

“Tell me what’s your landfill and I explain your social system” – sociocultural aspects of enhanced landfill mining governance in Germany

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Abstract

The supply security discourse on raw materials in Europe has promoted research about mining landfills from municipal solid waste as well as mining activities. Landfill mining governance in Germany is challenged by complex actor configurations in heterogeneous communities and social networks, influenced by various social factors. In order to understand the sociocultural factors that underlie and are constitutive for landfill mining governance, we compare two typical German landfill types resulting from municipal solid waste management and mining activities. We argue that initiating sociotechnical niches in a way that they can later develop into mainstreamed practice and technology reflects a major challenge for landfill mining governance. Our results indicate differences in the social constitution of identified German landfill types, which decisively influences landfill mining governance.

Introduction

The issue of the supply risk of raw materials has been increasingly discussed in European countries since the early-2000s¹ and has taken up into the political agenda in Europe as well as Germany, where a Raw Materials Strategy was launched in 2010. The Raw Materials Strategy is supported by federal research initiatives on innovative technologies for resource efficiency, focusing on secondary mining options like landfill mining.^{2,3} Owing to this discourse, a new focus was added to the practice of landfill mining, which has been discussed in recent decades in the context of sustainable development (reduction of land consumption), healthy environments (mainly groundwater and soil protection) and regional development.⁴ In several European countries, landfill mining (LFM) is seen as an approach to recycle materials from

landfills.^{5,6,7} In this connection, the goal of LFM is to use the potential of already mined and used resources to further (re-) integrate them into other product cycles. While LFM has been focused on developing technologies to recycle materials from landfills as efficiently as possible, in the last decade, the idea of enhanced landfill mining (ELFM) has emerged. ELFM goes beyond and broadens the idea of landfill mining by including the processes of waste dumping, which should change in a way whereby landfills are operated as intermediate storage.^{8,9} Furthermore ELFM, includes the phases of operating a landfill, aiming to reduce CO₂ emissions, as well as the aftercare period, which shall be shortened.^{4,6,8,10,11} Most important for our argument is the fact that the ELFM concept not only focuses on developing technologies for dumping, operating and recycling materials, but it also emphasizes the importance of social aspects, practices and governance structures in achieving envisioned goals.⁶

Within this paper, we argue that mining landfills is not only a challenge for technological development but it also challenges the governance of landfilling, recycling and developing innovative technologies. As governance, we understand all processes and actions of diverse actors that aim to coordinate action and decision-making within a specific field, here recycling materials from landfills. Aspects of governing landfill mining have been discussed to date from juridical,^{12,13} socio-economic¹⁴ as well as resource management perspectives.^{15,16,17} Current research indicates social fractures and conflict lines along actor constellations.^{18,19} These conflicts concern issues of public participation, the management of complex actor constellations like heterogeneous community constellations, as well as issues like dense populations around landfills.¹⁹ Within the current debate on landfill mining, societal factors are not dealt with in detail. However, in order to develop appropriate governance approaches social structures and dynamics, practices and values as well as conflictive ‘frictions’ related to landfills have to be understood. Accordingly, this paper aims to improve our understanding of sociocultural factors around landfill mining.

Thereby, we rely on transition theory and - more precisely - the concept of transition management. In recent years, this concept has become popular for studying and managing societal change towards sustainability.^{20,21,22} The transition management concept describes an interdisciplinary research line and delineates from “institutional theory, evolutionary economics, and sociology of technology”.²³ Conceptually, transition management perceives technical systems (like landfills) embedded in sociocultural settings and practice environments and thus presents a holistic theoretical intent to explain societal change over middle range and long-term scenarios, considering its social environments and interactions. This lens is useful in terms of understanding the dynamics of recent developments of landfill mining. The emergence of the idea of landfill mining and the development of specific technologies for it will be understood as technological niche(s) that may succeed and become part

of the sociotechnical system of landfilling and thereby modify it, or alternatively which may fail and disappear after a while (see next section).

Within the theoretical perspective of transition management, the challenge for governance is to organize niche development in a way whereby niches become part of the sociotechnical system. Our underlying hypothesis is that different landfill types are connected with different social settings. Accordingly, only a better understanding of social structures and interactions related to different types of landfills allows developing appropriate governance approaches that support the integration of the (technological) niche into the sociotechnical system.

Therefore, we address the following questions in this paper: How does ‘the social’ around landfill mining differ in relation to ‘what and how is it dumped’? What governance approaches are appropriate to facilitate and support the take up of niches into the sociotechnical system of landfilling?

We approach these questions by comparatively and contrastively depicting two landfill types in Germany, defined regarding the origin of the residues: municipal solid waste landfill and mining landfill (mainly tailings and slag heaps). Following the political initiatives on raw material supply in Germany, several research projects have been initiated with the purpose of exploring the resource potential of landfills made from municipal solid waste and landfills stemming from industrial or mining activities (tailings, landfills). Although suggestions have been offered, a commonly accepted terminology on different types of recycling materials from landfills does not yet exist.²⁴ Therefore, we understand both mining of landfills from municipal solid waste and mining from tailings and landfills from industrial and mining activities, as ‘landfill mining’. To address our research questions, we will frame municipal solid waste landfills and mining landfills in terms of transition management. The dynamics of the two niches will be explored and conclusions on governance aspects will be drawn.

In the following section, the theoretical framework of transition management will be introduced, followed by a brief methodological section. Subsequently, the two landfill types will be introduced in terms of transition management, before the niche-regime dynamics for each landfill type will be discussed regarding governance requirements. Although the examples are taken from Germany, in our concluding remarks we will also reason on impacts for governing landfill mining in other European countries.

Theoretical framework

Transition management picks up on describing qualities of change from a “multi-layer perspective”.²³ The concept facilitates assessing the dynamics of transitions from a multi-layer perspective by suggesting three heuristic, analytical concepts: a) the sociotechnical landscape, b) sociotechnical regime and c) technical niche. The configurations (actors, interactions, etc.) and dynamics of change of each of these

layers contribute to the formation of transition paths. The three concepts will further be referred to as the components of a social system.

First, the *sociotechnical landscape* is “an exogenous environment beyond the direct influence of niche and regime actors”.²³ For instance; it includes macro-economic developments like financial crises, deep cultural patterns such as values and norms as well as macro-political developments such as changes in the political system. Landscape changes are rather long-term dynamics that last decades or even centuries, influencing the configuration of the sociotechnical regime. In addition, landscape dynamics that influence regimes are called “landscape pressure”.

Second, the *sociotechnical regime* comprises a complex, intertwined yet stable constellation of actor groups from industry, politics, science and civil society. This includes user-communities and incumbent firms. Furthermore, user preferences, technologies, practical applications of technologies and producing knowledge, as well as legal regulations and policies account for regime configurations.²³ Sociotechnical regimes stabilize trajectories – namely the specific configuration and shape of the system’s elements – through their practice routines, policies and regulating norms, as well as learning and adaption to new technical systems. Only landscape pressure and/or strong evolving niches challenge the sociotechnical regime and lead to new configurations. Governance literature concerned with the spreading of sustainability-niche innovations recognizes the regime level as a steering wheel for societal change, determining the “development and use of technologies”.²⁵ This underscores social interaction between both the regime and niche level as a key mechanism for change.

The third concept is the *technical niche*. Transition management places weight on niche actors, who aim to pressure the sociotechnical regime to realise a regime change, meaning the reconfiguration of elements: “Niche-innovations are carried and developed by small networks of dedicated actors, often outsiders or fringe actors.”²³ Technical niches – which are mostly unstable - are not part of mainstream markets and perform a rather low output. As actors play an important role at both the sociotechnical regime and the niche level, they represent the ‘interface’ between these two levels due to their actions and practices.²³ Niche governance literature has tried to underpin causal relations of niche-regime interactions to advance niche management for societal change towards sustainability.^{26,27} Niche management is also referred to as strategic niche management, underpinning a knowledge-intense perspective of transitions.

Geels and Schot (2007)²³ suggest a typology of transitions pathways representing sociotechnical regime change. A regime transition is understood as a change of routines and practices, whereby the dynamics of all three levels have to come together to achieve a regime change. Provoking regime change can be seen as an overall niche goal and the actual governance challenge that we depict in this paper. The authors (2007) also state “that different timings of multi-level interactions have different

outcomes”.²³ For instance, developed niches – namely those with a relatively stable configuration of actors, technologies, practices, etc. – would have more success triggering transitions than underdeveloped niches once landscape pressure evolves. Interactions between innovating niches and the sociotechnical regime can have a symbiotic character and thereby stabilize the regime, or niche innovations remain in a competitive relation to the regime, aiming to replace it. These interactions are triggered by landscape dynamics that favor niches on their way to the regime level and challenge the current regime configuration. Based upon these assumptions about niche-regime interactions, the two scholars provide six different transition types, as outlined hereafter.²³ (1) Within the scenario of *reproduction process/path*, no landscape pressure can be observed. The regime reproduces itself and remains within its trajectory. Although niches develop under these conditions, they have no impact on the regime level and thus cannot “break through”. This can be seen as a systemic *status quo*, whereby the sociotechnical configuration remains stable. (2) The *transformation path* is characterized by regimes under landscape pressure. These modify their innovation direction if niches are underdeveloped at this given time. Such a modification is a rather gradual process, driven by the regime actors themselves. Niches will not influence this modification. (3) The *de-alignment and re-alignment path* is taken when regimes collapse under too much landscape pressure. Geels and Schot (2007)²³ explicitly speak of regime actors “losing faith” and thus triggering a regime de-alignment. If niches are underdeveloped at this point, many different competing niches emerge and can develop until one niche dominates the others. The dominant niche leads the regime to re-align with its innovation. (4) The *technological substitution path* can be identified when niches are fully developed and regimes become pressured by landscape shocks. At this moment, niches break through and their technological or social innovation is taken up by the regime. (5) In the *reconfiguration pathway*, niches’ innovations are adopted by the regime and enable further gradual adjustments. This symbiotic innovation character excludes conflict since actors of both the niche and the regime level act according to the changing landscape. (6) During the *sequence of transition pathways*, disruptive change occurs under landscape pressure, leading to transformation and subsequently reconfiguration, followed by substitution or de-alignment and re-alignment.²³

Having introduced these central concepts of transition management, we will now turn to two types of landfill mining, exploring the dynamics of these niches and existing sociotechnical driving forces of this system.

Method

The focus in this paper is placed upon Germany, since in recent years several (research) activities have been carried out to estimate the potential to mine landfills stemming from municipal solid waste or mining activities (tailings, landfills).

Methodically, our research relies on a literature review and qualitative analysis of documents and conversations with experts from politics, science, economy, administration and civil society. In order to understand the sociotechnical system of landfilling and its structure in terms of transition management, we analyzed five research projects on municipal solid waste landfill mining in the following federal states: North Rhine-Westphalia (one landfill), Hesse (two landfills), Baden-Württemberg (two landfills) and Berlin-Brandenburg (two landfills). Furthermore, we focused on research activities around landfills from mining processes in the German region Harz in the federal states of Saxony Anhalt and Lower Saxony. We will compare the two niches of municipal solid waste landfills and mining landfills using the framework provided by transition management. In the following section, both landfill types will be introduced by describing elements and dynamics of the niche, regime and landscape level. Furthermore, we will compare these two niches of mined landfills and discuss the dynamics observed regarding types of transition. Based upon our analysis, governance options will be developed.

Mined landfills in Germany: transformation from a needless good to a resource

In this paper, we have built two different types regarding the origin of residues. One landfill type stems from collection of municipal solid waste, while a second landfill type was identified according to its origin from mining. Here, slag was stored in tailings and other residues from mining processes.

The following section identifies the components of sociotechnical landscape, sociotechnical regime and sociotechnical niche and their dynamics regarding these two different types of landfills.

The municipal solid waste type

Since humankind began to settle, the dumping of solid waste has been shaped by the philosophy “out of sight out of mind”.^{28,29,30} Municipal solid waste has caused several waste crises over the centuries due to the amount of waste, health hazards and odor nuisance. In the middle of the 20th century, ‘piles of rubbish’ emerged as a consequence of consumerism and the introduction of ‘throw-away’ products. Therefore, the dumping of municipal solid waste changed from pits and town dumps to centralized landfills.^{28,31,30} The challenge was to not only cope with the amount of waste and its reduction, but also with environmental issues like groundwater and soil contamination. To address these issues, technical innovations like leachate management have been introduced.³² Nonetheless, despite these innovations the amount of waste still increased and environmental hazards persisted. In order to cope

with these issues and the changing perception of municipal solid waste as a resource, the recycling of municipal solid waste was introduced.^{31,30} The current sociotechnical system was shaped by far-reaching changes in the practices of waste dumping, the development of new technologies and the introduction of specific legal frameworks.

Sociotechnical Landscape. In Germany, the current debate on the resource potentials of landfills is influenced by the supply security discourse of raw materials.³³ According to experts, the discussion emerged as a reaction to Chinese rare earth export restrictions from 2005 until 2015³⁴. These export restrictions can be understood as an economic dynamic on the landscape level. This landscape pressure led to activities on the regime level, especially promoting research on landfill mining for raw materials of strategic economic importance. However, to date landfills are still framed as final storage and not yet as a secondary source.⁵ Thus, the impact of the landscape pressure of economic dynamics can be seen as a window of opportunity for the active creation of technological niches (initiation of research), but not as influencing the configuration and trajectory of the sociotechnical regime. As we will show below, the idea of economic efficiency and feasibility is an influential paradigm on the landscape level.

Sociotechnical regime. The practice of dumping of municipal solid waste has changed over recent decades. At present, municipal solid waste is collected from legally defined areas and dumped on specific, centralized landfills. In Germany, waste management is regulated by environmental policies on the national, federal state and regional level. According to existing regulation, local authorities are responsible for the implementation and control of waste management. Three different local landfill ownership models can currently be identified in our case studies: a) owned and managed by local authorities; b) owned and managed by operating companies owned by local authorities; and c) owned and managed private-public partnerships. This structural diversity should not be misunderstood as a “regime discontent”²³ in the sense of competing practices; rather, it stems from the federal character of Germany, allowing for administrative reforms of the federal states as well as municipal decisions due to the (decentralizing) principle of subsidiarity. Thus, all three are specific configurations of regimes that coexist and essentially follow the same principles and ideas. When the German raw material strategy was launched – picking up on the supply security discourse of raw materials - the German Federal Ministry of Education and Research and the German Federal Ministry for Economic Affairs and Energy funded research clusters aiming to develop methods and technologies to exploit resources from different kinds of landfills.³³ These developments can be interpreted as landscape pressure, influencing the regime level.²³

However, the landscape level influences the regime in several ways. In conversations, experts point to the fact that the need for all activities to be economically feasible slows down further research activities on landfill mining in Germany, as the mining of landfills at present creates no income and the necessary investments in technologies

are high. This situation can be interpreted as an expression of a strong alignment of regime structures (firms can operate if they generate income) with a landscape paradigm (economic efficiency). Furthermore, it shows how trends of persistence influence regime change through the introduction of new practices and technologies that need to be realized by incumbent firms, which partly finance landfill mining research projects.

(Technical) Niche. Several landfill mining research projects were realized to assess municipal solid waste landfill potentials in Eastern and Western Germany. Some of these projects followed the waste-to-energy as well as the waste-to-material approach.⁶ Waste-to-energy includes the production of energy by landfill gas, while waste-to-material aims at extracting and recycling raw materials fractions like ferrum, copper and aluminium. As test drillings were evaluated as being successful, the focus of the projects was extended to the development of innovative technologies for mining and recycling raw materials from landfills. These research projects were initiated and carried out by scientists, local authorities and firms working in the field of recycling and waste management, partly under the participation of environmental ministries. Although research activities take place in the niche, these actors are also part of the regime. Furthermore, landscape pressure due to the supply security discourse of raw materials supported the development of the existing niche.

Scientists, local authorities and firms working in the field of recycling and waste management built small networks aiming to discuss the potential of landfill mining and develop new technologies, thus bringing the idea of waste mining into the existing regime of waste management. This is in line with Geels and Schot's (2007)²³ argument concerning the structure and dynamic of niches. To date, it seems that these landfill mining activities are mostly science-driven, albeit initiated both by researchers and local authorities. This underscores the symbiotic character of this niche-innovation regarding its alignment with the sociotechnical regime. Rather than niche fighting the existing sociotechnical regime, regime actors cooperate with the niche, whereby this dynamic could help to take up the practice of landfill mining into the regime level.

The mining landfill type

During centuries of mining and processing of iron, non-ferrous metals and industrial minerals were stored in landfills and tailings next to mines and smelters. In some German regions, the mining of these materials lasted until the 1960s and even the 1990s. Although mining landfills were previously seen as the storage of valuable materials, they are usually perceived and designed as final storages. Thus, as a result of cleaning-up activities, tailings are covered by artificial blankets that minimize the leaching of unhealthy materials.

The emergence of landfill mining research on slag heaps and tailings resulting from former mining activities has become evident in recent years. Respective research projects focus on historical mining regions, namely the Harz Mountains and the Ore Mountains. In the eastern part of the Harz region, copper extraction took place until 1992, leading to the storage of dead rocks, sludge and slags in landfills, heaps and tailings.

Current research in this region is focused on strategic metals as well as copper, zinc and tin, of which reasonable concentrations have been detected in mining landfills. From a technical perspective, it seems practicable to exploit them, even though all projects have failed in finding feasible business models to date. Thus, while long-term resource extraction from mining landfills has happened rather unsystematically and spontaneously, with a focus on securing landfills and tailings as final storage, the debate on the scarcity of materials has recently triggered activities to deal with these remains differently.

Sociotechnical Landscape. Mining sludge and tailings is influenced by the supply security discourse of raw materials, which emerged owing to Chinese export restrictions on rare earths.^{33,34} As a consequence of these macro-economic developments, research projects have been initiated and experiments with new methods of secondary resource extraction carried out.

Furthermore, publications and conversations with experts have indicated a strongly perceived influence of global pricing on rare material extraction in Germany's historical mining regions. These macro-economic constraints and changes can be interpreted as landscape pressure, since such dynamics provoke action yet are out of reach for actors of concern.²³ The discourse on supply risk has changed the paradigm of a general perceived unfeasibility of mining in Germany. Other discourses concerning land consumption and environmental risks caused by landfills also characterize the landscape and coexistent with the resource scarcity discourse.

Sociotechnical regime. In recent decades, activities connected with landfills from mining in Germany have been focused on cleaning up environmental burdens, e.g. minimizing the leaching of hazardous materials and coming to safe landfills that may potentially be reused for sport and leisure activities, housing or nature conservation. Thus, these landfills largely remain under community responsibility or private owners, belonging to the realm of environmental law from a legal perspective, namely the law on soil protection.

Despite this situation, experts argue the research would still make sense as it produces 'steady state' knowledge regarding extraction methods. Such knowledge could be used once resource prices rise again. Resource economies are led by spot markets setting unstable incentives to invest even in R&D. Considering this, as well as the notion that the mining sector constantly adapts to vast pricing dynamics and having in mind the in

transparency of price building on resource markets, this measure could be interpreted as a practice of sectorial learning and culture²³ aiming at a technical substitution.

The tailing and sludge landfill type is also prone to conflicts concerning nature and monument protection, preserving historical sites. This leads to different stakeholder perspectives resulting in controversies concerning landfill mining and thus it can be interpreted as regime discontent influencing regime trajectories.²³

(Technical) Niche. Niche actors can be grouped into ex-miners, firms interested in secondary resource extraction from landfills as well as researchers. Ex-miners feel committed to revitalize old structures, extraction practices, traditions and identity. By contrast, researchers see their work as a means for preparing a sectorial transition from a more 'mining-like' perspective towards vast price dynamics and irregularities. According to interviews, actors were well aware of the prevailing knowledge of ex-miners concerning how and where the material was dumped. Investing companies fully depended on the cost-effectiveness of their projects. Falling prices as well as the complex structure of the tailings and slag heaps complicated the realization of projects. Conversations with actors involved in these research projects confirmed strong interactions between niche actors, whereby it seems apt to describe this as an interrelated community.²³

Activities connected with mining landfills from mining activities that have recently emerged are best described as being 'science-driven'. Existing projects are funded by the German Federal Ministry of Education and Research and initiated by researchers from universities and research institutions. These research projects are usually designed in a way that incumbent firms (those already active in this field, e.g. from metal recycling) may step into this cycle at a later stage, taking up with business models mainstreaming the new methods and technologies marked-ready. While R&D was thought to sufficiently engage in niche-building to attract incumbent firms willing to invest in secondary mining in the future, when projects started raw material prices fell again and some projects became economically unfeasible. Moreover, this situation can be interpreted as a reaction to landscape pressure.

Activities within this niche in some regions - such as the eastern part of the Harz - are led by associations of ex-miners after failing scientific projects, financed by the Federal Ministry of Education and Research (r2-cluster). Nevertheless, recent research on mining landfills from mining processes aims to develop and apply innovative technologies such as bio-leaching to extract strategic raw materials from tailings and slag heaps.

Discussion – Niche-regime dynamics and the governance of landfill mining

Five transition types and transformation paths were introduced at the beginning of this paper, capturing differences in the development stage of niches as well as the niche-regime and regime-landscape interactions.²³ In the following, we discuss current developments in mining municipal solid waste landfills and landfills from mining regarding transition dynamics. We draw conclusions on requirements for governing these processes, assuming that the overall goal to scale up niches of landfill mining on the regime level.

Niches actors of both landfill types distinctively mobilize resources to push projects for initializing niches or further develop them. In the case of mining-related landfills, in some of the projects we identified strong idealistic pressure groups - e.g. of ex-miners - which began networking with the aim of funding research and pilot projects in landfill mining. The engagement of such groups may last several years and result in networks with scientists who activate further network partners and may apply for public or even private funding. Although other projects within the mining landfill niche are primarily science-driven, local interest groups that are in favour of mining or aim towards environmental protection or protection of cultural heritage often come into play when projects are realized. Such groups may support or refuse the niche development. Municipal solid waste landfill projects in all realized projects were science-driven and engaged with administration, funding ministries and incumbent firms, which are well settled in the waste management system. It seems that niche actors are simultaneously part of the regime. Thus far, interest groups from outside the regime have not been active in favour of or against new developments in any of the projects.

These observations imply that the initial focus of agency in niches can differ: in the case of mining landfills, in addition to researchers, local networks seem to account for the development of the niche, whereas the niche of municipal solid waste landfill mining is mainly initiated and developed by actors from outside of the regime. This leaves opportunities for niche governance to focus on different 'steering wheels'.

The perception of landscape pressures guides regime actors' activities during processes of change, although this perception differs among landfill types. This is especially true regarding the perception of external shocks. When asked what factors hinder regime transition towards resource extraction from landfills in Germany, experts concerned with mining-related landfills strongly refer to short-term dynamics of raw material prices that are external to their scope of action. These experts see fewer problems in the development of exploiting methods. By contrast, experts in municipal solid waste landfills refer to missing technology as a source of major concern and seem to perceive landscape pressure only gradually and less disruptive, thus claiming that the further development of these technologies is a major task. They also

point to the fact that mining solid waste landfills is economically not feasible at present. This argument is in line with the dominant paradigm of economic efficiency that has long been taken up in the waste-regime's structure and trajectory. These observations mean that actors of the mining-related landfill regime perceives themselves as being under stronger landscape pressure than the municipal solid waste landfill regime, partly because the niche of mining landfill exploitation has been created in response to landscape pressure related to the discourse of resource scarcity. Therefore, the detection of resource potentials becomes a strategic practice within this niche. Tailings and slag heaps contain higher concentrations of strategic raw materials, which are seen as important within the German high tech strategy. In this light, it seems apt to state that the sociotechnical regime of mining landfills reacts more responsively to landscape pressures, especially those caused by global disruptive pricing. This poses difficulties on long-term governance-strategies concerning resource extraction from mining-related landfills. By contrast, for niches in the municipal solid waste landfill regime, the governance challenge is to develop further despite little or no landscape pressure opening windows of opportunity for niches entering the regime.

If we ask for potential transformation paths, it is important to note that in both our analysed cases niche actors in the further development of the niche cooperated with the regime, thus hinting at a symbiotic type of innovation. Therefore, the category "outsider" is misleading in terms of describing the "small networks" with which our cases deal.²³ In both cases, landfill mining was widely supported by regime actors and led to alignment and cooperation. Supportive interactions between both levels indicate the existence of the transformation path and the technological substitution path, since these paths explicitly describe symbiotic innovations in the sense of a niche-regime alignment.²³ We argue that according to the transition management framework, the municipal solid waste type is best described as a *transformation path*, since regime actors see themselves being exposed to landscape pressure. As typical for trajectories of the transformation path, perceived landscape pressure steadily loomed in niche-building activity in the case of municipal solid waste landfill mining. Here, landscape pressure was perceived over a long period, leading to gradual changes of the regime.²³ It enhanced the gradual adaption of practices; for example, the invention of groundwater management in the 1970s or the change of the wording of the German waste regulation from Waste Disposal Act to Waste Management Act in 1996.³⁰ Indeed, these gradual changes within the regime opened the door for an introduction of recycling practice.

The mining landfill type could be described as a technological *substitution pathway* because regime and niche actors perceived landscape pressure.²³ Actors of the sociotechnical regime perceived Chinese export restrictions as fundamental landscape pressure. This provoked the formulation of the German Rare Materials Strategy in

2010 and thus the regime directly engaged in niche-building via a research cluster that often takes up initiatives by local groups.

Landfill mining to date can be understood as an innovative practice that must be characterized as a niche development in several technological regimes. Our results indicate that landfill mining governance should focus on initiating groups, networks and communities with care and including ‘innovation prehistories’ to understand sociocultural trajectories influencing niche creation and governance. Transition management “understands transitions as outcomes of alignments between developments at multiple levels”.²³ Our findings indicate the existence of such niche-regime alignments in different landfill regimes. Cooperation or/and alignment seems a key mechanism for pushing landfill mining.

Conclusion

About a decade ago, the discourse on supply risk of raw materials added a new focus on landfill mining, which aims to recycle material from landfills in several European countries. In line with the concept of enhanced landfill mining (ELFM), our point of departure within this paper has been the argument that mining landfills is not only a challenge for technological development but it also challenges the governance of landfilling, recycling and developing innovative technologies. By analysing the social structures of two different types of landfills, we have contributed towards understanding sociocultural factors as a precondition to develop appropriate governance approaches for landfill mining.

At present, landfill mining in Germany can be seen as a research-based innovation process at an early stage, which in terms of transition theory can be characterized as niche development.³⁵ Our analysis shows that landfill mining activities in Germany differ in a way what it seems correct to state that they represent two different types of landfill mining: municipal solid waste landfills and mining landfills. Social networks around these landfill mining types differ in constituting pressure groups pushing for mainstreaming their innovative activity. Interestingly, municipal solid waste landfill mining activities are mostly driven by scientists, scientific networks and firms active in waste and landfill management, namely incumbents of the waste management regime. By contrast, in the case of landfills from mining activities (tailings and slag heaps), networks seem to strongly require the voluntary activity (‘idealistic surplus’) of local interest groups (e.g. ex-miners) and (private) firms, which have not been engaged in landfilling or waste management thus far. Moreover, resource mobilization (e.g. knowledge, funding) is different for the two types of landfills: mining municipal solid waste strongly relies on actors mobilizing resources in social networks on the regime level, whereas mining landfill niches rather seem to gather resources by “outsiders” but from incumbent firms, even though the mining landfill niche is aligned with the

regime (symbiotic innovation). This leads to a more advanced cooperation from the transition management perspective.

Emerging practices of landfill mining in Germany differ regarding the landfill types. The removal of waste remains central to municipal solid waste landfill mining, whereas mining slag heaps and tailings focuses on resource extraction only. Thus, practices take up the dynamics of the landscape level, whether concerning external shocks such as rising or falling prices of raw materials or a more gradual change of discourses such as from orientation towards dumping waste to recycling. It is currently unclear how the dynamics that we have identified translate into framings, which - once interpreted - subsequently push niche-building and development in landfill mining. Future social scientific research should thus focus on the perception of practices, since their perception could affect the further diffusion of such innovations. This seems a key aspect of landfill mining governance.

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