



A forest-based bioeconomy for Germany? Strengths, weaknesses and policy options for lignocellulosic biorefineries



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ABSTRACT

The ambition to develop a bioeconomy depends largely on the forest-based sector. For creating higher-value chains, technological innovations are sought in the field of lignocellulosic biorefining. Although biorefinery concepts have been under development for decades now in Germany, many relevant technological developments are still confined to the laboratory and pilot scale. By taking on a technological innovation systems (TIS) approach, this article provides an empirical analysis of the development of lignocellulosic biorefineries in Germany, as well as prospects and implications for the forest and wood sector. Specific attention is accorded to actors' perceptions, in particular regarding the direction of innovation. To this end, we discuss the conditions under which actors from different sectors (forest and wood industry, chemical industry and energy sector) interact and play different roles in the emerging field. The analysis highlights a number of internal and external system weaknesses (e.g., fragmented policies, underdeveloped market formation, technological immaturity, incomplete actor networks etc.). However, we argue that the innovation system presents a series of strengths as well. Besides the clear need for policy integration and coordination, the analysis highlights some specific policy options that could support the development of lignocellulosic biorefineries in Germany.

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1. Introduction

Bioeconomy is high on the political agenda for both the European Union (EU) and Germany alike (BMBF, 2014; European Commission, 2012). Although its meaning is still in flux (Pülz et al., 2014), scholars and policy makers broadly understand bioeconomy as the transition from a fossil-based economy to an economy where the basic sources for products, chemicals and energy would be derived from renewable biological resources (European Commission, 2012; McCormick and Kautto, 2013). The forest-based bioeconomy is an important sub-sector of the overall bioeconomy under which forests are projected to provide a significant contribution of biomass (Hetemäki, 2014; Scarlat et al., 2015). To date, the material use of wood in Germany is dominated by “classical” applications such as woodwork, pulp and paper, and wood for bioenergy (Jochem et al., 2015; Mantau, 2012). However, under a bioeconomy regime, this biomass is expected to be maximized and valorised through new value chains beyond the

forementioned classical applications. New value chains would begin with biorefinery processing and result in high value products and other remaining residues destined for lower value applications (Van Lancker et al., 2016).

Thus, technological development in the field of woody lignocellulosic biorefining is a first crucial step for the establishment of any new and/or additional value-chain creation from the forest sector, and for the overall development of the forest-based bioeconomy in Germany. “Lignocellulosic biorefineries” (henceforth LB) are process plants that use lignocellulosic biomass (e.g., forest wood, harvesting residues) to produce a series of bulk products (e.g., biofuels) and high-value products (e.g., biochemical products). There has been growing interest in so called “forest biorefinery” concepts, particularly in northern (i.e., Finland and Sweden) and western European (i.e., Germany and Austria) countries with high-quality R&D, mature forest-based industries and abundant lignocellulosic biomass resources (see e.g., Hellsmark et al., 2016; Näyhä et al., 2014; Stern et al., 2015). However, LB have yet to become established. The prospect of such technologies becomes particularly interesting to discuss in the context of Germany, one of Europe's biggest economies, and a world leading pulp and paper

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producer that seeks to develop new technological solutions in support of a bioeconomy (BMBF, 2012).

Both policy makers and scholars acknowledge that slow technological development can hinder the development of the forest-based bioeconomy (BMBF, 2011) and thus confine many relevant technological developments to the laboratory and pilot scale (Hagemann et al., 2016). Technological transitions are not always feasible. In fact, it is well documented that technological transitions are often conflicting with established socio-institutional networks and that these are usually confronted with different obstacles such as regulations, infrastructure, user practices, maintenance networks, and markets (Geels, 2002). At the early stage of their development, it is unknown how technologies will evolve, which kind of actors they will involve and which business models will prevail (Wirth and Markard, 2011). Even if technologies eventually prevail and comply with policy objectives and regulations, gaining legitimacy is still challenging. This can, for example, be exemplified by the rise and fall of agricultural biogas in Germany over the past decade (Markard et al., 2016). Hence, one can understand the emergence of new technologies as a complex process shaped by different actor networks, institutional structures and developments in a broader context (Wirth and Markard, 2011). The role of policy is to enable these different technologies to move towards growth (Bergek et al., 2008a). This implies that both policy makers and entrepreneurs need to identify appropriate system-building activities that can increase the strength of technology enablement mechanisms while simultaneously reducing various blocking mechanisms (Bergek et al., 2008a). One way of identifying such strengths and weaknesses is by adopting a technological innovation systems (TIS) perspective (Bergek et al., 2008a; Carlsson et al., 2002; Hellsmark et al., 2016; Jacobsson, 2008). The TIS has gained considerable attention as a conceptual framework that can account for the complexity of technological innovation processes, the different dimensions of interaction, as well as the different possible context developments (Wirth and Markard, 2011). This paper builds on a TIS perspective in order to provide an empirical analysis of the LB innovation system in Germany.

To date, the evolution of bioeconomy is mainly at a political strategic level (Golembiewski et al., 2015). While there is now a growing literature addressing the bioeconomy concept (e.g., Bugge et al., 2016; Pätäri et al., 2016; Pfau et al., 2014; Staffas et al., 2013; Van Lancker et al., 2016), few studies have addressed the bioeconomy from a political science perspective (e.g., Goven and Pavone, 2015; Kleinschmit et al., 2014; Pülzl et al., 2014). Regarding the wood-based sector in Germany, some studies have addressed possible scenarios of a wood-based bioeconomy (Hagemann et al., 2016) or have focused on the policy requirements needed to initiate a bioeconomy transition (Pannicke et al., 2015). Prior TIS studies have addressed the development of biomass conversion technologies (e.g., Markard et al., 2009; Wirth and Markard, 2011), but few have addressed LB technologies specifically (Hellsmark et al., 2016), or their relevance in the context of a forest-bioeconomy (e.g., Näyhä et al., 2015; Sorda and Madlener, 2012; Stern et al., 2015). Very few TIS studies have accorded specific attention to actors' perceptions and assessments of the direction of innovations (e.g., Meijer et al., 2006). Considering the importance of LB for the transition to a forest-based bioeconomy in Germany, the likeliness of this technological transition deserves particular attention. There is, therefore, a need to examine this prospective technology and its constitutive elements and actors in depth.

The main objective of this empirical study is to understand the specific features of the LB innovation system, and contextualise it in a broader landscape of existing (competing) technologies, as well as market and policy structures that shape the German context. More

specifically, this study aims (i) to identify the key system weaknesses that hinder the establishment of LB in Germany; and (ii) to identify required policy options for enabling this innovation system in Germany by building on existing system strengths. We discuss the direction of LB and the innovation system's prospects for the forest and wood sector, in an attempt to set the ground for future discussions about the likeliness of a forest-based bioeconomy in Germany.

We proceed as follows: section 2 presents the main features of the TIS framework as well as the methods and data sources. Sections 3 and 4 present the results of interviews and document analysis. Finally, section 5 presents the discussion and conclusions of the study.

2. Conceptual and methodological considerations

2.1. Technological innovation systems (TIS) framework

Theoretically, this study builds on the TIS approach. The application of this approach has been characterized as a "heuristic attempt" (Hekkert et al., 2007) that focuses on particular aspects in the development of novel technologies, as well as the organizational and institutional changes required for emerging technological innovations (Bergek et al., 2008a; Hekkert et al., 2007).

TISs are understood here as: "a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product" (Markard and Truffer, 2008: 611). Thus, innovation systems have three structural elements: *actors*, *networks* and *institutions*. *Actors* can be individuals but can also represent firms along a value chain, as well as other organisations such as universities, industry, bridging organisations, other interest organisations (e.g., ENGOs) and government bodies (Bergek et al., 2008a; Wirth and Markard, 2011). The *networks* can be of various types, such as "learning networks" that link suppliers with users, companies with universities and research organisations, thus creating important ties of knowledge transfer; "policy networks" can be indicative of advocacy coalitions made up of actors sharing the same beliefs and seeking to influence the political agenda (Sabatier, 1998). As a diverse range of actors and organisations can interact within the TIS, both types of networks have to be considered (Bergek et al., 2008a). Finally, *institutions* can be understood as legal and regulatory aspects, norms and cognitive rules that influence the decisions, activities and learning processes of actors (Bergek et al., 2008a; Markard et al., 2016; Wirth and Markard, 2011). They become particularly relevant since firms in competing TISs compete on the one hand over the marketplace (for goods and services), and on the other, compete for gaining influence over institutions (Bergek et al., 2008a).

In order to identify central policy issues in a specific innovation system, the structural focus of the TIS analysis is complemented by a "process" focus. Thus, by introducing a second level of key processes named "innovation functions", so called "system weaknesses" associated with slowing down the diffusion of the system can be identified. Although the TIS analysis is mainly concerned with system weaknesses (Bergek et al., 2008a; Hekkert et al., 2007), recent theoretical contributions to the framework by Hellsmark et al. (2016) suggest highlighting the dynamics between both system weaknesses and strengths, and thus placing more emphasis on system strengths given their potential importance for motivating political action and for leveraging strengths in the international context.

Innovation functions are (positive or negative) contributions of different system components in relation to the overall "system goal" (Bergek et al., 2008a). The innovation functions employed in

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