimann, T., 2019. Bioeconomy and SDGs: does the bioeconomy support the achievement of the SDGs? Earth's Future 7, 43–57. https://doi.org/10.1029/2018EF001014.

Hicks, D., 2002. Lessons for the Future: The Missing Dimension in Education, 1st ed. Futures and Education Series Routledge Falmer, London.

Huckle, J., Wals, A.E.J., 2015. The UN decade of education for sustainable development: business as usual in the end. Environ. Educ. Res. 21, 491–505. https://doi.org/10. 1080/13504622.2015.1011084.

Hulme, M., 2009. Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity. Cambridge University Press, Cambridge.

Kandaramath Hari, T., Yaakob, Z., Binitha, N.N., 2015. Aviation biofuel from renewable resources: routes, opportunities and challenges. Renew. Sust. Energ. Rev. 42, 1234–1244. https://doi.org/10.1016/j.rser.2014.10.095.

Knierim, A., Laschewski, L., Boyarintseva, O., 2018. Inter- and transdisciplinarity in bioeconomy. In: Lewandowski, I. (Ed.), Bioeconomy. 90. Springer International Publishing, Cham, pp. 39–72.

Lask, J., Maier, J., Tchouga, B., Vargas-Carpintero, R., 2018. The bioeconomist. In: Lewandowski, I. (Ed.), Bioeconomy. Springer International Publishing, Cham, pp. 341–354.

Leach, M., Scoones, I., Stirling, A.C., 2010. Dynamic Sustainabilities: Technology, Environment, Social Justice. Earthscan, London.

Leach, M., Rockström, J., Raskin, P., Scoones, I., Stirling, A.C., Smith, A., et al., 2012. Transforming innovation for sustainability. Ecol. Soc. https://doi.org/10.5751/ES- 04933-170211.

Leemans, R., van Amstel, A., Battjes, C., Kreileman, E., Toet, S., 1996. The land cover and carbon cycle consequences of large-scale utilizations of biomass as an energy source. Glob. Environ. Chang. 6, 335–357. https://doi.org/10.1016/S0959-3780(96)00028-3.

McCormick, K., Kautto, N., 2013. The bioeconomy in Europe: an overview. Sustainability 5, 2589–2608. https://doi.org/10.3390/su5062589.

Mezirow, J., 1978. Perspective transformation. Adult Educ. Q. 28, 100–110. https://doi. org/10.1177/074171367802800202.

Mezirow, J., 1991. Transformative Dimensions of Adult Learning, 1st ed. Jossey-Bass, San Francisco.

Mezirow, J., 2000. Learning as Transformation: Critical Perspectives on a Theory in Progress. Jossey Bass, San Francisco.

MWK, 2013. Konzept für eine baden-württembergische Forschungsstrategie „Bioökonomie“. Stuttgart. https://mwk.baden-wuerttemberg.de/fileadmin/ redaktion/m-mwk/intern/dateien/pdf/Forschung/Konzept_Forschungsstrategie_ Biooekonomie.pdf, Accessed date: 21 September 2017.

Narodoslawsky, M., Niederl-Schmidinger, A., Halasz, L., 2008. Utilising renewable resources economically: new challenges and chances for process development. J. Clean. Prod. 16, 164–170. https://doi.org/10.1016/j.jclepro.2006.08.023.

O'Brien, K., Sygna, L., 2013. Responding to climate change: the three spheres of transformation. In: University of, O. (Ed.), Transformation in a Changing Climate, Oslo, Norway, 19.06.2013-21.06.2013, pp. 16–23.

Perez, C., 1985. Microelectronics, long waves and world structural change: new perspectives for developing countries. World Dev. 13, 441–463. https://doi.org/10. 1016/0305-750X(85)90140-8.

Perez, C., 2003. Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages. Edward Elgar Publishing, Cheltenham.

Perez, C., 2016. Capitalism, technology and a green global golden age: the role of history in helping to shape the future. In: Jacobs, M., Mazzucato, M. (Eds.), Rethinking Capitalism: Economics and Policy for Sustainable and Inclusive Growth. Wiley- Blackwell, Oxford, pp. 191–217.

Pfau, S.F., Hagens, J.E., Dankbaar, B., Smits, A.J., 2014. Visions of sustainability in bioeconomy research. Sustainability 6, 1222–1249. https://doi.org/10.3390/ su6031222.

ProClim, C, 1997. Research on sustainability and global change – visions in science policy by Swiss researchers. Bern. https://naturalsciences.ch/uuid/3df3d017-7928-56dd- 864f-63904096048d?r=20170706115333_1499300833_97d18713-8a31-5e4b-bea2-f1f63980ae97, Accessed date: 22 July 2019.

Pyka, A., 2017a. Dedicated innovation systems to support the transformation towards sustainability: creating income opportunities and employment in the knowledge- based digital bioeconomy. Journal of Open Innovation: Technology, Market, and Complexity 3, 1–18. https://doi.org/10.1186/s40852-017-0079-7.

Pyka, A., 2017b. Transformation of economic systems: the bio-economy case. In: Dabbert, S., Lewandowski, I., Weiss, J., Pyka, A. (Eds.), Knowledge-driven Developments in the Bioeconomy: Technological and Economic Perspectives, 1st ed. Springer, Cham, pp. 3–16.

Rauschmayer, F., Bauler, T., Schäpke, N., 2015. Towards a thick understanding of sustainability transitions — linking transition management, capabilities and social practices. Ecol. Econ. 109, 211–221. https://doi.org/10.1016/j.ecolecon.2014.11.018.

Rittel, H.W., Webber, M.M., 1973. Dilemmas in a general theory of planning. Policy. Sci.4, 155–169. https://doi.org/10.1007/BF01405730.

Rogers, M.E., 1994. Learning About Global Futures: An Exploration of Learning Processes and Changes in Adults. Dissertation. University of Toronto, Toronto.

Rönnlund, I., Pursula, T., Bröckl, M., Hakala, L., Luoma, P., Aho, M., et al., 2014. Creating value from bioresources: innovation in Nordic Bioeconomy. Oslo. https://norden. diva-portal.org/smash/get/diva2:709329/FULLTEXT01.pdf, Accessed date: 25 July 2019.

Schlaile, M.P., Urmetzer, S., Blok, V., Andersen, A.D., Timmermans, J., Mueller, M., et al., 2017. Innovation systems for transformations towards sustainability? Taking the normative dimension seriously. Sustainability 9, 1–20. https://doi.org/10.3390/ su9122253.

Schlitz, M.M., Vieten, C., Miller, E.M., 2010. Worldview transformation and the development of social consciousness. J. Conscious. Stud. 17 (7–8), 18–36.

Schneidewind, U., 2013. Transformative literacy: Gesellschaftliche Veränderungsprozesse verstehen und gestalten. GAIA 22 (2), 82–86.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., et al., 2008. Use of US Croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319, 1238–1240. https://doi.org/10.1126/science. 1151861.

Singer-Brodowski, M., 2016a. Studierende als GestalterInnen einer Hochschulbildung für nachhaltige Entwicklung: Selbstorganisierte und problembasierte Nachhaltigkeitskurse und ihr Beitrag zur überfachlichen Kompetenzentwicklung Studierender. Umweltkommunikation v. 8 BWV Berliner Wissenschafts-Verlag, Berlin.

Singer-Brodowski, M., 2016b. Transformatives Lernen als neue Theorie-Perspektive in der BNE. In: Umweltdachverband GmbH (Ed.), Jahrbuch Bildung für nachhaltige Entwicklung – Im Wandel. Forum Umweltbildung im Umweltdachverband, Wien, pp. 130–139.

Singer-Brodowski, M., Brock, A., Etzkorn, N., Otte, I., 2018a. Monitoring of education for sustainable development in Germany – insights from early childhood education, school and higher education. Environ. Educ. Res. 1–16. https://doi.org/10.1080/ 13504622.2018.1440380.

Singer-Brodowski, M., Grossmann, K., Bartke, S., Huning, S., Weinsziehr, T., Hagemann, N., 2018b. Competency-oriented education for sustainable development. Int. J. Sustain. High. Educ. 3. https://doi.org/10.1108/IJSHE-12-2017-0223.

Sipos, Y., Battisti, B., Grimm, K., 2008. Achieving transformative sustainability learning: engaging head, hands and heart. Int. J. Sustain. High. Educ. 9, 68–86. https://doi. org/10.1108/14676370810842193.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., et al., 2015. Planetary boundaries: guiding human development on a changing planet. Science. https://doi.org/10.1126/science.1259855.

Sterling, S., 2011. Transformative learning and sustainability: sketching the conceptual ground. In: Learning and Teaching in Higher Education. 5. pp. 16–33.

Stern, N., 2008. The economics of climate change. Am. Econ. Rev. 98 (2), 1–37.

Steuer, N., Marks, N., 2008. University challenge: towards a well-being approach to quality in higher education. London. http://b.3cdn.net/nefoundation/ 176e59e9cc07f9e21c_qkm6iby2y.pdf, Accessed date: 22 July 2019.

Stibbe, A. (Ed.), 2009. The Handbook of Sustainability Literacy. Greenbooks, Dartington.

The European Bioeconomy Stakeholders Panel, 2017. European Bioeconomy Stakeholders Manifesto. Brussels. http://ec.europa.eu/research/bioeconomy/pdf/ european_bioeconomy_stakeholders_manifesto.pdf, Accessed date: 25 July 2019.

UN, 2015. Transforming Our World: The 2030 Agenda for Sustainable Development. New York. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf, Accessed date: 25 July 2019.

UNESCO, 2006. Framework for the UNDESD International Implementation Scheme. Paris. https://unesdoc.unesco.org/ark:/48223/pf0000148650, Accessed date: 25 July 2019.

Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830. https:// doi.org/10.1016/S0301-4215(00)00070-7.

Urmetzer, S., Schlaile, M., Bogner, K., Mueller, M., Pyka, A., 2018. Exploring the dedicated knowledge base of a transformation towards a sustainable bioeconomy. Sustainability 10, 1694. https://doi.org/10.3390/su10061694.

VERBI Software GmbH, 2018. MAXQDA.

Waddock, S., Meszoely, G.M., Waddell, S., Dentoni, D., 2015. The complexity of wicked problems in large scale change. J. Organ. Chang. Manag. 28, 993–1012. https://doi. org/10.1108/JOCM-08-2014-0146.

WBGU, 2011. World in Transition – A Social Contract for Sustainability. Berlin. https:// www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/hauptgutachten/ hg2011/pdf/wbgu_jg2011_en.pdf, Accessed date: 25 July 2019.

Wehrden, H. von, Luederitz, C., Leventon, J., Russel, S., 2017. Methodological challenges in sustainability science: a call for method plurality, procedural rigor and long- itudinal research. Challenges in Sustainability 5, 35–42. https://doi.org/10.12924/ cis2017.05010035.

Wiek, A., Kay, B., 2015. Learning while transforming: solution-oriented learning for urban sustainability in Phoenix, Arizona // Learning while transforming: solution- oriented learning for urban sustainability in Phoenix, Arizona. Curr. Opin. Environ. Sustain. 16, 29–36. https://doi.org/10.1016/j.cosust.2015.07.001

Chapter V

New business models to change the systemic innovation logic towards sustainability

V. New business models to change the systemic innovation logic towards sustainability

Abstract

The paper explores the potential of new business models to contribute to an overall dedication of innovation systems to a transformation to sustainability. To take account of the systemic nature of global sustainability challenges, the author adopts a business model perspective which allows to connect individual actors' purpose and activities with systemic outcomes. Departing from innovation systems theory, sustainability transitions, and corporate sustainability, a systematic literature review provides the basis for developing three propositions that conceptualize the potential contribution of dedicated business models to sustainability transformations. Business models that contribute to an increased dedication to sustainability in innovation systems can be expected to feature (i) an explicit commitment to sustainability related values; (ii) reliance on new material, technological, and intellectual resources that offer higher levels of sustainability; and (iii) mechanisms to nurture changed demands of consumers and suppliers in terms of expected sustainability principles. The paucity of relevant literature limits the explanatory power of the study. It also lacks an empirical substantiation, which is beyond the scope of this conceptual paper. The study contributes to the growing scholarship on sustainable business models by taking a slightly different stance: Dedicated business models are expected to become effective on the level of the trajectories of the innovation system. They endow firms with the capacity to reframe the overall innovation challenge as systemic and sustainability related, explore alternative heuristics, and change the general perception of success from (pure) profit maximization towards achieving higher levels of sustainability.

Keywords

Business model, business model innovation, innovation system, dedicated innovation system, innovation trajectory, sustainability

Status of publication

This article has been submitted to the Journal of Business Models with the title "What's the problem? How new business models may change the systemic innovation logic towards sustainability". It is currently under revision.

The content of the text has not been altered. For reasons of consistency, the language and the formatting have been changed slightly.

1. Introduction

Scholars increasingly acknowledge that the global sustainability challenges such as climate change, ecological degradation, waste, or poverty are interconnected issues that must be explored and addressed from a systems perspective (Steffen et al. 2015; Swart et al. 2004; Murphy 2012). The rising awareness of systemic interrelations and the acknowledgement of the complexity of societal, environmental, and economic problems also appears to have revived systems thinking and respective notions of governance (Abson et al. 2017; Meadows 1999; Voß et al. 2006). In contrast, private firms' efforts to take account of sustainability issues in business are often based upon a rather narrow and local understanding of sustaina-bility (Whiteman et al. 2013). Reporting on economic, social, and environmental performance has become the credentials for corporate sustainability (Milne and Gray 2013) rendering them competitors rather than acknowledging them inseparable and synergistic contributors to shareholder value (Fiksel 2003). With its exclusive focus on quantitative, direct indicators, this approach to sustainability — also referred to as triple bottom line (Elkington 2013) — ignores rather qualitative and structural as well as indirect and systemic impacts of businesses. Does a car manufacturer using bioplastic for interior paneling contribute sufficiently to the solution of problems originating from the drastic increase in individual transport, greenhouse gas emissions, and air pollution? Notwithstanding improvements in integrating sustainability in corporate performance reporting (e.g., via integrated reporting supported by the Global Reporting Initiative), sustainability reporting in general adopts a firm-centered (inside-out) perspective grounded on economic efficiency and encourages management to incremental improvements along business-as-usual trajectories (Alexander and Blum 2016; Dyllick and Muff 2016). Instead, firms must be prompted to develop an understanding of the surrounding socio-economic system and — by adopting an outside-in perspective — to contribute to continuous innovation and improvement of the same (Fiksel 2003; Dyllick and Muff 2016).

One well-established framework to analyze systems in the context of progress and innovation is the notion of systems of innovation or innovation systems (IS) (Dosi et al. 1988; Freeman 1987; Lundvall 1992). It considers innovation as a collective output of the systemic interplay among scientific, political, and business actors who continuously exchange knowledge according to given rules and patterns (institutions). While the co-evolution of the IS and its elements has generally been acknowledged widely (Dantas and Bell 2011; Lundvall 2007; Motohashi 2005), the effect of individual management decisions within firms on the functioning and outcome of the IS has not been explored very well. This results in a very vague conceptualization of the role of the firm in IS generally, which also holds for the characterization of the established firms' contribution to sustainability transitions. Instead, transitions researchers have commonly framed currently successful firms as part of the problem that must be overcome in order to destabilize present unsustainable regimes (Geels 2014). Accordingly, very young conceptual advancements of IS for sustainability (Lindner et al. 2016; Pyka 2017; Urmetzer and Pyka 2019) also neglect the potential contribution of currently powerful private actors in realizing normative improvements of the system. This underestimation is worrying considering the influence, power, and sheer number of incumbents that can hardly be imagined to be entirely substituted before long (Wells and Nieuwenhuis 2012). Luckily, first studies into the transformative role of firms in sustainability transitions (Andersen and Markard 2017; Augenstein and Palzkill 2016; Hansen and Coenen 2017; Loorbach and Wijsman 2013) started to bridge the observed disconnection between regime conforming firms and transition endeavors.

From the micro-level perspective, a useful conceptual approach to address the systemic effect of corporate strategies is the sustainable business model framework which connects the firm-level with the systems level (Bocken et al. 2014; Stubbs and Cocklin 2008). Accordingly, it has been shown in several studies that the systems context of a firm, in terms of natural, social, institutional, industry, and technology specific systems, influences the design and content of sustainable business models (Morioka et al. 2017). Similar impact on business models (BM) has been detected from influences of IS (Ahlstrom et al. 2018; Hannon et al. 2015). However, little research has been done on the co-evolutionary relation of BM innovation and IS configuration. In other words, the evolutionary interdependencies of BM and IS have remained rather unspecific. Against the backdrop of urgent systemic sustainability challenges, it remains open how new BM can support the fundamental changes required in the structure, the dynamics, and the outcomes of the surrounding IS.

This gap is addressed in the article at hand by posing the following research question:

> In which ways can new business models contribute to innovation systems' dedication towards sustainability?

The article will conceptually refine the notion of dedicated innovation systems (DIS) (Pyka 2017) by highlighting the potential of innovating firms to increase the innovation system's overall dedication to sustainability transformations. More specifically, it will explore the distinct characteristics of new BM that enable (incumbent) firms to contribute to the required systemic change. While literature about motivations and incentives for firms to engage in sustainability abounds (see, e.g., Bossle et al. 2016; Hahn and Scheermesser 2006; Ariely et al. 2009; Mahoney et al. 2013; Dangelico and Pujari 2010), it is generally agreed that our current (capitalist) system in its present form does not naturally promote such behavior (Porter and Kramer 2011; Schweickart 2009; Hawken et al. 2013; Jackson 2009). Instead of exploring the possibilities of firms in the current innovation system, the research at hand focuses on the opportunity and capacity of incumbents to contribute to a system-wide change in terms of facilitating a systemic dedication to sustainability via new BM. In this, it provides pathways towards better linking management sciences with economics thus contributing to fostering interdisciplinary BM research.

The following Section serves as a short introduction into dedicated innovation systems and systems thinking in general, carves out the central role of knowledge sources and search heuristics in innovation-driven transformation processes, and introduces to business models for sustainability. Section 3 presents the procedure and results of a systematic literature review on the co-evolution of business models and IS. Together with the theoretical frameworks introduced in Section 2 these are used to reflect on possible business model character-istics that increase firms' systemic effect on DIS in section 4. Three propositions are offered to summarize the discussion and facilitate further research on 'dedicated' business models. Section 5 concludes.

2. Conceptual background

2.1 Dedicated innovation systems

An innovation system (IS) consists of "interacting private and public firms (either large or small), universities, and government agencies aiming at the production of science and technology …" (Niosi et al. 1993, p. 212). This is achieved by the continuous creation and flow of new knowledge which is eventually introduced "into the economy in the form of innovations, [and diffused and transformed] into something valuable, for example, international competitiveness and economic growth." (Gregersen and Johnson 1997, p. 482). Due to their history and application, IS have a strong (often implicit) focus on technological innovation, competitiveness, and economic development (Schlaile et al. 2017). Lately, however, IS research has started to also consider innovation as a source of the required radical changes in response to global sustainability challenges. This calls for an expanded framing of IS beyond the incubator of technological remedies by incorporating a system-wide dedication to the continuity and resilience of social and ecological systems, inter- and intra-generational justice, and quality of life (Daimer et al. 2012; Lindner et al. 2016; Schlaile et al. 2017; Tödtling and Trippl 2018; Urmetzer and Pyka 2019; Warnke et al. 2016; Weber and Truffer 2017). Such dedicated innovation systems (DIS) "explicitly go beyond technological innovation and eco-nomic growth and allow for paradigmatic change towards sustainability: They are 'dedicated' to foster the joint search for transformative innovations" (Pyka 2017, p. 3). In accordance with Dosi's evolutionary notion of technological paradigms (Dosi 1982) it can be expected that a dedication towards sustainability within an IS manifests itself in a fundamental change of its trajectories that guide innovative activity. Such change is reflected in the application of entirely new search heuristics, including the definition of the 'relevant' problems, the knowledge claimed necessary to solve them, as well as a common understanding of what progress or 'success' means. Simply put, the conception of 'business-as-usual' changes. While Dosi himself recognizes "the selective and focussing effect [on the selection and emergence of new paradigms] induced by various forms of stricto sensu non-economic interests" (Dosi 1982, p. 160), it has not been explored so far, how such non-economic interests like the preservation of ecosystems or the wellbeing of current and future generations actually influence trajectories and who will be in the position to intentionally do so. Since the DIS approach "targets radical transformations of existing institutions …" (Pyka 2017, p. 3), the powerful incumbent industries have so far not been expected to be the ones taking the lead. Due to their embeddedness in the system, firms have for a long time been regarded as incapable of influencing market structure, consumer demand, institutions, and infrastructures towards more sustainable configurations (Smith et al. 2005). Incumbents' focus naturally is put on the exploitation of existing procedures and infrastructure (Schaltegger et al. 2016) thus rather supporting the continuation of current trajectories. Consequently, throughout a major part of the literature, incumbents take on quite a passive role by only changing under severe pressure from civil society, policy, and consumers (Penna and Geels 2015), being incentivized by imminent creative destruction from external forces (Kivimaa and Kern 2016), or public policy programs (Jacobsson and Bergek 2011). Negative externalities of production processes are traditionally taken care of by the public sector, and social and environmental development beyond business interests are regarded to be the responsibility of the government (Kieft et al. 2017; Málovics et al. 2008; Steward 2012). Consequently, corporate sustainability endeavors have usually not departed from dominant trajectories while instead continuously relying on linear growth, increasing consumption, and maximized shareholder wealth (Sharma and Lee 2012). In "traditional" IS such behavior is in full accordance with what is expected from incumbent private firms. In DIS, by contrast, that role might (have to) change.

2.2 Connecting collective and individual levels

From a systems perspective it is not trivial to make out individual patterns of action that will collectively lead to a desired outcome of the whole. Instead, quite often the diverging aims of subunits together effectuate systemic outcomes that have not been intended by any of them. As Donella Meadows assures, "one of the most frustrating aspects of systems is that the purposes of subunits may add up to an overall behaviour that no one wants" (2008, p. 15). Reversely, a system with the purpose of producing innovation dedicated to sustainability is not likely to be made of interacting private and public firms, universities, and government agencies each pursuing their isolated, specific sustainability goals. We know little of the systemic role of the various micro-processes within IS subsystems in innovation processes, a fact that makes planning of deliberate intervention in systems towards desired outcomes extremely difficult if not impossible. Strong and instrumental links have been built between the IS literature and sustainability before (see Urmetzer and Pyka 2019 for an overview), but these concepts hardly illuminated those individual routines, competences, and norms necessary to afford the required transformation.

An overarching concept that can provide a gateway to better understand the relation of individual purpose and systemic outcome is knowledge (cf. Berkes 2009). Knowledge has been termed the most important resource of modern economies (Lundvall and Johnson 1994), and its creation, diffusion, and use are regarded key processes in innovation, especially from the IS perspective (Gregersen and Johnson 1997). In the context of sustainability transitions the usual focus on technological search heuristics must be extended to allow for regarding flows of other types of knowledge, too (Urmetzer et al. 2018), including non-economic societal values (Garst et al. 2019). The crucial difference to undirected IS processes is that dedicated innovation requires to be based on knowledge produced, diffused, and used for other purposes in addition to techno-economic efficiency improvement (Schlaile et al. 2017) thus fundamentally changing trajectories. Figure 5 illustrates the relation of IS subsystems, trajectories, and IS outcomes as conceptualized for this research. It pictures innovation trajectories as one central lever for the different IS actors to influence the way the IS functions and thus the kind of innovation it produces.

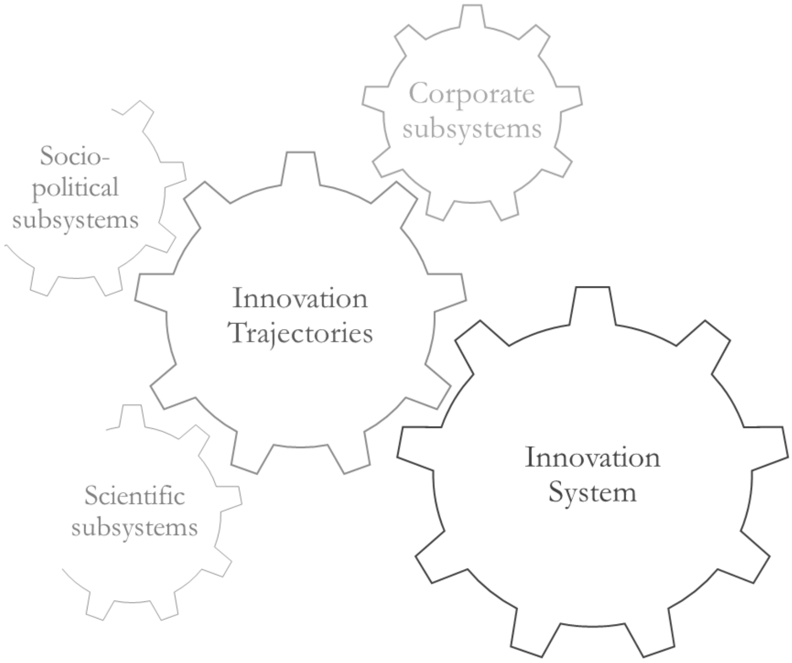

Figure 5 Interrelation of the corporate subsystems (firms) with innovation trajectories and IS as conceptualized in the context of the study.

For the individual subsystems in IS to become motors of dedicated innovation this means that they must (i) frame the innovation challenge as systemic and sustainability related (in Dosi's terms: define the relevant problem), (ii) explore alternative heuristics and sources of knowledge production and use (in Dosi's terms: define the knowledge required to solve the problem), and (iii) change the general perception of success from (pure) profit maximization towards societal desirability (in Dosi's terms: define the meaning of progress). So, in their role as subsystems of IS, how can firms operationalize these claims?

An example: An automobile industry's trajectory dedicated to sustainability would require of an incumbent automobile company to (i) understand and reconsider its individual role in the societal challenges connected to congestion, air pollution, and climate change (what Dyllick and Muff, 2016, term the outside-in perspective). Consequently, it would have to (ii) open up and use their expertise to find solutions that provide mobility instead of combustion engines. The respective new search heuristics would probably require, for instance, experimentation with alternative mobility concepts and extraneous technologies, collaboration with public transport enterprises, competitors, consumer associations and citizens' initiative, as well as adapted procurement policies. Accordingly, (iii) progress or 'success' would need to be redefined from "faster, safer, smarter" to "cleaner, smarter, more durable". At the same time, researchers and consultants concerned with the overall effect of incumbent firms on sustainability in IS must not take current trajectories as given, but instead look beyond the consequences of a firms' individual innovations, its corporate sustainability measures, and its triple bottom line performance. They need to consider the purpose and systemic effects of how a company does business.

2.3 Beyond corporate sustainability: The business model perspective

This knowledge-centered perspective on businesses' contribution to sustainability transformations has been argued to be in stark contrast to specific, incremental change initiatives such as traditional notions of corporate social responsibility or the triple bottom line (Miller Gaither et al. 2018; Milne and Gray 2013; Schaltegger and Burritt 2018). For "reporting progress on sustainability influences stakeholders' perceptions and is therefore an important tactic, but on its own it does not appear to be a significant driver of sustainability" (Stubbs and Cocklin 2008, p. 115). But even without insinuating greenwashing — against the backdrop of the overall aim to transform the IS, these endeavors must be regarded to be too narrow in focus. In this way, corporate social responsibility actually runs the risk of contributing to the manifestation of unsustainable system configurations instead of putting the firm in "the broader context of necessary structural and systemic change that stands beyond the reach of mainstream corporate responsibility initiatives." (Waddock and White 2007, p. 42; see also Bocken et al. 2014; Hart 1997; Sharma and Lee 2012; Dyllick and Muff 2016).

To open up towards this broader context a suitable unit for the analysis of a firm's capacity to become a system (co-)builder of a DIS, is the business model (BM). According to Teece, a BM "describes the design or architecture of the value creation, delivery and capture mecha-nisms employed" by a firm (2010, p. 179). The concept also offers great insights into businesses' roles in sustainability transformations because it ultimately reflects the way a company 'does business' (Amit and Zott 2008), in that it combines the firm-level with the systems perspective (Bocken et al. 2014; Bocken 2019; Boons and Lüdeke-Freund 2013; Schaltegger et al. 2016; Stubbs and Cocklin 2008), and encapsulates the belief system of a company – a fundamental driver of corporate decision making and, subsequently, action (Martins et al. 2015; Massa et al. 2017; Tikkanen et al. 2005). However, in contrast to the requirements for BM for sustainability (Bocken et al. 2015; Boons and Lüdeke-Freund 2013; Schaltegger et al. 2016; Stubbs and Cocklin 2008), new BM for DIS take a slightly different stance. While the former is supposed to serve as a tool to align technological and social innovation of the focal firm with system-level sustainability (Bocken et al. 2014), BM for DIS aim for a *paradigmatic* change by introducing a dedication to sustainability as normative direction in innovation processes across the (innovation) system. In other words, BM for sustainability change the configuration and performance of socio-technical systems, whereas BM for DIS are expected to change the innovation trajectories (see Figure 5).

Although notions and usage of BM vary widely across literature and practice, the following three fundamental elements are generally seen to make up a BM (Bocken et al. 2014) and shall serve as the scaffolding for exploring the knowledge-based systemic relationship between BM and DIS: (1) Value proposition (the way to describe the product or service offered), (2) value creation and delivery (the way new business opportunities are created and realized), and (3) value capture (the way revenues are earned from the provision of goods or services).

3. Business models in systems of innovation

An increasing number of studies have explored the role of new BM in socio-technical sys-tems transitioning to sustainability (Boons and Lüdeke-Freund 2013; Bocken et al. 2014; Bocken and Short 2016; Schaltegger et al. 2012, 2016; Stubbs and Cocklin 2008). The purpose of the study at hand is to contribute to this quickly developing strand of literature by focusing on the intricate relationship between (changes in) the corporate innovation rationale (as embodied in BM) and the introduction of a dedication towards sustainability across the IS.

3.1 Methodology and data

To explore the literature on BM in the context of IS, a systematic literature review was carried out (Kivimaa et al. 2019; Petticrew and Roberts 2008). A scientific literature repository search based on keywords was followed by an expansion of the resulting articles to their reference lists and citations to identify further articles. It was explicitly searched for research contributions at the interface of BM and IS to gain insights into conceptual work on the co-evolutionary relation of the two. The selection of articles was completed in four steps: First, Scopus was browsed combining the search terms "business model" AND ("innovation system" OR "system of innovation") in the title-abstract-keywords fields, which yielded 74 items. The publication had to be (1) a peer-reviewed piece of academic work in the field of social science and business studies and (2) appearing in Scopus until April 4th 2019. Second, the respective article abstracts were carefully analyzed using the following exclusion criteria: (3) articles that used one of the search terms in a fundamentally different sense were excluded (i.e., the term "business model" needed to be used in the sense of design or architecture of the value creation, delivery, and capture employed by a firm (Teece 2010), whereas "innovation system" needed to refer back to the evolutionary framework as described by the fathers of the concept (e.g., Freeman 1987; Lundvall 1998); (4) articles that treated the two focal key concepts only superficially or separately without addressing their interplay were excluded from the analysis. Abstract reading resulted in a selection of 37 articles of which 22 were omitted based on reading the full papers (exclusion criteria 3 and 4), resulting in 15 articles feeding into the next step. This involved searching the reference lists of the selected 15 articles for earlier relevant contributions, also considering terms with similar meaning. This "backward citation snowballing" added two articles to the analysis. The "cited by" option in google scholar helped to carry out a "forward citation snowballing" for each of the 17 articles. The resulting list of citing articles was then scanned according to the above exclusion criteria. This offered an additional set of three new articles. The final list of articles considered in the systematic review contained 20. All the articles were read and coded.

3.2 Results

The way how business models operate in IS and how specific IS configurations and functions affect business models has been studied rarely since 2000, yet with growing intensity (four articles in the first half of the period compared to 16 in the second half). This approximately concurs with the period during which both of the concepts on their owns evolved, too (Klein and Sauer 2016; Massa et al. 2017). Most of the articles either refer to national IS (six articles) or to technological IS (six articles), while three studies explore regional IS, one a sec-toral IS, and the remainder just uses IS as a general approach without specifying a particular level of analysis. The types of industry studied vary greatly from low-tech fields (agriculture, gardening) to high-tech sectors (nanotechnology, biotechnology) and typical "transitions" industries such as the energy or the mobility sector. Nine publications – and since 2014 almost all of them — explicitly consider the contribution of BM to sustainability in IS. This observation and the fact that also the sustainability transitions community is increasingly discovering BM research (Bidmon and Knab 2018) confirms the general suitability of this con-cept to explore long-term systemic transitions from a micro perspective (Arevalo et al. 2011).

The notion of the term BM varies across the publications ranging from encompassing certain innovation and marketing strategies of the focal firm (Casper 2000), an "interplay between innovation strategies and resources" (Markard and Truffer 2008, p. 460), the organizational method of how the firm does business (Kalvet 2010), and how it creates, proposes, and/or captures value (Adams et al. 2016; Breznitz 2007; Grin et al. 2018; Hannon et al. 2015; Provance et al. 2011; Sarasini and Linder 2018). Not surprisingly, those authors who stress the value creation element of BM also appear to be the ones that ascribe to BM an active role in shaping the IS (Grin et al. 2018; Kishna et al. 2017; Yun et al. 2017). From this perspective, firms no longer only respond to the demands and interests of customers, policy, or competitors, but partake in defining what is of value.

About half of the selected studies describe the relation between BM and IS as being purely unidirectional, in that the authors do acknowledge the influence of different IS configurations and specifications on the emergence of certain BM but not vice versa. Some of those scholars, for instance, show how national institutional frameworks influence organizational structures and innovation strategies of individual firms (Ahlstrom et al. 2018; Casper 2000) or whole industries (Breznitz 2007). The other half of the set of publications either describe the co-evolutionary relationship of business models and IS (Adams et al. 2016; Bidmon and Knab 2018; Grin et al. 2018; Kishna et al. 2017; Planko et al. 2017; Sarasini and Linder 2018) or explicitly scrutinize different ways of how business models have been found to change the configuration or behavior of IS (Chiaroni et al. 2008; Markard and Truffer 2008; McCall 2013; Yun et al. 2017; Laukkanen and Patala 2014). Of this latter half, three studies (Laukkanen and Patala 2014; Markard and Truffer 2008; Planko et al. 2017) analyze the effect of BM according to their ability to drive IS processes, conceptualized by various scholars as functions of technological innovation systems (Bergek et al. 2008; Hekkert et al. 2007; Jacobsson and Bergek 2004). The functions offer a validated concept to break down overall IS performance and thus provide the theoretical foundation for empirical studies on the interface between the system and the actors. Markard and Truffer (2008), for example, consider the IS as composed of a variety of actor groups each contributing a specific set of resources and innovation activities necessary to fulfil the basic functions of the IS (knowledge creation, guidance of the search, supply of resources, the creation of positive externalities, and market formation). Although in their analysis the authors do not explicitly consider BM, they do come close to the concept by distinguishing three different corporate innovation strategy types: leading, learning, and image shaping. They conclude that firms adopting a leading innovation strategy can actively shape IS trajectories by (strongly) influencing all system functions, especially the direction of innovation (function: guidance of search). The other two studies that draw on systems functions (Laukkanen and Patala 2014; Planko et al. 2017) rather use the concept to describe different setups of IS while not further elaborating on the potential impact of business models on the fulfilment of the IS functions.

One recurrently identified role of firms in shaping IS via BM is that of system builders (Adams et al. 2016; Grin et al. 2018; Musiolik et al. 2012) or network and cluster creators/changers (Adams et al. 2016; Bidmon and Knab 2018; Kishna et al. 2017; Musiolik et al. 2012; Yun et al. 2017). Musolik and colleagues (2012) analyze the potential of individual organizations and formal networks to pool their abilities, influence, and endowments (referred to as resources) to strategically change the IS they are part of. In a literature review, Adams and colleagues (2016) find evidence that establishing more sustainable systems requires firms to proactively and radically change their philosophy and behavior, be creative, acquire new knowledge, redefine their purpose in society, and collaborate with peers, government, or NGO's. The latter requirement, i.e. to collaborate with others in order to increase business's impact on systemic outcomes, is brought up by six studies examined (Adams et al. 2016; Grin et al. 2018; McCall 2013; Musiolik et al. 2012; Planko et al. 2017; Sarasini and Linder 2018). A few interesting additional points are made by McCall (2013), who emphasizes the important role of collaboration in strengthening regional competitiveness, facilitating long-term planning among traditionally rather short-term considerations of single firms, and sharing and improving knowledge and competences. Further possibilities for businesses to shape IS include the creation of legitimacy and new markets (Grin et al. 2018; Planko et al. 2017), the creation and diffusion of knowledge relevant for systems change (including, e.g., consumer awareness campaigns or technical knowhow) (Chiaroni et al. 2008; Grin et al. 2018; McCall 2013; Planko et al. 2017), an open communication of alternative visions and paradigms (Grin et al. 2018; Laukkanen and Patala 2014), and the active destruction of current institutions (e.g., practices or regulations) (Grin et al. 2018; Yun et al. 2017).

4. Discussion: Business models for dedicated innovation systems

The literature on the potential impact of BM on the outcomes of IS is scarce and lacks concrete implications for research as well as for practice. The findings, however, do provide some general insights that help us better understand the potential of incumbents to introduce a dedication to sustainability into the entire IS by changing their BM. Against the conceptual background of DIS and the expected nature of BM in DIS, the following Section will discuss some of the findings and use them to conceptualize the elements of BM effective in DIS.

With reference to what has been deducted in Section 2, the introduction of a dedication in IS must be conceptualized as paradigmatic change through the alteration of trajectories. The literature analyzed suggests that IS influence the development and behavior of firms and are at the same time influenced by firms and other important subsystems, such as policy, science, and civil society, for that matter. Furthermore, it has been acknowledged that BM can be understood as an internal agreement of a firm how business is done. As such, BM of firms in an IS collectively co-create the base line of its trajectories, i.e. the problem definition (in the following referred to as Dosi I), the search heuristics (including what to search and where to search, in the following referred to as Dosi II), as well as the definition of what successful innovations are (in the following referred to as Dosi III). Businesses are thus capable of changing trajectories, for instance towards more sustainable modes of production, by in-novations in their BM. The research question posed at the outset of this article regarding how new BM could contribute to IS' dedication towards sustainability shall be answered by the following discussion of the results and the successive formulation of propositions to guide further research. The propositions are summarized in the subsequent Figure 6.

4.1 Value proposition

The fundamental philosophy behind a firm's business is reflected in the way how and in relation to whom it proposes the value it intends to create. A proactive shift in an incumbent firm's value proposition, e.g., away from pure profit maximization towards attending societal goals, must thus be regarded crucial for a firm intending to shape IS toward a dedication to sustainability. One possible expression of the willingness of a firm for such change is the exposition of innovation behavior that takes on a leading position within an industry. Albeit not in a sustainability context, Markard and Truffer (2008), for instance, substantiate the power of firms that adopt a leading innovation strategy to actively shape IS trajectories by (strongly) influencing all system functions, especially the direction of innovation (function: guidance of search). The empirical evidence points to the power of a changed value proposition to co-determine innovation trajectories – a potential with strong implications for the dissemination of a dedication to sustainability (see also Schaltegger et al. 2012). Some authors bring to mind that such change in value proposition relating to the core business logic are systemically most effective when undergone in collaboration with peers (Adams et al. 2016; Grin et al. 2018; Vargo et al. 2015), since "the ultimate objectives of sustainability lie beyond the individual capacity of firms to achieve" (Adams et al. 2016, p. 193).

Such BM innovation concerning the value proposition can be regarded the decisive link between firm-level dedication and its proliferation throughout DIS: it extends the decision-making basis for innovation strategies traditionally comprising cost, risk, margin, reputation, and innovative capability (Schaltegger et al. 2012) towards sustainability related value propositions ranging from the reduction of social and environmental harm to an increase of positive impact or solving societal challenges (Bocken et al. 2014). Following this and based on reflections of other scholars (Abdelkafi and Täuscher 2016; Miller Gaither et al. 2018; Schaltegger et al. 2012; Schaltegger and Burritt 2018), it seems that the degree of dedication of corporate sustainability endeavors, as reflected in bold value propositions, correlates with their potential effect on the dedication of the entire IS. Furthermore, the literature review has shown that open communication of such extended visions and paradigms is essential if IS are to be affected (Grin et al. 2018; Laukkanen and Patala 2014).

> Proposition 1: The value proposition of a BM that contributes to IS' dedication towards sustainability reflects a firm's commitment to sustainability related values and open communication of the same. This way a firm can act upon the IS wide problem definition (Dosi I: problem definition).

4.2 Value creation and delivery

It has been suggested that firms who make a conscious decision regarding the business opportunity they aim to seize by emphasizing the value creation and delivery element in their BM tend to have a strong influence on the evolution of the surrounding IS (Grin et al. 2018; Kishna et al. 2017; Yun et al. 2017). In fact, value creation is seen as being "at the heart of any business model" (Bocken et al. 2014, p. 43). In the knowledge-based context of alternative trajectories, changes in the operational aspects of business, such as the determination of key activities, resources, stakeholders, and technologies bear a special meaning. This is the part of the BM where decisions regarding the search heuristics for innovative activity become manifest. For an alternative innovation logic, it can, for instance, be fundamental to determine new sources of knowledge (outside the traditional expertise and suppliers) and to seek new collaboration partners. This could improve the success of the adoption of whole new value creation paradigms as provided, for instance, by a circular business model dis-rupting the traditional take-make-waste industrial paradigm (The Ellen MacArthur Foundation 2013). For a reduction of uncertainty in innovative endeavors for the value creation and delivery, literature recommends the involvement of the surrounding IS by networking with peers and other allies (Adams et al. 2016; Bidmon and Knab 2018; Kishna et al. 2017; Musiolik et al. 2012; Yun et al. 2017; McCall 2013; Planko et al. 2017; Sarasini and Linder 2018) to collaboratively align existing institutions (Grin et al. 2018; Yun et al. 2017) and to eventually reconfigure traditional supply chains (Bidmon and Knab 2018; Kishna et al. 2017; Laukkanen and Patala 2014; Musiolik et al. 2012; Sarasini and Linder 2018).

> Proposition 2: The value creation and delivery of a BM that contributes to IS' dedication towards sustainability draws on unprecedented linkages within the IS that provide access to new material, technological, and intellectual resources to reach higher levels of sustainability. This way a firm can act upon the diffusion of alternative directions of search across the IS to reach a critical mass (Dosi II: search heuristics).

4.3 Value capture

The role of a firm's change in its value capture for IS development has not been studied much. As long as value is interpreted in purely monetary terms, strategies for its capture can be expected to be a barrier rather than a driver of BM innovation towards DIS. Bocken and Short (2016) present a few cases where firms accommodate their sustainability engagement by charging a premium price for a more durable product and/or a better after-purchase service. Such BM innovation, albeit not paradigm-breaking in itself, indeed has the potential to instigate paradigmatic change in IS trajectories, for instance, by introducing the sufficiency principle to the logic of innovation. Such alternative trajectory could motivate firms to shift towards the provision of robust and long-lasting products, whereas consumers would become accustomed to an appreciation of high-quality products or to the benefits of consuming a service instead of owning a product. This would also change the definition of inno-vation success, and of progress for that matter. An innovative product would be defined, for instance, by a prolonged lifetime, easier accessibility, and smart appliance. Along these lines, the product service systems (PSS) hold some potential for dedicated BM innovation. A PSS has been defined as "a system of products, services, supporting networks and infrastruc-ture designed to be competitive, satisfy customer needs and have lower environmental impact than traditional business models" (Mont 2002, p. 239). The sustainable PSS concept offers an approach to value capture which takes account of the ability of producers to influence supply and/or consumption and thus altering trajectories. By offering services in connection to products, firms have the chance to persistently alter producer and consumer prac-tices in a way that reduces material input and increases utility (Mylan 2015). Accordingly, value capture innovations effective on the IS level have generally been found to require the capacity to involve a broad array of stakeholders (Adams et al. 2016; Laukkanen and Patala 2014), to educate consumers and suppliers (Grin et al. 2018), and thus create legitimacy and new markets (Planko et al. 2017; Grin et al. 2018).

> Proposition 3: The value capture of a BM that contributes to IS' dedication towards sustainability nurtures changed demands of consumers and suppliers who acknowledge sustainability principles, such as the superiority of quality and utility over quantity and ownership. This way a firm can act upon the general perception of innovation success among IS subsystems (Dosi III: definition of success).

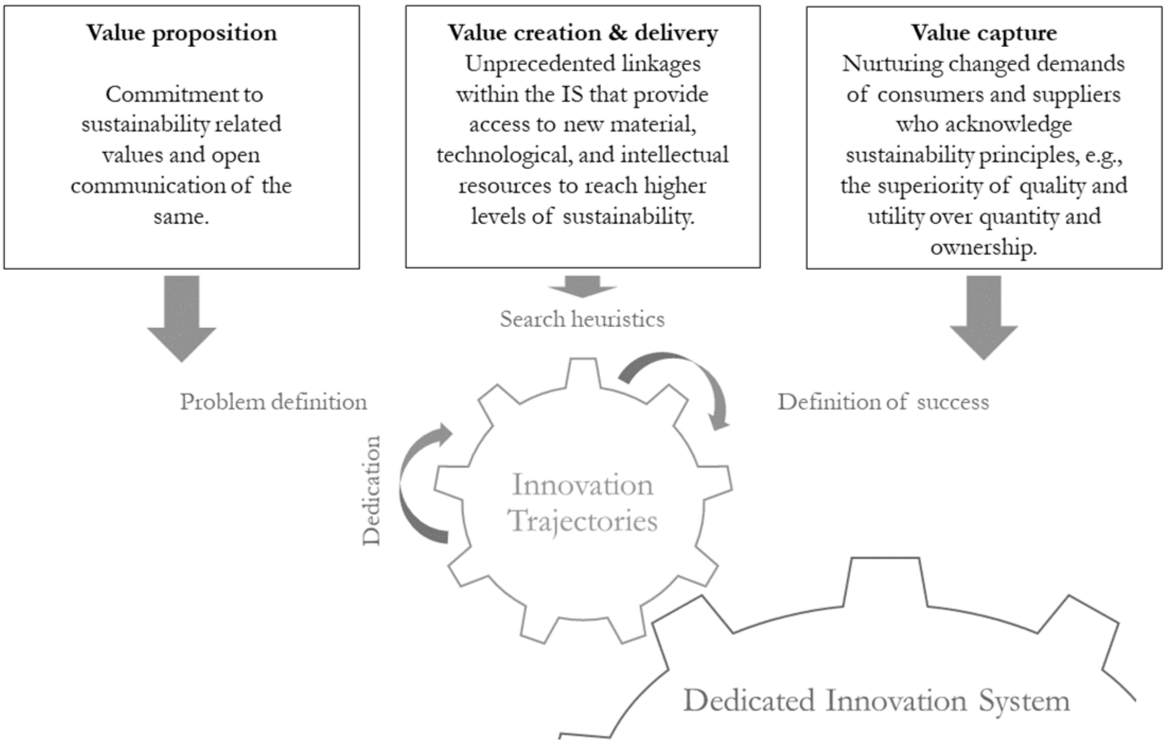

Figure 6 Overview of the elements of BM that contribute to IS's dedication towards sustainability via changed inno-vation trajectories.

5. Conclusion

It has been rightly argued that enterprises can only be considered sustainable when the system of which they are part is sustainable (Jennings and Zandbergen 1995). The resulting challenge for innovating firms is the acknowledgement that they cannot be expected to disrupt current trajectories in IS with their individual BM. This challenge, however, also entails a great opportunity: Based on the conviction that action is better than reaction and trusting that the transformation to sustainability will ultimately gain momentum, incumbents must be encouraged to actively shape the very trajectories they subordinate their innovation strategies to. To do so, they must innovate their BM by (1) redefining the 'relevant' problems and acknowledge their role in them; (2) opening up their search heuristics to gain the knowledge claimed necessary to solve these problems; and (3) propagating a common understanding of what 'success' means in this context. In this, firms will only be successful in collaboration with other IS actors (policy, consumers, civil society, entrepreneurs, competitors, academia). This is the only way they will be able to distribute the burden of risk, create legitimacy, and contribute to changing market paradigms. Conflating the findings of this study with how Bocken and colleagues frame sustainable BM (Bocken et al. 2014: 44), the following definition of a BM that contributes to IS's dedication towards sustainability or dedicated business model is proposed: 'A business model that significantly changes the logic of trajectories in the entire innovation system towards the principles of sustainability, through describing the way the organization and its value-network define, create, deliver, and capture value.'

The limitations of the study are twofold: firstly, the line of argument is based on a relatively small sample of literature reviewed which is owed to the fact that the co-evolutionary relation between BM and IS has not been researched much so far. The second limitation arises from a lack of explanatory power by a 'theory of the dedicated firm', which oversimplifies the motivation and driving mechanisms within firms to change their BM. Discussions of these issues with sustainability leaders of large incumbent enterprises reveal various ontological issues, such as, for instance, the heterogeneity within corporate management, uncertainties regarding future socio-political developments, as well as the volatility of societal values (see also Garst et al. 2019). These are some of the reasons why the paper comes up with rather generic implications that are not yet mature enough to guide dedicated management endeavors. To increase the practical relevance and to refine the conceptual base of BM innovation towards DIS will require further research, e.g., by testing the propositions posed above in empirical cases. Future conceptual research could inquire into the impact of BM on individual IS functions (building on Markard and Truffer 2008) or deploy the leverage points concept, which may help to identify most effective points of intervention in BM to impact IS trajectories towards a dedication to sustainability (Abson et al. 2017; Meadows 1999).

6. References

Abdelkafi N and Täuscher K (2016) Business Models for Sustainability From a System Dynam-ics Perspective. Organization & Environment 29(1): 74–96.

Abson DJ, Fischer J, Leventon J, et al. (2017) Leverage points for sustainability transformation. Ambio 46(1): 30–39.

Adams R, Jeanrenaud S, Bessant J, et al. (2016) Sustainability-oriented Innovation: A Systematic Review. International Journal of Management Reviews 18(2): 180–205.

Ahlstrom D, Yang X, Wang L, et al. (2018) A global perspective of entrepreneurship and innovation in China. Multinational Business Review 26(4): 302–318.

Alexander D and Blum V (2016) Ecological economics: A Luhmannian analysis of integrated reporting. Ecological Economics 129: 241–251.

Amit R and Zott C (2008) Creating value through business model innovation. In: MIT (ed.) Sloan Management Review: Top 10 lessons on strategy.

Andersen AD and Markard J (2017) Innovating incumbents and technological complementa-rities: How recent dynamics in the HVDC industry can inform transition theories. Working Papers on Innovation Studies.

Arevalo JA, Castelló I, Colle S de, et al. (2011) Introduction to the special issue: integrating sustainability in business models. Journal of Management Development 30(10): 941–954.

Ariely D, Bracha A and Meier S (2009) Doing Good or Doing Well? Image Motivation and Monetary Incentives in Behaving Prosocially. American Economic Review 99(1): 544–555.

Augenstein K and Palzkill A (2016) The Dilemma of Incumbents in Sustainability Transitions: A Narrative Approach. Administrative Sciences 6(1): 1.

Bergek A, Jacobsson S, Carlsson B, et al. (2008) Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy 37(3): 407–429.

Berkes F (2009) Evolution of co-management: role of knowledge generation, bridging organ-izations and social learning. Journal of environmental management 90(5): 1692–1702.

Bidmon CM and Knab SF (2018) The three roles of business models in societal transitions: New linkages between business model and transition research. Journal of Cleaner Pro-duction 178: 903–916.

Bocken N (2019) Sustainable Business Models. In: Leal Filho W, Azul A, Brandli L, Özuyar P and Wall T (eds) Decent Work and Economic Growth: Cham: Springer.

Bocken NMP, Rana P and Short SW (2015) Value mapping for sustainable business thinking. Journal of Industrial and Production Engineering 32(1): 67–81.

Bocken NMP and Short SW (2016) Towards a sufficiency-driven business model: Experiences and opportunities. Environmental Innovation and Societal Transitions 18: 41–61.

Bocken NMP, Short SW, Rana P, et al. (2014) A literature and practice review to develop sustainable business model archetypes. Journal of Cleaner Production 65: 42–56.

Boons F and Lüdeke-Freund F (2013) Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. Journal of Cleaner Production 45: 9–19.

Bossle MB, Dutra de Barcellos M, Vieira LM, et al. (2016) The drivers for adoption of eco-innovation. Journal of Cleaner Production 113: 861–872.

Breznitz D (2007) Industrial R&D as a national policy: Horizontal technology policies and industry-state co-evolution in the growth of the Israeli software industry. Research Policy 36(9): 1465–1482.

Casper S (2000) Institutional Adaptiveness, Technology Policy, and the Diffusion of New Business Models: The Case of German Biotechnology. Organization Studies 21(5): 887–914.

Chiaroni D, Chiesa V, De Massis A, et al. (2008) The knowledge-bridging role of Technical and Scientific Services in knowledge-intensive industries. International Journal Technolo-gy Management 41(3/4): 249–272.

Daimer S, Hufnagl M and Warnke P (2012) Challenge-oriented policy-making and innovation systems theory: Reconsidering systemic instruments. In: Koschatzky K (ed.) Innovation system revisited: Experiences from 40 years of Fraunhofer ISI research: Karlsruhe: Fraunhofer ISI, pp. 217–234.

Dangelico RM and Pujari D (2010) Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability. Journal of Business Ethics 95(3): 471–486.

Dantas E and Bell M (2011) The Co-Evolution of Firm-Centered Knowledge Networks and Capabilities in Late Industrializing Countries: The Case of Petrobras in the Offshore Oil Innovation System in Brazil. World Development 39(9): 1570–1591.

Dosi G (1982) Technological paradigms and technological trajectories: A suggested interpre-tation of the determinants and directions of technical change. Research Policy 11(3): 147–162.

Dosi G, Freeman C, Nelson RR, et al. (eds) (1988) Technical change and economic theory. London: Pinter.

Dyllick T and Muff K (2016) Clarifying the Meaning of Sustainable Business. Organization & Environment 29(2): 156–174.

Elkington J (2013) Enter the Triple Bottom Line. In: Elkington J (ed.) The Triple Bottom Line: Routledge, pp. 23–38.

Fiksel J (2003) Designing Resilient, Sustainable Systems. Environmental Science & Technology 37(23): 5330–5339.

Freeman C (1987) Technology Policy and Economic Performance: Lessons from Japan. London: Pinter.

Garst J, Blok V, Branzei O, et al. (2019) Toward a Value-Sensitive Absorptive Capacity Framework: Navigating Intervalue and Intravalue Conflicts to Answer the Societal Call for Health. Business & Society: 000765031987610.

Geels FW (2014) Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. Theory, Culture & Society 31(5): 21–40.

Gregersen B and Johnson B (1997) Learning Economies, Innovation Systems and European Integration. Regional Studies 31(5): 479–490.

Grin J, Hassink J, Karadzic V, et al. (2018) Transformative Leadership and Contextual Change. Sustainability 10(7): 2159.

Hahn T and Scheermesser M (2006) Approaches to corporate sustainability among German companies. Corporate Social Responsibility and Environmental Management 13(3): 150–165.

Hannon MJ, Foxon TJ and Gale WF (2015) 'Demand pull' government policies to support Product-Service System activity: the case of Energy Service Companies (ESCos) in the UK. Journal of Cleaner Production 108: 900–915.

Hansen T and Coenen L (2017) Unpacking resource mobilisation by incumbents for biorefin-eries: the role of micro-level factors for technological innovation system weaknesses. Technology Analysis & Strategic Management 29(5): 500–513.

Hart SL (1997) Beyond Greening: Strategies for a Sustainable World. Harvard Business Review 75(1).

Hawken P, Lovins AB and Hunter Lovins L (2013) Natural Capitalism. Routledge.

Hekkert MP, Suurs RAA, Negro SO, et al. (2007) Functions of innovation systems: A new ap-proach for analysing technological change. Technological Forecasting and Social Change 74(4): 413–432.

Jackson T (2009) Prosperity without Growth. Routledge.

Jacobsson S and Bergek A (2004) Transforming the energy sector: the evolution of technolog-ical systems in renewable energy technology. Industrial and Corporate Change 13(5): 815–849.

Jacobsson S and Bergek A (2011) Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environmental Innovation and Societal Tran-sitions 1(1): 41–57.

Jennings PD and Zandbergen PA (1995) Ecologically Sustainable Organizations: An Institu-tional Approach. Academy of Management Review 20(4): 1015–1052.

Kalvet T (2010) Business Models of the Largest Enterprises in a Small Country Context: The Case of Estonia. Administrative Culture 11(1): 128–151.

Kieft A, Harmsen R and Hekkert MP (2017) Interactions between systemic problems in inno-vation systems: The case of energy-efficient houses in the Netherlands. Environmental Innovation and Societal Transitions 24: 32–44.

Kishna M, Negro S, Alkemade F, et al. (2017) Innovation at the end of the life cycle: discontinuous innovation strategies by incumbents. Industry and Innovation 24(3): 263–279.

Kivimaa P, Boon W, Hyysalo S, et al. (2019) Towards a typology of intermediaries in sustainability transitions: A systematic review and a research agenda. Research Policy 48(4): 1062–1075.

Kivimaa P and Kern F (2016) Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Research Policy 45(1): 205–217.

Klein M and Sauer A (2016) Celebrating 30 years of innovation system research: What you need to know about innovation systems. Available at: https://www.econstor.eu/bitstream/10419/147305/1/871710765.pdf (accessed 20 April 2019).

Laukkanen M and Patala S (2014) Analysing barriers to sustainable business model innova-tions: Innovation systems approach. International Journal of Innovation Management 18(06).

Lindner R, Daimer S, Beckert B, et al. (2016) Addressing directionality: Orientation failure and the systems of innovation heuristic. Towards reflexive governance.

Loorbach D and Wijsman K (2013) Business transition management: exploring a new role for business in sustainability transitions. Journal of Cleaner Production 45: 20–28.

Lundvall B-ä and Johnson B (1994) The Learning Economy. Journal of Industry Studies 1(2): 23–42.

Lundvall B-Å (ed) (1992) National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. London: Pinter.

Lundvall B-Å (2007) National Innovation Systems - Analytical Concept and Development Tool. Industry and Innovation 14(1): 95–119.

Mahoney LS, Thorne L, Cecil L, et al. (2013) A research note on standalone corporate social responsibility reports: Signaling or greenwashing? Critical Perspectives on Accounting 24(4-5): 350–359.

Málovics G, Csigéné NN and Kraus S (2008) The role of corporate social responsibility in strong sustainability. The Journal of Socio-Economics 37(3): 907–918.

Markard J and Truffer B (2008) Actor-oriented analysis of innovation systems: exploring micro–meso level linkages in the case of stationary fuel cells. Technology Analysis & Strate-gic Management 20(4): 443–464.

Martins LL, Rindova VP and Greenbaum BE (2015) Unlocking the Hidden Value of Concepts: A Cognitive Approach to Business Model Innovation. Strategic Entrepreneurship Journal 9(1): 99–117.

Massa L, Tucci CL and Afuah A (2017) A Critical Assessment of Business Model Research. Academy of Management Annals 11(1): 73–104.

McCall T (2013) Transitions in Regional Development Policy: Comparative to Competitive Advantage. In: Kinnear S (ed.) Regional advantage and innovation: Achieving Australia's national outcomes. Heidelberg: Springer, pp. 73–98.

Meadows DH (1999) Leverage Points: Places to Intervene in a System. Hartland: The Sustainability Institute.

Meadows DH (2008) Thinking in systems: A primer. London: Earthscan.

Miller Gaither B, Austin L and Schulz M (2018) Delineating CSR and social change: Querying corporations as actors for social good. Public Relations Inquiry 7(1): 45–61.

Milne MJ and Gray R (2013) W(h)ither Ecology? The Triple Bottom Line, the Global Reporting Initiative, and Corporate Sustainability Reporting. Journal of Business Ethics 118(1): 13–29.

Mont OK (2002) Clarifying the concept of product–service system. Journal of Cleaner Produc-tion 10(3): 237–245.

Morioka SN, Bolis I, Evans S, et al. (2017) Transforming sustainability challenges into competitive advantage: Multiple case studies kaleidoscope converging into sustainable busi-ness models. Journal of Cleaner Production 167: 723–738.

Motohashi K (2005) University–industry collaborations in Japan: The role of new technology-based firms in transforming the National Innovation System. Research Policy 34(5): 583–594.

Murphy R (2012) Sustainability: A Wicked Problem. Sociologica 2.

Musiolik J, Markard J and Hekkert M (2012) Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. Technological Forecasting and Social Change 79(6): 1032–1048.

Mylan J (2015) Understanding the diffusion of Sustainable Product-Service Systems: Insights from the sociology of consumption and practice theory. Journal of Cleaner Production 97: 13–20.

Niosi J, Saviotti P, Bellon B, et al. (1993) National systems of innovation: In search of a workable concept. Technology in Society 15(2): 207–227.

Penna CC and Geels FW (2015) Climate change and the slow reorientation of the American car industry (1979–2012): An application and extension of the Dialectic Issue LifeCycle (DILC) model. Research Policy 44(5): 1029–1048.

Petticrew M and Roberts H (2008) Systematic reviews in the social sciences: A practical guide. John Wiley & Sons.

Planko J, Cramer J, Hekkert MP, et al. (2017) Combining the technological innovation systems framework with the entrepreneurs' perspective on innovation. Technology Analysis & Strategic Management 29(6): 614–625.

Porter ME and Kramer MR (2011) Creating Shared Value: How to reinvent capitalism - and unleash a wave of innovation and growth. Harvard Business Review.

Provance M, Donnelly RG and Carayannis EG (2011) Institutional influences on business model choice by new ventures in the microgenerated energy industry. Energy Policy 39(9): 5630–5637.

Pyka A (2017) Dedicated innovation systems to support the transformation towards sustainability: Creating income opportunities and employment in the knowledge-based digital bioeconomy. Journal of Open Innovation: Technology, Market, and Complexity 3(27): 1–18.

Sarasini S and Linder M (2018) Integrating a business model perspective into transition theory: The example of new mobility services. Environmental Innovation and Societal Transi-tions 27: 16–31.

Schaltegger S and Burritt R (2018) Business Cases and Corporate Engagement with Sustainability: Differentiating Ethical Motivations. Journal of Business Ethics 147(2): 241–259.

Schaltegger S, Lüdeke-Freund F and Hansen EG (2012) Business cases for sustainability: The role of business model innovation for corporate sustainability. International Journal of Innovation and Sustainable Development 6(2).

Schaltegger S, Lüdeke-Freund F and Hansen EG (2016) Business Models for Sustainability: A Co-Evolutionary Analysis of Sustainable Entrepreneurship, Innovation, and Transformation. Organization & Environment 29(3): 264–289.

Schlaile MP, Urmetzer S, Blok V, et al. (2017) Innovation systems for transformations to-wards sustainability? Taking the normative dimension seriously. Sustainability 9(12): 1–20.

Schweickart D (2009) Is sustainable capitalism an oxymoron? Perspectives on Global Devel-opment and Technology 8(2-3): 559–580.

Sharma A and Lee M-DP (2012) Sustainable Global Enterprise. Journal of Management Inquiry 21(2): 161–178.

Smith A, Stirling A and Berkhout F (2005) The governance of sustainable socio-technical transitions. Research Policy 34(10): 1491–1510.

Steffen W, Richardson K, Rockström J, et al. (2015) Planetary boundaries: Guiding human development on a changing planet. Science 347(6223).

Steward F (2012) Transformative innovation policy to meet the challenge of climate change: sociotechnical networks aligned with consumption and end-use as new transition arenas for a low-carbon society or green economy. Technology Analysis & Strategic Manage-ment 24(4): 331–343.

Stubbs W and Cocklin C (2008) Conceptualizing a "Sustainability Business Model". Organization & Environment 21(2): 103–127.

Swart RJ, Raskin P and Robinson J (2004) The problem of the future: sustainability science and scenario analysis. Global Environmental Change 14(2): 137–146.

Teece DJ (2010) Business Models, Business Strategy and Innovation. Long Range Planning 43(2-3): 172–194.

The Ellen MacArthur Foundation (2013) Circular Economy. Available at: https://www.ellenmacarthurfoundation.org/ (accessed 17 May 2019).

Tikkanen H, Lamberg J-A, Parvinen P, et al. (2005) Managerial cognition, action and the business model of the firm. Management Decision 43(6): 789–809.

Tödtling F and Trippl M (2018) Regional innovation policies for new path development – be-yond neo-liberal and traditional systemic views. European Planning Studies 26(9): 1779–1795.

Urmetzer S and Pyka A (2019) Innovation Systems for Sustainability. In: Leal Filho W, Azul A, Brandli L, Özuyar P and Wall T (eds) Decent Work and Economic Growth: Cham: Spring-er.

Urmetzer S, Schlaile M, Bogner K, et al. (2018) Exploring the Dedicated Knowledge Base of a Transformation towards a Sustainable Bioeconomy. Sustainability 10(6): 1694.

Vargo SL, Wieland H and Akaka MA (2015) Innovation through institutionalization: A service ecosystems perspective. Industrial Marketing Management 44: 63–72.

Voß J-P, Bauknecht D and Kemp R (eds) (2006) Reflexive governance for sustainable development. Cheltenham: Edward Elgar Publishing.

Waddock S and White A (2007) On Ceres, the GRI and Corporation 20/20: Sandra Waddock talks to Allen White. Journal of Corporate Citizenship 26: 38–42.

Warnke P, Koschatzky K, Dönitz E, et al. (2016) Opening up the innovation system framework towards new actors and institutions.

Weber KM and Truffer B (2017) Moving innovation systems research to the next level: towards an integrative agenda. Oxford Review of Economic Policy 33(1): 101–121.

Wells P and Nieuwenhuis P (2012) Transition failure: Understanding continuity in the automotive industry. Technological Forecasting and Social Change 79(9): 1681–1692.

Whiteman G, Walker B and Perego P (2013) Planetary Boundaries: Ecological Foundations for Corporate Sustainability. Journal of Management Studies 50(2): 307–336.

Yun JJ, Won D, Park K, et al. (2017) Growth of a platform business model as an entrepreneurial ecosystem and its effects on regional development. European Planning Studies 25(5): 805–826.

Chapter VI

Conclusion

VI. Conclusion

1. Discussion of the results

The studies presented in the course of my dissertation project address different knowledge-based gateways to sustainability transformations. As overarching theoretical concept, I consult the innovation systems (IS) framework, which allows for a technologically and geographically flexible reflection on interactive innovation processes based on knowledge creation, diffusion, and use among systemic actors, such as private businesses, state authorities, research institutions, and consumers. The normative dimension prerequisite for accommodating the requirement of sustainability into the search heuristics of innovating actors is accounted for by inquiries into their dedication to goals beyond economic efficiency and competitiveness. The aggregate of these dedicated goals determines the rate and direction of innovative activity in IS and is conceptualized as a new innovation paradigm. The results reveal that a consideration of dedicated transformation processes from an innovation paradigm perspective offers theoretical insights that can and should inform public, academic, as well as corporate sustainability endeavors. But just how does the innovation paradigm approach offer leverage on sustainability transformations?

With reference to this first part of my overarching research question, the following illuminating insights gained from the paradigmatic approach to sustainability transformations can be put on record: First, the consideration of innovation paradigms prompts research to probe and explicitly spell out the normative dimension of innovation processes in IS in comparison with those in dedicated IS. This is the initial and decisive step to understand and possibly inform actions aiming at deliberate change (Chapter II). The call for a move away from a pure *technocentric* perception towards a so called *sutaincentric* approach is not new. It has been brought forward by management scholars in an effort to improve the validity of organizational theory faced with the challenges of the late 20th century (Gladwin et al. 1995; Hahn et al. 2018). Equally, we can state that scientific inquiries into IS actors' dedication require that research on sustainability transformations "must shift from (…) exterior nuts and bolts to interior hearts and minds" (Gladwin et al. 1995, p. 899). To do so, the "interior" of the intended new innovation paradigm in comparison to the current techno-economic paradigm needs to be scrutinized. Understanding the characteristics of the dedicated knowledge base that informs this new paradigm in dedicated IS provides a valuable rationale for governance in sustainability transformations. It encourages policy makers to allow for more public participation and to take on a perspective of innovation policy that goes beyond purely technological perfection (Chapter III). Among many other things, this will require the reassessment and adaptation of curricula at different educational levels. For triggering a paradigmatic shift requires the skills to deeply reflect on and possibly reconsider personal assumptions, world views, and values by future decision makers (Chapter IV). Lastly, I offer insight into the relation of private businesses to altered innovation paradigms. It has been shown that by actively shaping the trajectories determining innovative activity in innovation paradigms firms can (with their "hearts and minds") contribute at a systemic level to sustainability transformations and thus be potentially more effective than by applying conventional corporate sustainability approaches (based on changes in the configuration of "nuts and bolts") (Chapter V). More concretely and with reference to the second part of my research question, what implications we can capture for enabling the introduction of a sustainable bioeconomy, I will discuss these findings in the following.

The minimal agreement on the world-wide variety of bioeconomy definitions (see: Chapter I, Section 4) obviously implies a change in the resource base from fossil to primarily biogenic sources (Hausknost et al. 2017). But if we aspire to assess the potential of the bioeconomy for fostering sustainability transformations, the understanding of the bioeconomy needs further scrutiny. In line with the results of Chapters II and III, the sustainable bioeconomy must be perceived as a contested and truly normative concept that cannot be achieved by the accumulation of techno-economic knowledge alone. To make the bioeconomy effective in addressing some of the systemic sustainability challenges, we must abandon the purely technological substitution agenda. I have thus proposed to view the sustainable bioeconomy as a new paradigm that determines the rate and the direction of innovation in a dedicated IS. Once the sustainable bioeconomy paradigm is effective, I argue, it will spontaneously trigger – amongst others – a change in resources used without having it imposed from authorities. On the basis of new knowledge on involved systems and common goals, the new direction will be legitimized and its urgency clear to the participants of the dedicated IS. This will help to spread out the responsibility for as well as the benefits from the transformation to private businesses, state authorities, research institutions, and consumers.

Looking closer into the perspective of innovation paradigms helps to explain why the purely resource-based and technocratic approach to bioeconomy would remain make-up on an otherwise unsustainable IS: It merely causes a change in one of the three pillars of an innovation paradigm (see Chapter I, Section 2) by additional techno-economic knowledge: the material and technologies as part of the solution space. Thus, the logic underlying innovation does not really change, since the selection of the relevant problems to be solved (problem space) as well as the selection of the natural principles relied upon (systemic principles) remain unchanged. Consequently, current supply chains, existing infrastructure, conventional research directions, and demand will likely render alternative materials, compounds, fuels, and processes uncompetitive (Correll et al. 2014; Tait and Wield 2019). An IS updated in techno-economic knowledge alone will be likely to keep supporting and using the present patterns of production and consumption with the effect that biogenic alternatives are either pushed to premium niches or require strict control by the state, for instance via incentives, regulations, and sanctions (IEA 2019; Kircher 2019; Carus et al. 2014). Furthermore, the expected positive effects on sustainability are likely to be reversed through overexploitation of natural resources or unexpected systemic feedback, such as the increase of greenhouse gas emissions due to changes in land-use following the heavily subsidized introduction of biofuels in the US (Searchinger et al. 2008; Kircher, 2019) (see Figure 7).

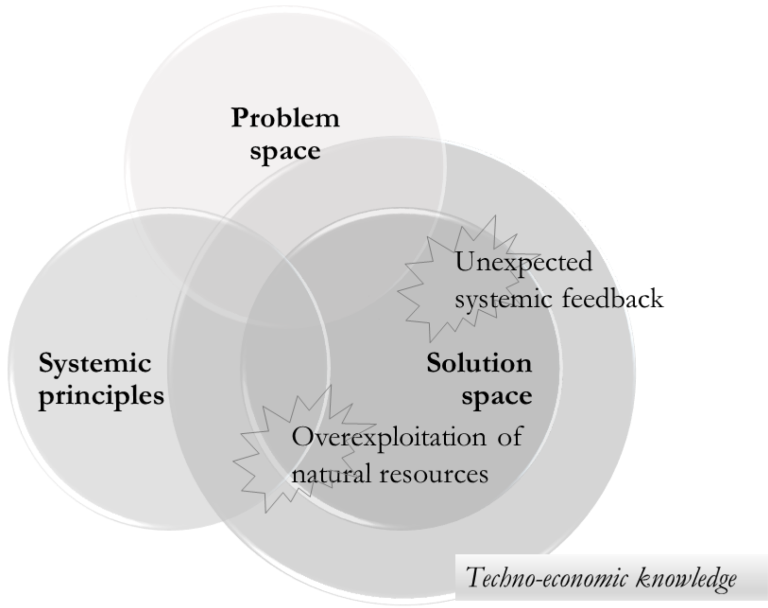

Figure 7 Imbalance of the innovation paradigm through the expansion of only the pillar of the solution space by techno-economic knowledge.

A lasting and impactful shift at the level of the innovation paradigm must thus become effective also in terms of changes in the problem space and in the selection of systemic principles. This requires knowledge beyond technological know-how and economic optimization. It calls for an update also in systems knowledge, normative knowledge, and transformative knowledge – the collective of knowledge types that are also referred to as dedicated knowledge. The characteristics of dedicated knowledge with regards to how it is created, diffused, and used in IS teach us that such update does not happen automatically. Instead, policies aiming at the introduction of a sustainable bioeconomy through a shift in the innovation paradigm require alternative strategies: Effective policy instruments must be designed to also extend the problem space by enhancing the awareness across the IS actors. This must involve improving the overall systems knowledge on current and future bio-based systems of production and consumption, mobilizing normative knowledge from within the societies, and creating overall bioeconomy literacy. The development and implementation of such strategies is far from trivial considering the stickiness, locality, context specificity, dispersal, and path dependence of dedicated knowledge – characteristics that necessitate awareness and care to be handled for successful knowledge management (Chapter III). Consequently, it is fundamental to understand that the paradigm shift towards the logic of a sustainable bioeconomy needs to be stimulated and attended by well-trained decision makers. They must comprehensively understand the art of adequate governance towards a sustainable bioeconomy. This involves, for instance, an enrichment of fundamental technical knowledge by good communication and decision-making skills as well as competence in shaping participatory political processes (Chapter IV). In such a way, future decision makers will be enabled to broaden the scope and the benefits of a sustainable bioeconomy to all participants in the IS.

And this is where I depart from perceiving the bioeconomy as an end in itself towards framing it in its entirety and with all consequences as a decisive innovation logic to achieve sustainability transformations. When all actors of an IS – including science, business, politics, and civil society – commonly reframe the present perception of the innovation challenge (the problem space) for sustainability as being qualitatively distinct from a purely techno-economic exercise, the solution space for innovations automatically shifts, too (see Figure 8, arrow to the right). Only then will the problem to be solved no longer be restricted to making existing technologies easier to handle, less harmful, or more efficient. Instead, innovators are given the responsibility to recognize their contribution to the larger problem and discover possibilities to address its alleviation. This demands them to step back and reappraise possible business models and technologies against the backdrop of the current normative requirements. If technologies are taken for what they are – a means for achieving a particular end (Dosi and Grazzi 2010) – they lose their absolute raison d'être as soon as the ends (the problem space) change. To come back to the example of innovation in the automobile sector: When the achievement of fast, safe, and convenient transportation is expanded by the attributes clean, inclusive, and reliable, investigation is needed about new means – entirely new mobility concepts that will most likely abandon the trajectory of ever more powerfully motorized vehicles for individual transport. By extending the problem space in such a way, inquiries in the direction of improved public transport, shared individual mobility, or even towards reducing the necessity for mobility (e.g., by facilitating telework, digitizing services, or improving accessibility of facilities) become possible. This "new common sense for innovation and behaviour" (Perez 2016, p. 200) relocates innovation processes from the relatively narrow portfolio of individual innovators to a multitude of stakeholders. And, of course, it surpasses the narrow understanding of a bio-based economy. Seen from a systemic perspective, however, this is unavoidable. And it will prompt, among others, the demand for integrated solutions that favor, for instance, the renewability of resources, the avoidance of carbon dioxide, digital solutions, and the principle of circularity, while dismissing emission intensive technologies and single-use, fossil materials.

On the corporate level, the framing of a sustainable bioeconomy as a new innovation paradigm must involve a fundamental change of the intra-organizational decision making basis. Traditionally proposed values underlying traditional business models, such as cost, risk, margin, reputation, and innovative capability, are extended towards the substitution or reduction of (fossil) carbon dioxide emissions, renewability of resources, and the reusability of products. For this courageous step, firms will have to seek collaboration partners among the other IS actors (policy, consumers, civil society, entrepreneurs, competitors, academia). They will be rewarded by the opportunity to actively shape changing innovation paradigms. This will, in turn, directly determine key activities within the firms and quasi automatically prompt decisions such as, for instance, preferring renewable inputs over fossil ones, selecting collaboration partners knowledgeable and supportive in circular production, or consulting local initiatives for improving the social impact on site and elsewhere (Chapter V). In this paradigmatic context, the individual actions within firms will have the potential to stimulate a whole new direction of innovative activity in peers and in more distant technological fields and sectors (Perez 2016).

The shifts in these two pillars of a new innovation paradigm, in the solution space and in the problem space, can already be expected to actuate a quite powerful turn towards a dedication to sustainability in IS. However, only additional changes in the third pillar of innovation paradigms will promise a lasting effect on IS. It is referred to as a shift in the selection of the natural principles (Dosi 1982) or as a reconsideration of the systemic principles currently at work in present IS and their associated socio-ecological systems (see Chapter I, Section 3). In the context of a paradigmatic change towards a sustainable knowledge-based bioeconomy, this must encompass, for instance, a fundamental change in the appreciation of resources in general to achieve a dedication to the total avoidance of waste anywhere in the IS. Another principle must be the acknowledgement that a tremendous reduction of industrialized societies' carbon footprint is unavoidable due to our obligations towards global and future societies. A change in this last pillar of innovation paradigms demands decision makers in bioeconomy transformations to be prepared to 'think outside the box' in the sense that they are able to depart from conventional thinking determined by existing paradigms (Chapter IV). This will, in turn, inspire the creation of new normative knowledge by influencing the perception of urgency of the relevant problems thus expanding the problem space (see Figure 8, arrow to the left).

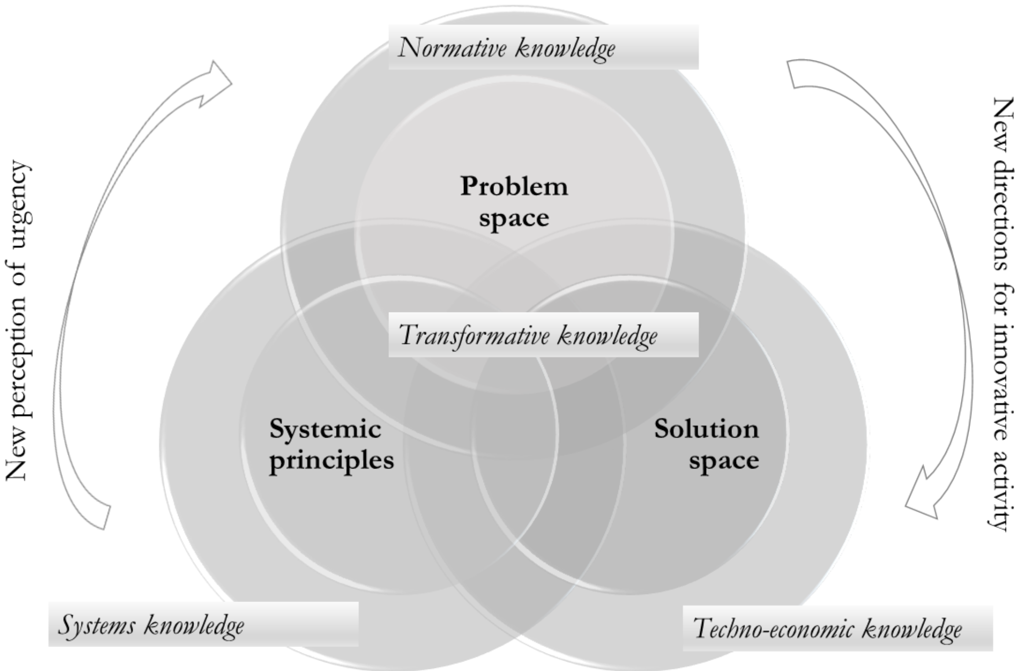

Figure 8 The knowledge-based processes at work in changing all three pillars of an innovation paradigm

What follows from my research in the course of this dissertation is that lasting change must happen on the paradigmatic level. Only if IS achieve a self-sustaining dedication to solving systemic sustainability challenges, can the powerful mechanisms at work in economic development be instrumentalized for sustainability transformations. It is important to acknowledge that such a shift in innovation paradigms is possible but will by no means happen automatically. By building on the example of a sustainable knowledge-based bioeconomy as an aspired new innovation paradigm in IS, I could show that shifting paradigms requires united efforts by all IS actors: Researchers must ask themselves different questions, policy makers must engage in different strategies, educators must teach different skills, businesses must create different value, consumers must demand different services. These united efforts have been framed earlier on as dedication to a sustainable bioeconomy and comprise the creation, diffusion, and use of dedicated knowledge. The different components of this knowledge base will become effective in changing the three pillars of current innovation paradigms: the problem space, the solution space, and the selection of systemic principles at work. These changes will activate new innovation processes by changing the search heuristics, for instance in offering new directions for innovative activity or in altering the perception of urgency to solve specific problems (see Figure 8).

2. Closure

Just like Greta (Thunberg 2018), I am convinced that we cannot save the world unless we change the rules according to which our economic systems play. My contribution to this change of rules is a theoretical discussion of a potentially powerful new gateway to change. With the proposition of taking on a paradigmatic perspective on sustainability transitions in general and on the introduction of a sustainable knowledge-based bioeconomy in particular, I intend to inspire new research, new policies, new curricula, as well as new corporate strategies.

On top of the limitations of each one of the studies I present in each Chapter, I must admit that there are two general shortcomings of my approach: First, by employing the IS framework in a very general way, I have missed the opportunity to take account of the incredibly diverse manifestations of configurations and mechanisms at work in IS at different geographical locations and scales, in different sectoral domains, as well as concerning different technologies. This is particularly problematic in the case of the bioeconomy, which is not restricted to any specific sector or technology and which will have to be established and implemented in a variety of ways and very well adapted to geographical, socio-economic, and cultural circumstances present in the respective regions (Urmetzer and Pyka 2017). At the present stage, my research is situated at a very theoretical level. But I am eager to explore the practical implications in different geographical and cultural contexts in the future. Second, my critique of current bioeconomy policies is very general and lacks an empirical examination of strategies declared, policy instruments applied, and effects generated. I apologize for not taking appropriate account of movements into the right direction, such as the installation of the bioeconomy stakeholders panel by the European Union (The European Bioeconomy Stakeholders Panel 2017), the funding program Bioeconomy as Societal Change of the German government (Federal Ministry of Education and Research 2014), or transformative elements in the measures stipulated by the very recent bioeconomy strategy of the state of Baden-Württemberg (UM and MLR 2019). More empirical research, ideally based on a variety of case studies (Sanz-Hernández et al. 2019), could enlighten the black box of bioeconomy policy effectiveness and help to translate some of my findings to practice to increase its potential to better inform bioeconomy governance (Devaney et al. 2017) and eventually make the sustainable knowledge-based bioeconomy a reality.

3. References

Abson, D.J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., Wehrden, H. von, Abernethy, P., Ives, C.D., Jager, N.W. and Lang, D.J. (2017), "Leverage points for sustainability transformation", Ambio, Vol. 46 No. 1, pp. 30–39.

Abson, D.J., Wehrden, H. von, Baumgärtner, S., Fischer, J., Hanspach, J., Härdtle, W., Heinrichs, H., Klein, A.M., Lang, D.J., Martens, P. and Walmsley, D. (2014), "Ecosystem services as a boundary object for sustainability", Ecological Economics, Vol. 103, pp. 29–37.

Anderson, M.L. and Auffhammer, M. (2014), "Pounds That Kill: The External Costs of Vehicle Weight", The Review of Economic Studies, Vol. 81 No. 2, pp. 535–571.

Banister, D. (2015), "Great Cities and Their Traffic: Michael Thomson Revisited", Built Environment, Vol. 41 No. 3, pp. 435–446.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008), "Analyzing the functional dynamics of technological innovation systems. A scheme of analysis", Research Policy, Vol. 37 No. 3, pp. 407–429.

Besi, M. de and McCormick, K. (2015), "Towards a Bioeconomy in Europe: National, Regional and Industrial Strategies", Sustainability, Vol. 7 No. 8, pp. 10461–10478.

Blok, V., Gremmen, B. and Wesselink, R. (2016), "Dealing with the Wicked problem of Sustainability: The Role of Individual Virtuous Competence", Business and Professional Ethics Journal, Vol. 34, pp. 297–327.

Borén, S., Nurhadi, L., Ny, H., Robèrt, K.-H., Broman, G. and Trygg, L. (2017), "A strategic approach to sustainable transport system development – Part 2: the case of a vision for electric vehicle systems in southeast Sweden", Journal of Cleaner Production, Vol. 140, pp. 62–71.

Bugge, M., Hansen, T. and Klitkou, A. (2016), "What Is the Bioeconomy? A Review of the Literature", Sustainability, Vol. 8 No. 7.

Cajaiba-Santana, G. (2014), "Social innovation: Moving the field forward. A conceptual framework", Technological Forecasting and Social Change, Vol. 82, pp. 42–51.

Carus, M., Carrez, D., Kaeb, H., Ravenstijn, J. and Venus, J. (2011), "Level Playing Field for Bio-based Chemistry and Materials. Policy Paper on Bio-Based Economy in the EU", Nova Institute, pp. 4–18.

Carus, M., Eder, A. and Beckmann, J. (2014), "GreenPremium Prices Along the Value Chain of Bio-based Products", nova paper on bio-based economy, Vol. 3.

Coenen, L., Benneworth, P. and Truffer, B. (2012), "Toward a spatial perspective on sustainability transitions", Research Policy, Vol. 41 No. 6, pp. 968–979.

Conklin, J. (2006), "Wicked problems and social complexity", in Conklin, J. (Ed.), Dialogue mapping: Building shared understanding of wicked problems, 1st ed., John Wiley & Sons, Chichester, pp. 3–40.

Correll, D., Suzuki, Y. and Martens, B.J. (2014), "Logistical supply chain design for bioeconomy applications", Biomass and Bioenergy, Vol. 66, pp. 60–69.

Daimer, S., Hufnagl, M. and Warnke, P. (2012), "Challenge-oriented policy-making and innovation systems theory: Reconsidering systemic instruments", in Koschatzky, K. (Ed.), Innovation system revisited: Experiences from 40 years of Fraunhofer ISI research, Fraunhofer ISI, Karlsruhe, pp. 217–234.

D'Amato, D., Droste, N., Allen, B., Kettunen, M., Lähtinen, K., Korhonen, J., Leskinen, P., Matthies, B.D. and Toppinen, A. (2017), "Green, circular, bio economy: A comparative analysis of sustainability avenues", Journal of Cleaner Production, Vol. 168, pp. 716–734.

David, P.A. (1985), "Clio and the Economics of QWERTY", The American Economic Review, Vol. 75 No. 2, pp. 332–337.

Devaney, L., Henchion, M. and Regan, Á. (2017), "Good Governance in the Bioeconomy", EuroChoices, Vol. 16 No. 2, pp. 41–46.

Dewald, U. and Fromhold-Eisebith, M. (2015), "Trajectories of sustainability transitions in scale-transcending innovation systems: The case of photovoltaics", Environmental Innovation and Societal Transitions, Vol. 17, pp. 110–125.

Dosi, G. (1982), "Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change", Research Policy, Vol. 11 No. 3, pp. 147–162.

Dosi, G., Freeman, C., Nelson, R.R., Silverberg, G. and Soete, L. (Eds.) (1988), Technical change and economic theory, Pinter, London.

Dosi, G. and Grazzi, M. (2010), "On the nature of technologies: knowledge, procedures, artifacts and production inputs", Cambridge Journal of Economics, Vol. 34 No. 1, pp. 173–184.

EC (2018), A sustainable bioeconomy for Europe: Strengthening the connection between economy, society and the environment: updated bioeconomy strategy, Luxembourg, available at: https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf#view=fit&pagemode=none (accessed 17 December 2018).

Edquist, C. (Ed.) (1997), Systems of Innovation: Technologies, Institutions, and Organizations, Pinter, London, UK.

Edquist, C. (2005), "Systems of Innovation. Perspectives and Challenges", in Fagerberg, J., Mowery, D.C. and Nelson, R.R. (Eds.), The Oxford Handbook of Innovation, Oxford University Press, Oxford, UK, pp. 181–208.

Federal Ministry for Food and Agriculture (2014), Nationale Politikstrategie Bioökonomie: Nachwachsende Ressourcen und biotechnologische Verfahren als Basis für Ernährung, Industrie und Energie, Berlin, available at: https://www.bmel.de/SharedDocs/Downloads/Broschueren/BioOekonomiestrategie.pdf?__blob=publicationFile (accessed 22 July 2019).

Federal Ministry of Education and Research (2014), Bioeconomy as societal change: Konzept zur Förderung sozial- und wirtschaftswissenschaftlicher Forschung für die Bioökonomie, Berlin, available at: https://www.bmbf.de/pub/Biooekonomie_als_gesellschaftlicher_Wandel.pdf (accessed 27 November 2019).

Fischer, J. and Riechers, M. (2019), "A leverage points perspective on sustainability", People and Nature, Vol. 1 No. 1, pp. 115–120.

Folke, C., Hahn, T., Olsson, P. and Norberg, J. (2005), "Adaptive governance of social-ecological systems", Annual Review of Environment and Resources, Vol. 30, pp. 441–473.

Frantzeskaki, N., Loorbach, D. and Meadowcroft, J. (2012), "Governing societal transitions to sustainability", International Journal of Sustainable Development, Vol. 15 No. ½, pp. 19–36.

Freeman, C. (1987), Technology Policy and Economic Performance: Lessons from Japan, Pinter, London.

Freeman, C. (1991), "Innovation, Changes of Techno-Economic Paradigm and Biological Analogies in Economics", Revue économique, Vol. 42 No. 2, p. 211.

Freeman, C. (2002), "Continental, national and sub-national innovation systems—complementarity and economic growth", Research Policy, Vol. 31 No. 2, pp. 191–211.

Geels, F.W. (2004), "From sectoral systems of innovation to socio-technical systems", Research Policy, Vol. 33 No. 6-7, pp. 897–920.

Gladwin, T.N., Kennelly, J.J. and Krause, T.-S. (1995), "Shifting Paradigms for Sustainable Development: Implications for Management Theory and Research", The Academy of Management Review, Vol. 20 No. 4, pp. 874–907.

Gregersen, B. and Johnson, B. (1997), "Learning Economies, Innovation Systems and European Integration", Regional Studies, Vol. 31 No. 5, pp. 479–490.

Grin, J., Rotmans, J. and Schot, J. (2010), Transitions to sustainable development: New directions in the study of long term transformative change, Routledge, New York.

Hahn, T., Figge, F., Pinkse, J. and Preuss, L. (2018), "A Paradox Perspective on Corporate Sustainability: Descriptive, Instrumental, and Normative Aspects", Journal of Business Ethics, Vol. 148 No. 2, pp. 235–248.

Hausknost, D., Schriefl, E., Lauk, C. and Kalt, G. (2017), "A Transition to Which Bioeconomy? An Exploration of Diverging Techno-Political Choices", Sustainability, Vol. 9 No. 4.

Heimann, T. (2019), "Bioeconomy and SDGs: Does the Bioeconomy Support the Achievement of the SDGs?", Earth's Future, Vol. 7 No. 1, pp. 43–57.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S. and Smits, R.E.H.M. (2007), "Functions of innovation systems. A new approach for analysing technological change", Technological Forecasting and Social Change, Vol. 74 No. 4, pp. 413–432.

Hulme, M. (2009), Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity, Cambridge University Press, Cambridge.

IEA (2019), "Biofuels for Transport", available at: https://www.iea.org/tcep/transport/biofuels/ (accessed 12 December 2019).

Jacobsson, S. and Bergek, A. (2011), "Innovation system analyses and sustainability transitions: Contributions and suggestions for research", Environmental Innovation and Societal Transitions, Vol. 1 No. 1, pp. 41–57.

Jacobsson, S., Sandén, B. and Bångens, L. (2004), "Transforming the Energy System — the Evolution of the German Technological System for Solar Cells", Technology Analysis & Strategic Management, Vol. 16 No. 1, pp. 3–30.

Kircher (2019), "Bioeconomy: Markets, Implications, and Investment Opportunities", Economies, Vol. 7 No. 3, p. 73.

Kircher, M. (2012), "The transition to a bio-economy: emerging from the oil age", Biofuels, Bioproducts and Biorefining, Vol. 6 No. 4, pp. 369–375.

Kivimaa, P. and Kern, F. (2016), "Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions", Research Policy, Vol. 45 No. 1, pp. 205–217.

Klein, M. and Sauer, A. (2016), "Celebrating 30 years of innovation system research: What you need to know about innovation systems", available at: https://www.econstor.eu/bitstream/10419/147305/1/871710765.pdf (accessed 20 April 2019).

Knight, F.H. (1921), Risk, uncertainty and profit, Hart, Schaffner and Marx, New York.

Kuhn, T.S. (1962), The structure of scientific revolutions, The University of Chicago Press, Chicago.

Leemans, R., van Amstel, A., Battjes, C., Kreileman, E. and Toet, S. (1996), "The land cover and carbon cycle consequences of large-scale utilizations of biomass as an energy source", Global Environmental Change, Vol. 6 No. 4, pp. 335–357.

Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. and Schellnhuber, H.J. (2008), "Tipping elements in the Earth's climate system", Proceedings of the National Academy of Sciences of the United States of America, Vol. 105 No. 6, pp. 1786–1793.

Levidow, L., Birch, K. and Papaioannou, T. (2013), "Divergent Paradigms of European Agro-Food Innovation", Science, Technology, & Human Values, Vol. 38 No. 1, pp. 94–125.

Lewandowski, I. (2015), "Securing a sustainable biomass supply in a growing bioeconomy", Global Food Security, Vol. 6, pp. 34–42.

Li, S. (2012), "Traffic safety and vehicle choice: quantifying the effects of the 'arms race' on American roads", Journal of Applied Econometrics, Vol. 27 No. 1, pp. 34–62.

Lindner, R., Daimer, S., Beckert, B., Heyen, N., Koehler, J., Teufel, B., Warnke, P. and Wydra, S. (2016), Addressing directionality: Orientation failure and the systems of innovation heuristic. Towards reflexive governance, Fraunhofer ISI Discussion Papers Innovation Systems and Policy Analysis, Karlsruhe, available at: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccp/innovation-systems-policy-analysis/2016/discussionpaper_52_2016.pdf.

Lundvall, B.-Å. (Ed.) (1992), National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, Pinter, London.

Markard, J., Raven, R. and Truffer, B. (2012), "Sustainability transitions. An emerging field of research and its prospects", Research Policy, Vol. 41 No. 6, pp. 955–967.

McCormick, K. and Kautto, N. (2013), "The bioeconomy in Europe: An overview", Sustainability, Vol. 5 No. 6, pp. 2589–2608.

Meadows, D.H. (1999), Leverage Points: Places to Intervene in a System, The Sustainability Institute, Hartland.

Meadows, D.H. (2008), Thinking in systems: A primer, Earthscan, London.

Murphy, R. (2012), "Sustainability: A Wicked Problem", Sociologica, Vol. 2.

Næss, P. and Vogel, N. (2012), "Sustainable urban development and the multi-level transition perspective", Environmental Innovation and Societal Transitions, Vol. 4, pp. 36–50.

Nelson, R.R. (Ed.) (1993), National innovation systems: A comparative analysis, Oxford University Press, London, UK.

O'Brien, K. and Sygna, L. (2018), "Transformations in socio-ecological systems", in EEA Report No 25/2017: Perspectives on transitions to sustainability, Publications Office of the European Union, Luxembourg, pp. 28–44.

OECD (2009), The Bioeconomy to 2030 -Designing a policy agenda: Main Findings and Policy Conclusions, available at: https://www.oecd.org/futures/long-termtechnologicalsocietalchallenges/42837897.pdf (accessed 19 November 2019).

Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., Hurlbert, M., Anderton, K., Sethi, M. and Barau, A. (2017), "Exploring the governance and politics of transformations towards sustainability", Environmental Innovation and Societal Transitions, Vol. 24, pp. 1–16.

Perez, C. (2010), "Technological revolutions and techno-economic paradigms", Cambridge Journal of Economics, Vol. 34 No. 1, pp. 185–202.

Perez, C. (2016), "Capitalism, technology and a green global golden age: The role of history in helping to shape the future", in Jacobs, M. and Mazzucato, M. (Eds.), Rethinking capitalism: Economics and policy for sustainable and inclusive growth, Wiley-Blackwell, Oxford, pp. 191–217.

Pfau, S.F., Hagens, J.E., Dankbaar, B. and Smits, A.J. (2014), "Visions of sustainability in bioeconomy research", Sustainability, Vol. 6 No. 3, pp. 1222–1249.

ProClim, C. (1997), Research on Sustainability and Global Change – Visions in Science Policy by Swiss Researchers, Bern, available at: https://naturalsciences.ch/uuid/3df3d017-7928-56dd-864f-63904096048d?r=20170706115333_1499300833_97d18713-8a31-5e4b-bea2-f1f63980ae97 (accessed 22 July 2019).

Pyka, A. (2017), "Dedicated innovation systems to support the transformation towards sustainability: Creating income opportunities and employment in the knowledge-based digital bioeconomy", Journal of Open Innovation: Technology, Market, and Complexity, Vol. 3 No. 27, pp. 1–18.

Pyka, A., Bogner, K. and Urmetzer, S. (2019), "Productivity Slowdown, Exhausted Opportunities and the Power of Human Ingenuity—Schumpeter Meets Georgescu-Roegen", Journal of Open Innovation: Technology, Market, and Complexity, Vol. 5 No. 3, p. 39.

Raworth, K. (2017), Doughnut economics: Seven ways to think like a 21st-century economist, Chelsea Green Publishing., White River Junction, Vermont.

Reyer, C.P.O., Brouwers, N., Rammig, A., Brook, B.W., Epila, J., Grant, R.F., Holmgren, M., Langerwisch, F., Leuzinger, S., Lucht, W., Medlyn, B., Pfeifer, M., Steinkamp, J., Vanderwel, M.C., Verbeeck, H. and Villela, D.M. (2015), "Forest resilience and tipping points at different spatio-temporal scales: approaches and challenges", Journal of Ecology, Vol. 103 No. 1, pp. 5–15.

Ripple, W.J., Wolf, C., Newsome, T.M., Barnard, P. and Moomaw, W.R. (2019), "World Scientists' Warning of a Climate Emergency", BioScience, Vol. 5.

Rittel, H.W. and Webber, M.M. (1973), "Dilemmas in a general theory of planning", Policy Sciences, Vol. 4 No. 2, pp. 155–169.

Sanz-Hernández, A., Esteban, E. and Garrido, P. (2019), "Transition to a bioeconomy: Perspectives from social sciences", Journal of Cleaner Production, Vol. 224, pp. 107–119.

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C. and Walker, B. (2001), "Catastrophic Shifts in Ecosystems", Nature, Vol. 413.

Schlaile, M. and Urmetzer, S. (2019), "Transitions to sustainable development", in Leal Filho, W., Azul, A., Brandli, L., Özuyar, P. and Wall, T. (Eds.), Decent Work and Economic Growth, Encyclopedia of the UN Sustainable Development Goals, Springer, Cham.

Schlaile, M.P., Urmetzer, S., Blok, V., Andersen, A.D., Timmermans, J., Mueller, M., Fagerberg, J. and Pyka, A. (2017), "Innovation systems for transformations towards sustainability? Taking the normative dimension seriously", Sustainability, Vol. 9 No. 12, pp. 1–20.

Schot, J. and Steinmueller, W.E. (2018), "Three frames for innovation policy: R&D, systems of innovation and transformative change", Research Policy, Vol. 47 No. 9, pp. 1554–1567.

Schumpeter, J.A. (1943), Capitalism. Socialism and Democracy., Routledge, New York, NY, United States.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D. and Yu, T.-H. (2008), "Use of US Croplands for biofuels increases greenhouse gases through emissions from land-use change", Science, Vol. 319 No. 5867, pp. 1238–1240.

Seyfang, G. and Haxeltine, A. (2012), "Growing Grassroots Innovations: Exploring the Role of Community-Based Initiatives in Governing Sustainable Energy Transitions", Environment and Planning C: Government and Policy, Vol. 30 No. 3, pp. 381–400.

Simon, H.A. (1972), "Theories of Bounded Rationality", in McGuire, C.B. and Radner, R. (Eds.), Decision and Organization, North-Holland, pp. 161–176.

Smith, A., Voß, J.-P. and Grin, J. (2010), "Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges", Research Policy, Vol. 39 No. 4, pp. 435–448.

Staffas, L., Gustavsson, M. and McCormick, K. (2013), "Strategies and policies for the bioeconomy and bio-based economy: An analysis of official national approaches", Sustainability, Vol. 5 No. 6, pp. 2751–2769.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., Vries, W. de, Wit, C.A. de, Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B. and Sörlin, S. (2015), "Planetary boundaries: Guiding human development on a changing planet", Science, Vol. 347 No. 6223.

Stenmark, L.L. (2015), "Storytelling and Wicked Problems: Myths of the Absolute and Climate Change", Zygon®, Vol. 50 No. 4, pp. 922–936.

Tait, J. and Wield, D. (2019), "Policy support for disruptive innovation in the life sciences", Technology Analysis & Strategic Management, Vol. 57 No. 1, pp. 1–13.

The European Bioeconomy Stakeholders Panel (2017), European Bioeconomy Stakeholders Manifesto, Brussels, available at: http://ec.europa.eu/research/bioeconomy/pdf/european_bioeconomy_stakeholders_manifesto.pdf (accessed 25 July 2019).

The White House (2012), National Bioeconomy Blueprint, Washington D.C., available at: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf (accessed 19 November 2019).

Thunberg, G. (2018), The disarming case to act right now on climate change: TEDxStockholm.

Tödtling, F. and Trippl, M. (2018), "Regional innovation policies for new path development – beyond neo-liberal and traditional systemic views", European Planning Studies, Vol. 26 No. 9, pp. 1779–1795.

UM and MLR, Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector and Baden-Württemberg Ministry of the Rural Areas and Consumer Protection (2019), Landesstrategie Nachhaltige Bioökonomie Baden-Württemberg, available at: https://um.baden-wuerttemberg.de/fileadmin/redaktion/m-um/intern/Dateien/Dokumente/6_Wirtschaft/Landesstrategie_Nachhaltige_Biooekonomie.pdf (accessed 27 November 2019).

UN (2015), Transforming our world: The 2030 Agenda for Sustainable Development, New York, available at: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (accessed 25 July 2019).

Unruh, G.C. (2000), "Understanding carbon lock-in", Energy Policy, Vol. 28 No. 12, pp. 817–830.

Urmetzer, S. and Pyka, A. (2017), "Varieties of Knowledge-Based Bioeconomies", in Dabbert, S., Lewandowski, I., Weiss, J. and Pyka, A. (Eds.), Knowledge-Driven Developments in the Bioeconomy: Technological and Economic Perspectives, Vol. 2, 1st ed., Springer, Cham, pp. 57–82.

Urmetzer, S. and Pyka, A. (2019), "Innovation Systems for Sustainability", in Leal Filho, W., Azul, A., Brandli, L., Özuyar, P. and Wall, T. (Eds.), Decent Work and Economic Growth, Encyclopedia of the UN Sustainable Development Goals, Springer, Cham.

Urmetzer, S., Schlaile, M., Bogner, K., Mueller, M. and Pyka, A. (2018), "Exploring the Dedicated Knowledge Base of a Transformation towards a Sustainable Bioeconomy", Sustainability, Vol. 10 No. 6, p. 1694.

Vivien, F.-D., Nieddu, M., Befort, N., Debref, R. and Giampietro, M. (2019), "The Hijacking of the Bioeconomy", Ecological Economics, Vol. 159, pp. 189–197.

Weber, K.M. and Truffer, B. (2017), "Moving innovation systems research to the next level: towards an integrative agenda", Oxford Review of Economic Policy, Vol. 33 No. 1, pp. 101–121.

Wehrden, H. von, Luederitz, C., Leventon, J. and Russel, S. (2017), “Methodological Challenges in Sustainability Science: A Call for Method Plurality, Procedural Rigor and Longitudinal Research”, Challenges in Sustainability, Vol. 5 No. 1, pp. 35–42.