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The spatial impact of socio-technical transitions — The case of phosphorus recycling as a pilot of the circular economy

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ABSTRACT

Socio-technical innovations for the recovery of phosphorus (P) from sewage sludge (ashes) and the recycling of the secondary material in the agri-food system have been gaining prominent roles in current debates on circular economy. While research has been primarily focusing on questions on technical feasibility, the impact of the innovations on the social and material structures of the underlying socio-technical wastewater and agri-food systems has been receiving less attention. Drawing on theoretical insights from transition theory and empirical data from expert interviews, our analysis of two approaches to P recycling — phosphoric acid and struvite — shows how innovations create different spatial structures of actors, institutions, infrastructure, and material flows and in doing so promote or hamper fundamental changes in the socio-technical systems. In the wastewater system, both approaches foster the incumbent socio-technical regime of centralized wastewater treatment. In the agri-food system, on the one hand, the phosphoric acid approach supports large-scale industrial structures comprising the fertilizer industry and global P flows fostering the incumbent globalized agri-food regime. On the other hand, struvite facilitates the local distribution of fertilizers between wastewater treatment plants and farmers and supports small-scale P cycling providing opportunities for a structural reconfiguration of the agri-food system.

1. Introduction

Phosphorus (P) is an essential and non-substitutable component of living organisms. It is a limiting factor for plant growth and sufficient supply of agriculture with P is a prerequisite for global food security (Childers et al., 2011). Our current supply with P is highly dependent on mineral P sources, i.e. non-renewable phosphate rock ores. Around 90% of mineral P is applied in the global agri-food system as part of fertilizers and feed additives, while the remaining 10% is used in non-food industrial applications (Gantner et al., 2014; Scholz et al., 2014). Due to the finite nature of mineral P sources, P is a potentially critical nutrient for food production. Even though alarming studies on the lifetime of mineral P (Cordell et al., 2009) have been put into perspective (Scholz and Wellmer, 2013, 2016), EU countries' dependence on mineral P imports and the finiteness of high grade phosphate rock ores remain a critical issue for European agriculture rendering sustainable P management based on secondary P sources and efficient P use an important challenge for practitioners, policy-makers, and researchers (Chowdhury et al., 2017; Withers et al., 2015a). One current P sink that provides large potential for P recycling is the wastewater sector. In some European countries such as Switzerland, the Netherlands, and the UK, P in wastewater accounts for at least 70% of P imports in mineral fertilizers (Jedelhauser and Binder, 2015). Thus, the wastewater sector as a source of secondary P has been receiving growing attention in recent years (Cieślik and Konieczka, 2017; Pearce, 2015; Withers et al., 2015b; Zoboli et al., 2016). Since the direct recycling of stabilized P-rich sewage sludge on agricultural land has been or is going to be restricted by a number of European countries (Germany, Switzerland, and the Netherlands), new approaches to P recycling from the wastewater sector are needed (Eurostat, 2015; Kabbe, 2017). As a consequence, technologies for P recovery from wastewater, sewage sludge and sewage sludge ashes have been developed over the past years providing a new approach for returning P on agricultural land without the

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unwanted pollutants contained in sewage sludge (Schoumans et al., 2015).

In recent years, this topic has also been taken up by the European Commission (EC) seeking to close P cycles and to reduce EU's dependence on primary materials (European Commission, 2011, 2015; Ellen MacArthur Foundation et al., 2015). Thereby, the concept of Circular Economy (CE) has been put forward, which proposes to derive strategies for a shift from a linear to a circular resource economy (Ellen MacArthur Foundation et al., 2015; European Commission, 2015; Ghisellini et al., 2016; Hobson, 2016; Iacovidou et al., 2017; Winans et al., 2017; Yuan et al., 2006). CE “focuses on recycling, limiting and re-using the physical inputs to the economy, and using waste as a resource leading to reduced primary resource consumption” (European Environment Agency, 2014: 11; see Rizos et al., 2017 for an overview of different CE definitions and concepts). In this context, P recovery and recycling is considered a possible CE pilot, i.e. a potential case to “demonstrate that circular principles work in practice” (Ellen MacArthur Foundation et al., 2015: 40). However, despite this growing interest in P recycling, the question of *how* these circular principles work in practice remains open. Thus, a profound discussion of the social and material impact of CE projects such as P recovery in the wastewater sector and recycling in the agri-food system is needed. Which actors and institutions on which scales are involved in and affected by CE projects? What kind of infrastructural interventions do the projects comprise and how do the projects affect material flows? Furthermore, against the background of the transformative character of CE, there is a need to assess whether CE projects and their socio-material impacts actually contribute to fundamental shifts in socio-technical systems or rather strengthen incumbent system structures.

Whereas current CE ideas primarily point out the variety of potentials of and approaches to circular P management, we need complementary views to tackle the questions regarding the implications of CE projects for the overall structure of actors, institutions, infrastructure and flows. We argue that a geographical perspective is necessary for elaborating more profound insights into CE. So far, the geography of CE has mainly been discussed with regard to the place, where CE projects could be implemented, particularly focusing on cities as the ‘container’ of zero-waste projects, urban circular material flows or shared mobility systems (Ellen MacArthur Foundation et al., 2015). This perspective, however, neglects that CE is not only embedded in space but also impacts the spatial structure of both social, i.e. actors and institutions, and material, i.e. infrastructure and resource flows, system entities. Thus, studying CE can benefit from a broader geographical perspective in order to comprehensively assess how CE is affected by and itself affects the socio-material structures of systems.

Drawing on contributions from geographically-informed transition theory, the aims of the paper are (i) to analyse how socio-technical innovations in CE create new spatialities of actors, institutions, infrastructure, and flows; and (ii) to scrutinize how these spatial settings contribute to fundamental changes in the underlying socio-technical systems. We do so for the case of P recycling from the wastewater sector focusing on two technological approaches that are currently considered promising: struvite and phosphoric acid. In our analysis, we primarily refer to the case of Germany, as there is currently an ongoing political debate on sewage sludge management and several P recovery technologies are being implemented at full-scale or pilot-scale. However, as mentioned above, Germany is representative for a number of European countries where the direct application of sewage sludge on agricultural land is (going to be) restricted and where technical P recycling from the wastewater system is considered to be an important element of sustainable sewage sludge management in the future. It is important to note here that technical P recovery is not the sole pillar of a CE of P. Other recycling approaches such as urine separation as well as P sufficiency strategies, e.g. in terms of changes in human diets, are also part of a CE (Jedelhauser et al., 2018; Udert and Wächter, 2012). Furthermore, the recycling of stabilized sewage sludge still remains an important P cycle in many European countries. Our focus on the technical P recovery from sewage sludge (ashes) does not negate these approaches but is due to the current political and academic debate (particularly in Germany) and the lack of knowledge that exists in terms of the socio-material impact of these technologies.

In the following chapter 2, we present the theoretical framework of our analysis. After providing an introduction to the case study and a description of the methods in the methodological chapter 3, we show the results of the study in chapter 4. The paper ends with a discussion of the results and some concluding remarks (chapter 5).

2. Theoretical framework

2.1. Transition theory as an approach to studying fundamental socio-technical changes

Transition theory has gained remarkable prominence in studying transformative changes towards sustainability (Elzen et al., 2004; Grin et al., 2010; van den Bergh et al., 2011). It provides concepts for a systematic analysis of “processes that lead to a fundamental shift in socio-technical systems” (Markard et al., 2012: 956) by emphasizing the need for a co-evolvement of technological innovation and social change (Boschma et al., 2017; Truffer and Coenen, 2012). Transition theory is based on the common understanding that socio-technical systems are structured by regimes, i.e. the dominant mode of functioning of a socio-technical system. They form the status quo of institutionalised and socially embedded system structures consisting of a series of semi-coherent rules that guide the actions of actors (Geels, 2011). Since they predominantly develop incrementally along established development paths, they tend to maintain the status quo of the system structure (Geels, 2002). Fundamental shifts towards more sustainable modes of living require alternative socio-technical innovations developed in niches (Schot and Geels, 2007). As transition scholars are interested in investigating “the destabilization of existing regimes and the emergence of new regimes” (Markard et al., 2012: 957), the question arises whether these niche innovations are capable of undermining incumbent system logics and contributing to radical socio-technical change. For this, Fuenfschilling and Truffer (2016: 302) introduced the concept of “reconfiguration capacity” of innovations, i.e. their “capacity to alter the underlying socio-technical structures and thus enable institutional change”. This concept draws on work by Smith and Raven (2012: 1030), who differentiate between innovations that “fit and conform” to mainstream structures and innovations that “stretch and transform” the functioning of the socio-technical system. This provides a valuable approach to assessing whether the impact of CE goes beyond incremental adaptations via re-use, recycling or recovery of resources and eventually comprises fundamental socio-technical systemic shifts.

2.2. Conceptualizing space in transitions towards a CE

Various scholars emphasized the role of space and place in transition processes (Binz et al., 2014; Coenen et al., 2012; Coenen and Truffer, 2012; Debizet et al., 2016; Hodson and Marvin, 2010; Lawhon and Murphy, 2012; Raven et al., 2012; Shove and Walker, 2007; Smith et al., 2010; Truffer et al., 2015) and several