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Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance

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ABSTRACT

Test beds and living labs have emerged as a prominent approach to foster innovation across geographical regions and technical domains. They feed on the popular "grand societal challenges" discourse and the growing insight that adequate policy responses to these challenges will require drastic transformations of technology and society alike. Test beds and living labs represent an experimental, co-creative approach to innovation policy that aims to test, demonstrate, and advance new sociotechnical arrangements and associated modes of governance in a model environment under real-world conditions. In this paper, we develop an analytic framework for this distinctive approach to innovation. Our research draws on theories from Science and Technology Studies (STS) and Innovation Studies, as well as in-depth empirical analysis from two case studies – an urban smart energy campus and a rural renewable energy network. Our analysis reveals three characteristic frictions that test beds face: (1) the limits of controlled experimentation due to messy social responses and co-creation activity; (2) a tension between lab-like open-ended experimentation and pressures to demonstrate success; (3) the opposing needs of local socio-cultural specificity and scalability, i.e. the inherent promise of test bed outcomes being generalizable or transferrable because the tested "model society" is presumed to represent a future society at large. These tensions suggest that thinking of test beds as mere technology tests under real-world conditions is insufficient. Rather, test beds both test and re-configure society around a new set of technologies, envisioned futures, and associated modes of governance – occasionally against considerable resistance. By making social order explicitly available for experimentation, test beds tentatively stabilize new socio-technical orders on a local scale in an "as-if" mode of adoption and diffusion. Symmetric attention to the simultaneous co-production of new technical *and* social orders points to new opportunities and challenges for innovation governance in test-bed settings: Rather than mere enablers of technology, test beds could serve as true societal tests for the desirability of certain transformations. This will require rethinking notions of success and failure, planning with a view towards reversibility, and greater scrutiny of how power is distributed within such settings. Likewise, rather than envisioning test beds as low-regulation zones to drive innovation, they could be strategically deployed to co-develop socially desirable governance frameworks in tandem with emerging technologies in real-time.

1. Introduction

"Test beds" – and related concepts such as "living labs" or "real-world laboratories" – have emerged as a prominent approach to structure and stimulate innovation by testing new sociotechnical arrangements *in situ* and at a meso-scale (Evans and Karvonen, 2014; Groß et al., 2005; Hilgartner et al., 2015; Kareborn and Stahlbrost, 2009; Laurent, 2016; Renn, 2018; Stilgoe et al., 2013)[1] . For example,

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[1] Much of the literature (and many actors) use these terms somewhat interchangeably, depending on their empirical focus and disciplinary backgrounds. In this paper, we use primarily the term "test bed" for reasons of consistency and in alignment with our theme of "testing societies." This is not to suggest any sharp boundary to other terms. While distinct definitions are possible and helpful for certain analytic purposes, we are interested in certain characteristics that are *shared* by many of these concepts: a focus on experimentation, presumed spatial delineation, incubation of social transformation, co-creation, scalability, governance challenges, and a number of others. We will provide a working definition of "test beds" below that highlights these common features and point out differences to other concepts where needed.

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in September 2017 Canadian Prime Minister Justin Trudeau announced that Sidewalk Labs, a start-up under Google's parent company Alphabet, was approved to turn Toronto's waterfront into "a proving ground for technology-enabled urban environments around the world" (Hook, 2017). The initiative aims to integrate self-driving shuttles, adaptive traffic lights, modular housing, and freight-delivering robots – a "test bed for new technologies … that will help us build cleaner, smarter, greener cities," according to Canadian Prime Minister Justin Trudeau. To that end, the city made a commitment to "waive or exempt many existing regulations in areas like building codes, transportation, and energy in order to build the city it envisioned" (Hook, 2017).

In other places, test beds for autonomous vehicles are flourishing, affecting rural roads, highways, and cities alike (BR, 2016; Quartz, 2017). Test bed projects for smart and sustainable cities, whether in South Korea (Songdo), China (Tianjin), or Abu Dhabi (Masdar City), are experimenting with ways to fuse innovation with urban life to enable both new forms of urbanity and new forms of innovation, frequently with the ambition to become a model for other cities. University science parks and research campuses, too, are increasingly integrated with local industry and government partners, for example in the form of renewable energy smart grids or to explore new hybrid forms of knowledge production and implementation (König and Evans, 2013). On a larger scale, entire regions have been framed as test beds for regional re-development around certain technology clusters in an attempt to find recipes against economic and social decay also in similar regions (Späth and Rohracher, 2010).

Test beds resonate strongly with recent developments in innovation policy that emphasize "directionality" in innovation and seek to orient innovation systems towards "Grand Societal Challenges," "missions," or particular societal needs (e.g. of emerging economies) (Kuhlmann and Ordóñez-Matamoros, 2017; Kuhlmann and Rip, 2014; Mazzucato, 2018). Many test beds are initiated in collaboration with governmental bodies, emphasizing public good aspects and what Steinmueller and Schot, 2016call a new "Frame 3″ for transformative innovation policy. Moreover, they are frequently designed as explicit stepping stones for wider systemic transformations (Pfotenhauer, 2017) or as instruments for strategic niche management (Schot and Geels, 2008a).

While heralded by policy-makers for their transformative potential and directionality, test beds have also been subject to considerable contestation. Critics perceive these initiatives as profound social and political interventions that tend to evade democratic accountability, lack proper regulatory control or even suspend regulation, and hand over public spaces to companies – all in the name of innovation. For example, in the case of Toronto's Waterfront, the third advisory board member stepped down in 2018, as "senior leadership is consistently dodging important questions from concerned citizens and the media" about an initiative that will lead to a "monopoly-tech-company led, surveillance-based city" (Muzaffar, 2018). A number of accidents by self-driving vehicles, including the death of a cyclist in Tempe, Arizona, caused by an Uber test car (The Guardian, 2018), have sounded alarm bells and raised questions about different regulatory standards and approaches in global technology development. These examples suggest that traditional approaches for technology testing, product regulation or informed consent might be ineffective in test bed settings. This is partly due to the ambivalent role of society in these sites and partly because governance mechanisms are explicitly seen as up for grabs. They also reveal how power, benefits, and costs get re-distributed, and competing visions for the future of society negotiated, in sociotechnical transformations (Brown et al., 2000; Engels et al., 2017; Wentland, 2017).

In this paper, we develop a conceptual framework for test beds as an emerging instrument in innovation policy and a potential tool for the responsible governance of emerging technologies. We build on research from science and technology studies (STS) and innovation studies to explore the questions precisely what *and* who is being tested in test beds settings, which challenges actors face, and how to deploy test beds responsibly as instruments of innovation governance. Using data from two case studies situated in the context of the German energy transition, we investigate the conceptual, political, practical, and normative underpinnings of test bed-driven innovation. Test beds require a shift, we argue, in the conceptualization of what innovation is, how it operates, and who ought to be involved: Rather than seeing them as a means to test technologies in a real-world environment or as a tentative, locally confined release, we find it more helpful to focus on how test beds reconfigure societies – "testing" them against an envisioned new sociotechnical regime and associated visions of desirable futures (Wentland, 2016). This shift in perspective sheds light on three characteristic tensions that test beds regularly need to navigate: logics of experimentation, the creation of path-dependencies, and the limits of scaling up. The symmetric focus on technology testing and social intervention raises important questions about the responsible use of test beds as vehicles for innovation as well as their potential as instruments of innovation governance.

2. Developing a framework for test bed innovation

In the simplest sense, test beds could be considered controlled experimental spaces that facilitate a kind of performance or hypothesis testing under presumably realistic conditions. Test bed research might ask: Will commuters make use of ridesharing or switch to electric vehicles if parking and charging stations are distributed in a certain way – and, if so, what are the optimal distributions? Do the algorithms and sensors supporting autonomous vehicles really reduce accident rates – and what kind of sensors do we need to make that happen? Do robots perform reliably in complex environments such as hospitals or sewer canals – and what glitches exist? Like traditional technology tests, test beds thus share a number of characteristics with scientific hypothesis testing, including a focus on reproducibility and controlled environments (Pinch, 1993). They are expected to serve as benchmarks for functionality and reliability that confirm (or refute) certain predictions and can guide further development. This benchmarking may happen at different stages of technology development as prospective, current, or retrospective tests – each with their own purposes and requirements of control (Pinch, 1993).

Test beds have also been heralded as opportunities to learn from user feedback and data collection prior to a commercial rollout as part of the technology design process (Almirall et al., 2012; Dell'Era and Landoni, 2014). In this sense, test beds share some characteristics with beta-testing, field-tests, prototyping, and other open formats of testing unfinished devices, all of which hold considerable sway in engineering communities (Kullman, 2013; Suchman et al., 2002). They also resonate with notions of technological learning as prevalent in the innovation systems and evolutionary economics literature (Archibugi and Lundvall, 2001; Edquist, 2009), as well as the idea of strategic niche management known from the transition studies in which technologies can mature in protected spaces before being rolled out more broadly (Schot and Geels, 2008b).

At the same time, test beds break with these traditional understandings of technology testing and learning in important ways. First, unlike simple technological tests of individual devices, their envisioned benefits are tied to the possibility of testing (and jumpstarting) full-fledged new ways of living under the assumption that certain systemic changes have already happened and that society (at least in this model environment) has adjusted accordingly. Test beds thus often require substantial interventions into social orders, albeit at small scale. For example, the implementation of an urban test area for autonomous vehicles interferes with existing relationships between drivers, bikers, pedestrians, police officers, insurers, local residents, passers-through, roads, street signs, digital infrastructures, etc. – relationships that are tacitly relied upon and often legally codified. To that end, test beds may require the alteration of local laws and regulations, like zoning laws, privacy laws, liability regimes, or taxation, which is often considered part of what is experimented with and "tested." Test beds thus share some features with the idea of regulatory sandboxes, where exceptions to rules and regulations are approved on an on-off basis to foster innovation. They also resonate with research on the epistemic and material construction of "exceptional places," whether laboratories, special economic zones, or the containment of bio-threats (Latour, 1988; Laurent et al., forthcoming; Lezaun and Porter, 2015; Shapin and Schaffer, 1985), as well as studies of social engineering (Scott, 1998). Importantly, as societal interventions, they are tied to collectives rather than individuals, and hence inevitably raise questions of politics and governance.

Second, test beds and living labs thus re-interpret what is meant by "laboratory" in that they do not test technologies in a separate space *prior* to use within society. "Living" labs rather test new sociotechnical arrangements by tentatively adopting the very technologies in question "as if" the involved technologies had been found safe and had entered the market already. In effect, test beds introduce and tentatively adopt an emergent, unfinished and potentially risky technology precisely because certain design questions about risk and safety can only be resolved based on empirical use data. Thus, traditional boundaries between technology creation and use are blurred deliberately in test bed situations. This speculative introduction of not fully tested technologies and associated risks into society resonates with the idea of "society as a laboratory" introduced to capture the irreducible uncertainties and de facto non-testability when introducing large-scale technologies with systemic consequences, e.g. in the case of nuclear power (Beck, 1992; Krohn and Weyer, 1988). It goes beyond traditional "field tests" in that the explicit goal is the continued development, not the careful release, of a new technology, frequently by involving locally defined test populations.

Third, as a socially embedded approach to testing, test beds tailor innovation to the particular needs and conditions of concrete real-world sites. They frequently bring together unique actor constellations – scientists, engineers, government bodies, non-governmental organizations, consumers, users, producers, infrastructure developers, citizens, etc. – to develop solutions in a co-creative mode of engagement for a particular location, e.g. a city neighborhood or rural co-operative (Engels et al., 2017). This links the outcomes of test bed initiatives firmly to the particularities of that place, including the constellation of supporting actors, and complicates the common expectation that these outcomes could be usefully scaled to other scenarios (Canzler et al., 2017).

Fourth and related, by testing in a "miniature society," test bed developers make an active decision about what they consider to be a truthful representation of society.[2] One key insight from the "sociology of testing" (Pinch, 1993) is that what counts as real-world conditions for testing is never just "out there," but always subject to interpretation and occasionally highly contested, for example after accidents and disasters. Criteria of similarity and difference between the test environments and the real world are always actively chosen, evaluated, legitimated, and negotiated based on a range of contingent social factors (Constant, 1983; Mackenzie, 1989). For example, what counts as a credible use environment or expected bystander behavior for self-driving or electric cars is neither self-evident nor universal (Stilgoe, 2018). STS scholars have argued that what is being tested in technology tests is not so much the technology as the user in her ability to act according to the envisioned use patterns inscribed in the design of the technology (Oudshoorn and Pinch, 2003; Verbeek, 2006).

Finally, as social interventions based on certain assumptions about desirable technological change and real-world use patterns, test beds are necessarily political and normative, even if limited in scale. They embody particular visions of a future society, shaped by particular interests of those involved. As Hilgartner has shown, political debate over such temporarily materialized "vanguard visions" play a key role in "promoting or inhibiting [certain directions of] sociotechnical change. How, for example, do 'unimaginable' technological revolutions become not only imaginable but, at least for a time, plausible?" (Hilgartner, 2015). Test beds can be understood as public demonstrations and catalysts by which "relatively small collectives … formulate and act intentionally to realize particular sociotechnical visions of the future that have yet to be accepted by wider collectives, such as the nation" (Hilgartner, 2015: 34).

Given these various complications to the simple notion of a technology test, a more apposite starting point for theorizing test beds is the framework of *co-production* (Jasanoff, 2004). Co-production invites us to consider symmetrically how changes in social and technoscientific orders shape each and evolve in tandem. That is, changes in technology can at once be considered as interventions into the organization of society, just like social and political factors influence which technologies are deemed safe, desirable, and imaginable (Jasanoff, 2006; Jasanoff and Kim, 2015), or why and how societies engage in innovation (Pfotenhauer and Jasanoff, 2017). From this symmetric vantage point, it is society *as well as* technology that are subject to experimentation and testing in test bed settings. Test beds introduce and tentatively stabilize new sociotechnical arrangements – tied to a more or less well-defined local "test population" and relatively strict forms of spatial confinement and separation (e.g. a city, district, campus, or a special zone). They gauged these arrangements for potential problems, both in terms of technical performance and societal uptake. This locally stabilized "model version" of a new society is then frequently envisaged as the template for a scalable transformation by way of expanding the area outward (e.g. in the case of autonomous driving) or best practice transfer to other sites (e.g. smart cities).

Building on the idiom of co-production and our empirical analysis below, we define test beds as spatially confined, purposeful experimental settings aimed at testing and demonstrating the viability and scalability of new sociotechnical orders and associated forms of governance based on particular visions of desirable futures. This definition goes beyond a purely affirmative or instrumental take on testing, and captures what we consider the most salient analytic aspects of test beds: their overt intervention into social order with some form of delineation; the implied directionality of innovation (i.e. its normative character); the ambiguity between testing as benchmarking and testing as open-ended experimentation for learning; the role of public demonstration, the wide range of regulatory and governance implications; and the ambition to scale or transfer the results. In the following, we will trace these aspects through two case studies to explore how precisely they test societies and what can be learned from a more symmetric perspective on testing.

3. Methods and data

Our research uses a qualitative case-study approach (including limited-scope comparison) to build theory and extract generalizable observations (Eisenhardt and Graebner, 2007; Gibbert and Ruigrok, 2010; Yin, 2014). Case studies have maintained popularity in innovation research over the last few years because of their advantages in the exploration and understanding of complex social changes associated with emerging technologies (Haley, 2018; Pinkse et al., 2018; Turnheim and Geels, 2013). Our work draws on several periods of ethnographic fieldwork over five years, three dozen interviews, and extensive document analysis (Table 1). The long duration of the fieldwork allows us to cover a range of key moments in the life cycle of these initiatives, including their launches and early struggles, strategic decisions, shifting visions as well as day-to-day interactions. One of our authors was a participant observer in both projects and took part in project meetings,

[2] This construction of truthful representations resonates with research into the construction of publics through the participatory instruments, e.g. in public engagement exercises (Chilvers and Kearnes (2016); Felt and Fochler (2010); Voß and Amelung (2016); Lezaun and Soneryd (2007).

Table 1
Overview of empirical material.

	EUREF Campus	Energy Avantgarde Anhalt
Research period	10/2013-05/2016	11/2015-09/2017
Methods	Ethnography (observation, participation), interviews, document analysis	Ethnography (observation, participation), interviews, document analysis
Number of interviews	23 (incl. 2 group discussion)	13 (incl. 1 group discussion)
Type of documents	Newsletter, website, presentations, press coverage and press releases, social media, meeting minutes	Presentations, corporate publications, website, workshop and meeting minutes, press releases, social media

workshops, and informal talks. Given that many internal power relations, motivations, and interpretative patterns cannot be understood adequately from the "outside," this ethnographic work offers unique and valuable data to understand the mechanisms and operational modes of test bed sites in the making.

For our interviews, we chose a semi-structured, narrative-generating approach (Flick, 2010; Lamnek, 1989) to gain insights into the motivations, the accompanying visions and expectations, and the assessments of the actual test beds' developments from most of the actors involved. Our interviews included members of the initiatives' executive board and advisory boards, project leads, the heads of the funding institutions, and other involved developers, academic project partners, business representatives ranging from larger companies to start-ups, citizens, and users. Both sites were observed for a sufficiently long enough periods to capture both long-term participants and newcomers. All interviews were transcribed and coded with help of QDA software, as were documents and images. Our sample of two cases covers some of the heterogeneity of the test bed and living lab landscape; in particular, different test bed scales (an urban campus versus a regional network) and different organizational models. However, both test beds are also similar in that they were established as part of the German energy transition. Both focus on renewable energy and associated technologies such as smart cities and electric vehicles.

We adopted an iterative, inductive approach to extract the relevant tensions and characteristics of test beds. Here, our previous research on imaginaries of innovation (Engels and Münch, 2015; Pfotenhauer et al., 2018b; Pfotenhauer and Jasanoff, 2017) and further literature dealing with, among others, aspects of social testing (Chilvers and Kearnes, 2016; Pinch, 1993), competing visions (Konrad, 2013; Nordmann, 2013) and the co-production of technical and social orders from a comparative perspective (Jasanoff and Kim, 2013) served as initial sources for the analytical themes that guided the analysis of our empirical material. In our analysis, we extracted recurring themes across our data sets in order to depict: how actors define a "test bed" or a "living lab" and what they see as its necessary components; the individual expectations and visions and how these got inscribed into the respective test bed's design; the collective processes or contestations that may have led to changes and adaptions of the test bed; the role of the public and the user in these testing environments; as well as perceived tensions within the test bed strategy and corollary strategies to deal with the tensions. We condensed the themes into a set of codes and sub-codes, such as "mode of experimentation," "interpretation of testing," "scalability of the test bed," "competing visions," "organization of actor network," "participation," "local embeddedness," "perceived tensions," and "process dynamics," among others.

The research team applied this systematic approach to all available interview transcripts, sorting the data into these condensed and classified sections to capture the essence of each broader category and to prepare it for qualitative content analysis (Berg and Lune, 2012). Simultaneously, we related the interview data and the ethnographic material (statements from our field notes) to the results generated in our ongoing document analysis, which covered press releases and further materials, like websites and presentations from (internal and public) meetings.[3]

4. Testing future energy systems *in vivo*: two case studies

Over the past two decades, Germany's "*Energiewende*" has received considerable attention for its national flagship commitment to transition towards a low-carbon energy system and addressing a number of associated challenges, including sustainability, climate change, and innovation leadership in renewable energy technology. International observers have commended the country's coordinated effort to invest in decentralized renewable energy sources, such as solar and wind power, and the strong civil society backing it has enjoyed. While efforts by the federal government have arguably lost some momentum in recent years,[4] actors at the sub-national level have increasingly stepped up their engagement (Späth and Rohracher, 2012). Though not as visible as the national nuclear exit, the country has seen a flourishing of local innovation initiatives to test and implement new technologies and approaches in the energy sector at small scale – driven primarily by municipalities, regional alliances, non-governmental organizations (NGOs), and companies. This paradigm shift towards a bottom-up understanding of *Energiewende* based on local test beds, experimental spaces, and real-world laboratories as means for socially embedded innovation has received the blessing of the country's most powerful science organizations (Stifterverband für die Deutsche Wissenschaft and others, 2017) and the federal government itself (German Federal Government, 2015).

Taking this surge of local test bed initiatives for energy transitions in Germany as our motivational point of departure, we selected two (out of several dozen) cases for in-depth empirical study – the urban smart energy campus "European Energy Forum" (EUREF), and the regional renewable energy network "Energy Avantgarde Anhalt" (EAA). Both cases refer to themselves explicitly as test beds and/or living labs that have been featured repeatedly as flagship public demonstration projects.

4.1. The urban smart energy campus "European Energy Forum" (EUREF)

The EUREF campus – a "urban living lab for the *Energiewende*" and self-proclaimed "future place" (EUREF Campus Berlin, 2019) – is located within the district of Tempelhof-Schöneberg just southeast of the city center of Germany's bustling, cosmopolitan capital Berlin. With considerable support from public funding, EUREF has become a national flagship initiative and go-to reference point for the integration of energy, mobility, and building technologies. It features a micro-smart

[3] Since all available documents and the interviews transcriptions are in German, the quotations added used in this article were translated by the authors into English.

[4] The federal government has recently reduced incentives for renewable energy investments and partly re-oriented its policies towards coal extraction. Germany will likely miss its COP21 targets and has already lowered its climate goals, and other countries such as Sweden, Finland, and Portugal are emerging as new reference points in the global energy transition landscape.

grid, electric and autonomous vehicles, charging stations, wind turbines, solar photovoltaic systems, and a biogas-powered cogeneration plant, among other things. Located on the premises of a late-19th century former gasworks, a protected cultural heritage site purchased by a private investor, the campus shares some of the trademarks of post-reunification Berlin: industrial brick-and-mortar charm combined with glass façades and high tech, the scars and multiple layers of German history, and an unwavering appeal to a young, cosmopolitan crowd. Moreover, the campus is fenced off from its urban surroundings and accessible only through guarded gates.

EUREF's spatial delineation and private ownership have enabled a controlled environment as well as a relatively large degree of regulatory and organizational flexibility. For example, EUREF has implemented a customized road traffic regulation that gives privileged access to electric vehicles over combustion engines. Self-driving cars can be tested without the interference of Germany's strict road safety regulations, as can e-scooters whose introduction in Germany is still widely debated. This flexibility over space, projects, and people emphasizes a relatively systematic and controlled take on experimentation and testing. As one lead researcher in a smart grid project expressed, "[EUREF is] a living lab that allows us to try out what others only simulate and write about; where we learn for each domain ... from a legal and technological perspective, what stumbling blocks one will face in bringing such ideas to market."

At the same time, the diversity of tenants and local stakeholders, as well as frequent changes in infrastructure, has put limits on the extent to which scientific activities can be controlled or even anticipated. Since its inception in 2007, EUREF has grown to host approximately 3500 engineers and office workers within a 5.5-hectar area. A total of 150 companies and research organizations are located at EUREF, including large multinationals like Cisco Systems (with EUREF's "openBerlin" being one of nine international Cisco Internet of Everything Innovation Centers), the energy company Schneider Electric or the German railway company Deutsche Bahn alongside a significant number of start-ups.[5] Given the flurry of projects and explicitly fostered co-creative, cross-initiative interactions, it is at times unclear to actors what exactly is, or should be, demonstrated, as expectations and parameters are frequently shifting. Over the campus's lifetime, the installation of different types of charging stations for electric cars, ongoing adjustments to the campus's road and traffic system, as well as new office buildings have required repeated massive construction works. One engineer emphasized that

> "a lot can change very quickly; infrastructural assumptions on which we base our planning will be suddenly overturned completely. On the one hand, this is precisely the charm of the campus and why we are investing in it; on the other hand, it makes any straightforward approach impossible and requires us to constantly be flexible and adaptive."

The frequently changing conditions are also indicative of continual struggles over the purpose and directions of the EUREF test bed, and over whose interests are actually represented and furthered. As one interviewee described it, at all times "fights have to be fought [about] different interests and repeated disputes [and] how far one can actually go." One research engineer remarked on the constant "back and forth between 'Do we want more micro-smart grid?' or 'More overall floor space'" – a key tension between competing visions of EUREF as a research site and an attractive business location (Engels et al., 2017). While many actors consider EUREF a commercial success, for many scientists and engineers it does not live up to its promise of a controlled laboratory where they could test hypotheses under real-world conditions, let alone learn from failure. Similarly, many actors primarily view the overall mission of the EUREF campus as a showcase to publicly demonstrate the viability and success of the "*Energiewende*" – "proof that the *Energiewende* is feasible," as one project partner puts it. For policy-makers in Berlin and the federal government, the campus has become a regular and proudly featured stop for national and international delegations, business representatives, and scientists, to demonstrate the innovativeness of the city and possible solutions for challenges that other regions might be facing as well. For example, during her recent visit, German Federal Minister of Education and Research, Anja Karliczek, pointed out EUREF's crucial relevance for these challenges and its particular approach of finding solutions:

> Like under a burning lens, cities concentrate the central challenges of our time … Energy use, mobility, use of resources – we need practicable and sustainable solutions for these topics. This is why research, business and society work closely together on the EUREF Campus in Berlin. (Berlin Senate Chancellery for Higher Education and Research, 2018)

The showcase character is also evident in that has contributed to internal benchmarking pressure to "beat" American and Asian developers in the development of a viable new energy paradigm for urban living. Being "faster" and "bolder" than competitors is thereby perceived as a virtue and a core part of the campus's identity, as one interviewee proclaims. A group of engineers in the campus's micro-smart grid project argued that innovation "only happens through visible demonstration" vis-à-vis competitors, potential partners, and customers. A managing director of a large corporation with a branch at EUREF explains how abandoning traditional headquarter processes has allowed him to build prototypes "five times faster" in co-creation with partners, start-ups and customers.

The showcase character is further underscored by EUREF's physical appearance. Located on the premises of an iconic landmark gas storage facility that was essential to Berlin's energy supply in the first half of the early 20th century – the "Gasometer" –, EUREF makes symbolic use of the "aura" of this place. In the words of its participants, the campus's appearance renders the overall narrative and mission of the campus "logical" and "self-explanatory" to the public as a place where people deal with energy issues and from which Berlin will prosper. In all these regards, the campus is not just a neutral test site for novel technologies but also proof of the viability of Germany's national policy strategy and a real-world manifestation of a certain vision for working and living in the capital city.

Yet, the constant pressure to convince both locals and the outside world of the campus's key role in attaining a larger promise of societal transformation stands in partial conflict to the idea of scientific hypothesis testing and open-endedness in terms of outcome. Researchers and engineers face pressure to give way to ever-more tangible forms of demonstration and materialization, even if they deem the technology immature. Their perception is that EUREF's purpose is more about convincing investors, politicians and the public of the viability and superiority of certain technological paradigms than it is about exploring them.

For all its emphasis on uniqueness, EUREF also sees itself as a model, with ambitions of scalability in at least two senses. First, the technologies developed at EUREF ultimately ought to benefit Berlin. Many participants suggest that testing in EUREF is, in effect, equivalent to testing in the city and that technologies ought to be developed with a view towards their citywide feasibility. As one member of the micro-smart grid project explains, the focus on Berlin forces them to make the new paradigms "even more robust," particularly "the technologies behind it, the interfaces, the optimization." Second, in the eyes of many, EUREF serves as a miniature future city that could become a template for other cities than Berlin in terms of how to integrate energy, IT, and

[5] It also hosts research partners from the Technical University Berlin, the Potsdam Institute for Climate Impact Research, or the Mercator Research Institute on Global Commons and Climate Change, the KIC-affiliated climate innovation incubator "Green Garage," and has close links to the federal government and the City of Berlin (which regularly takes EUREF as reference and focal point for city initiatives, e.g. the recent smart city strategy).

mobility technologies in an urban environment. Thus, the main goal is not "to turn Berlin into a demo center for [company name]," as a managing director of a resident IT company put it; instead, Berlin itself should eventually become a "living smart city concept. … We just want to demonstrate that you can [implement smart sensor technologies] in a very small, scalable way."

Despite these overt intentions to scale up, the relative isolation of the gated EUREF campus from its Berlin neighborhood has limited the extent to which test bed activities are integrated into wider urban life, and how the local population can interact with EUREF's plans and tenants. While some technologies have also been tested outside the campus, broader sociotechnical living arrangements around integrated energy, mobility, and information technologies – including novel forms of regulation – have not made it beyond the test bed's high fencing. In part, this is because of the limited overlap between EUREF activities and Berlin's citizenry. Local residents have described the site as a "landed UFO" without any relevance for their everyday lives. One manager admits that EUREF "feels very, very technical and foreign to these people." In his view, the campus as a living lab still needs to "become more lively and contested" to be significant for Berlin as a whole. EUREF's model thus brings into relief the trade-offs between a tightly controlled experimental environment on private grounds on the one hand and, on the other, the potential benefits for up-scaling entailed by a more permeable, inclusive, and democratic test bed format.

While EUREF's impact on a scalable urban energy and sustainability transition might have been limited, the campus has indeed become widely noted as a best-practice model for innovation. EUREF's "test bed" reputation has become an "export product" in its own right, as one researcher put it. Rather than becoming a hub for regional rollout of smart and green technologies and associated new ways of living, EUREF leadership recently revealed plans to actively transfer the test bed campus concept to a former coalmine industrial site in the city of Essen (North Rhine-Westphalia) – a region with equally close ties to Germany's energy history: "In Essen, we want to expand and further develop what is happening in Berlin," the investor explains (Meinke, 2017). As a visual link, the gasworks dome will be moved from Berlin to the new campus and placed onto a cooling tower. Besides the second EUREF Campus in Essen ("EUREF-Campus Zollverein"), EUREF architects are also advising various Chinese cities on how to build smart, carbon-neutral city districts, and what role a test bed concept like EUREF can play for them. Yet, as some researchers have remarked, it remains to be seen if EUREF practices can indeed be sufficiently standardized to enable national or international emulation. Many see the unique value proposition and source of public credibility rooted in the uniqueness of the Berlin co-creation site as it is tied to specific local energy histories.

4.2. The rural renewable energy network "Energy Avantgarde Anhalt" (EAA)

Located in the Eastern region of the German state of Saxony-Anhalt, EAA is only an hour drive from EUREF and yet seemingly lightyears away. Like all former Eastern German states, Saxony-Anhalt has suffered from considerable demographic, political, and economic fractures over the past thirty years and continues to struggle with developing robust sources of economic growth. Its population features the highest average age and second-lowest GDP per capita among all federal states.

The rural renewable energy network EAA was launched in 2014 – partly in response to the perceived lack of tangible regional results from the federal *Energiewende* initiatives, partly as a regionally tailored socioeconomic development strategy. It was crafted around a vision of local energy production and consumption and based on local models for integration of electricity, heat, and mobility. It built on previous energy initiatives that had already pushed the region's share of renewables in the electricity mix close to 50 percent prior to EAA's launch (Energieavantgarde Anhalt, 2018). It also built on informal networks established during earlier attempts to position Anhalt as a hub for the federal *Energiewende*. Over the years, EAA has attracted considerable interest from national foundations, companies, and research organizations around its vision of local energy systems transformation.

From the beginning, EAA's strategy focused on regional co-creation and experimental implementation as cornerstones of energy research, technology development, business ideas, and new social organization models. As described by the EAA website, the "necessary technical, economic, and socio-cultural changes are being fashioned jointly by partners like the regional public utilities, renewable energy companies, and many municipalities. ... We call this big experiment the *Reallabor Anhalt*" (Energieavantgarde Anhalt, 2018).

In contrast to EUREF, EAA is not fenced-off. The "Reallabor Anhalt" region comprises more than 3500 square kilometers (almost one fifth of the state's territory) and 380,000 inhabitants across many different municipalities. Necessarily, ideas of experimentation, testing, control, and co-creation take a very different shape. To begin with, EAA needs to accommodate various publics, spread out over much larger territory, in its co-creation processes. Its deliberation and implementation plays out in public rather than in a private space. To enable formal representation of the diverse stakeholders and encourage participation, EAA chose a non-profit organizational status and a governance structure that tries to account for heterogeneity. Individual citizens are invited to participated in governance bodies alongside organized interests, such as companies and government. In the words of a research manager, "it takes a network approach to grasp the complexity [of social reality]" and to "capture, understand, and model it." This is, according to him, "precisely the approach of a real-world laboratory." Despite the good intentions, however, few individual citizens have actually joined the association. Instead, the core group consists primarily of experts and professionals from regional organizations, such as energy suppliers, public utility companies, and municipalities. Also participating are supra-regional organizations like foundations, research institutions, and the country's central federal authority on environmental matters.

Partly owing to this imbalanced representation, understandings of what the goals of the initiative were quickly diverged. How open or controlled the test bed should be is a contested matter. Actors remain at odds about what precisely ought to be tested. While some have accepted the unruliness, unpredictability, and genuine open-endedness of a public test bed of this scale and diversity – "you can never plan anything like [a regional transformation]" –, others saw EAA as a "business project" that required, like any other project, a concerted "effort of management and coordination" for successful implementation.

These tensions have been particularly pronounced in recurring conflicts between local and non-local EAA members, centering around questions about who gets to decide on the future of the region and whose vision is represented in the test bed. Here, the primarily local interests and deep rootedness in a regional identity of some stakeholders clashed with those of national or global actors. For many local participants, EAA stood for an opportunity of regional revitalization, distinction, and potential leadership. Blessed with a rich cultural heritage, Anhalt takes pride in being the cradle of the Protestant Reformation, a stronghold of enlightenment, and the former home of the modernist Bauhaus avant-garde. It features three UNESCO world heritage sites – including the Luther Memorials in Wittenberg and the Bauhaus Dessau – and self-consciously portrays itself as a spearhead of modernity, transformation, and visionaries. Many local actors emphasized that in order for EAA to be successful as a harbinger of transformation, it must be rooted in the region's cultural identity or, at the very least, should "harness the tradition to get attention," as one local interviewee put it.[6] At the same time, many local actors underscore that

[6] In almost every presentation or talk, the region's cultural heritage is utilized to lend credibility ("a credible tradition of reformation") and to legitimate current activities by referring to "historical reference points."

small but tangible benefits for the people living in the region are crucial for the credibility of the initiative in this economically problem-ridden region, and should take priority over "superficial attention seeking around the world." A local member of the network contended: "They can tweet all day long, for all I care, or other things that I cannot do. But we have to look at this region, which is aging. These are real people who just want to make their living, build water storage, or convert their heating systems. They are not leaders in IT or design. And yet our communication is geared towards [IT and design leaders]."

In contrast, national and international actors do not share the sense of regional particularity. To them, Anhalt is a smaller-scale stand-in for Germany's rural transition challenges writ large, both in terms of energy and socioeconomic transformation. For non-local actors, the features of Anhalt resemble those of many other rural German and European regions: low population density, a rural lifestyle, a problematic legacy energy infrastructures, the continuing decline of local industry, unemployment, an aging and declining population, the absence of a credible vision for the future of the region, and a resulting willingness of (or necessity for) public bodies to be open to experimentation. Many national actors expect EAA to serve as a playground and experimental space, putting at their disposal regulations and economic models that would be off limits at a federal level. As one participating manager suggests, rules and legal "frameworks will adopt to our thinking" to avoid "cutting off development processes." From a federal perspective, EAA is thus as much about placating regional economic development concerns and finding a region willing to experiment as it is about Germany's energy future.

These different perspectives create an ambivalence around what precisely the mission of the test bed is. On the one hand, some participants want to measure EAA's success by what it has achieved for Anhalt – "a local effect for the region," as one member puts it, tied to a genuine openness of outcomes. A local manager suggests, "that's what I call a laboratory: an exploration. Putting everything in and see what comes out. If it explodes, then we made a mistake, and if something new comes out of it, that's also nice." This quote emphasizes that EAA is as much about accepting, and learning from, failures as it is about success. In practice, this openness to failures has also led to "distrust in a single technological solution," as one of the local key actors explains. There is also an emphasis on diverse technologies, actors, and approaches. Focusing on a single technological project, like e.g. a large investment in a specific energy storage system, bears the risk of following a "wrong-headed development" for the region.

On the other hand, EAA is under pressure to limit open-endedness and show tangible outcomes on a national scale. From a federal perspective, EAA is a flagship demonstration project for the rural dimensions of the *Energiewende*, not just regionally but nationally – a proof of concept for "the energy transition as imagined by the German government," as one participant from Berlin suggested. If the regional network were to fail, it would provide strong evidence that the envisioned transition would not work on a national scale, either: "If everything we tried failed to make any significant progress – considering the complexity of the actors, the networks, the good ideas we have had – then the *Energiewende* will not succeed," one network member from Berlin explains the EAA's pioneering role.

These competing visions for EAA have implications for how actors perceive the future of the initiative and the relevance of its outcomes. Whereas national actors emphasize the similarity in Anhalt's challenges to those of other regions and focus on the touchstone role EAA can play for the *Energiewende*, local actors tend to dismiss the idea of becoming a model. For one, they insist that the cultural heritage and citizen interests are too unique to allow for replication elsewhere. They are also skeptical that transfer or scalability could ever work. Citing their own research into "so-called model projects and model regions, we realized rather quickly that we needed to be careful with 'model initiatives.' [Those initiatives] did not achieve real sustainability, because at the end of the day it was a simulation of things ... that fell apart the moment the project was over, since it did not create sufficient substance. ... That's why, we said no, we don't want to be a model."

This divergence in vision has only increased over time for EAA. Local actors increasingly perceive their role as predominantly controlled by a group of outsiders and experts, which in turn has created a sense of resistance. Tensions about the scope and governance structure of the test bed have even resulted in an organizational split – between a central project office in the capitol that can cater to national actors and visibility, and local branch office. A regional EAA member describes this loss of local control as an inevitable dynamic of test beds – an "inherent dynamic development of adding more and more external partners, scientific institutions, foundations, etc., who were interested in this 'real world laboratory' and who then ultimately defined it."

5. Analysis: testing societies, contesting identities

Our two case studies illustrate how two initiatives in Germany – the urban smart energy campus EUREF and the rural energy network EAA – have used test beds to spur innovation and bring about transformative change. Both act in the context of the *Energiewende,* though with distinct visions of what kind of future was being tested. EUREF proposed a cosmopolitan, high-tech vision of urban living and working in a smart, sustainable, innovative and hip capitol. It was realized through a private sector-led, business-centric initiative that redesigned urban space with frequently changing priorities and alliances. EUREF emphasized a blended technology creation and use environment hosted on privately owned grounds, with a focus on the infrastructure needs of engineering and business elites. EEA, in contrast, aimed to spearhead an energy future based on local energy production, use, and self-sufficiency – with a focus on individual needs, local decisions, and citizen engagement in local transformation processes. It was equally intended to drive socioeconomic revitalization by becoming a model region. Both sites adopted more or less strict forms of spatial confinement (a gated, privately owned campus and a loosely connected regional network that tried to guard against excessive federal influence, respectively), and experimented with new forms of governance and regulation (e.g. by suspending traffic regulations in the case of EUREF, and speculating on adaptive regulation in EAA). In both cases the visions for a future society were regularly contested, as were the purpose, priorities, and design of the test bed: EUREF was justified as a stand-in for a smart and sustainable cosmopolitan city; yet, none of the integrated sociotechnical systems and regulatory concepts were actually tested on a city-wide scale, and the spatial and functional separation of the test bed, fenced off from its environment, contributed to its perception of as a foreign object ("a landed UFO") in the city by local residents. What is more, conflicts ensued over the balance between scientific and business interests, and the pressures of showcasing successes. In EAA, a strong sense of regional identity and purpose by local actors collided with a more disrooted, statistical, centrally managed, scalable vision of economic development for the test bed.

The two case studies further revealed three characteristic tensions that call for a symmetric, co-productionist perspective of technoscientific and social "testing": First, neither case actually amounted to the envisaged smooth testing of a technology in society. While concrete technologies were installed and tested at both sites, each initiative revealed ample conflicts over the purpose of the test bed as well as about whose inputs count when, how, and why. Second, neither initiative was seen as a neutral "test" in the literal sense. Actors in both cases were invested in advancing particular solutions in line with their own values and interests, and frequently interested in demonstrating success rather than open-ended, quasi-scientific testing. Third, in each initiative, actors had to balance the need for a locally specific solution with ambitions of scalability and transferability. This ambivalence had ramifications on the permissible amount of experimentation and the struggles over local identity and control. In the following, we will discuss these three tensions as part of a conceptual and normative

Table 2
Summary of test bed case studies.

EUREF		EAA
Berlin as a smart, sustainable urban space with new forms of energy, mobility, and ICT; blended technology creation and a use environment	**Tested/ envisioned society**	Decentralized approach to local, sustainable energy production and use involving citizens; regional economic revitalization
Gated, privately owned campus	**Spatial confinement**	Loose regional network that guards against national influence
Much leeway on private grounds, e.g. suspending traffic regulations	**Experimental governance**	Expect adaptive regulation
Segregated, well-equipped testing area for social and technical experimentation; co-location; infrastructural adjustments	**Tension 1: control vs. co-creation**	Controversies because of inclusive approach; Rivalries between local and federal interests
Showcase of feasibility of integrated smart urban energy infrastructures; cement innovation leadership	**Tension 2: testing vs. demonstration**	Trial run of the rural German *Energiewende*
Seen as a model for Berlin but not tested outside of spatial confinement (i.e. *with* the rest of the city); transfer of EUREF model to another region	**Tension 3: local solutions vs. scalability**	Diverging commitments to local relevance, national scalability, identity, technological needs, and local economic development

framework that raises crucial design questions for test beds. We summarize the main results of this discussion in Table 2.

5.1. Controlled experimentation vs. Messy co-creation: allowing society to 'speak back'

As discussed earlier, one key value proposition of test beds is their ability to undertake quasi-scientific hypothesis or performance testing in a highly controlled environment. In this understanding, test beds are supposed to be lab-like research settings that enable monitoring or systematic variation of certain parameters in order to optimize the technology in question and catch unforeseen glitches. Our empirical research revealed that in both case studies, however, the environment was neither all that static nor easily controlled. At EUREF, uncertainties arising from evolving priorities, repeated infrastructure overhauls and serendipitous interactions among a heterogeneous set of tenants limited the utilization of the campus as a highly controlled testing site. EAA, in contrast, tried to account for diverse social responses by anchoring the initiative in a broadly inclusive organizational form. Yet, when pressure to exert control and streamline management mounted, frictions between local and federal interests erupted and led to the bifurcation of the organization.

This serendipity is not necessarily unintended. In fact, many test beds (like EAA) deliberately seek out the messiness, diversity of inputs, and unexpected disruptions of real-world environments as an asset for innovation – a trademark of open, creative environments. Yet, the emphasis on messy co-creation stands in sharp contrast to the paradigm of controlled experimentation: Instead of merely observing use behavior and focusing on technology optimization, co-creation processes among diverse groups (e.g. expert developers, users, consumers, governments, or otherwise affected groups) inevitably entail political conflict about what the purpose of a test bed is, whom it serves, how it ought to be governed, and what a "desirable future" looks like (Bijker et al., 1987; Pfotenhauer et al., 2018b). This is reminiscent of Gieryn's (2006) notion of "cities as truth spots" that serve at once as natural field-sites for observations, artificial laboratories for experimentation, and political sites of planning social intervention.

A critical design question for test beds is hence to what extent they allow the tested society to "speak back" – that is, to disrupt preconceived test designs and implementations pathways, and to inject their own visions of a desirable future into the innovation process. Should the environment "hold still" so that developers may observe, or should it "disrupt" the technologist's gaze to enable unforeseen innovative solutions? Are test beds a form of marketing or acceptance research, or a scientific testing ground, or an arena of political deliberation or contestation? Depending on where actors stand with regard to these positions, the value proposition of test beds changes. "Speaking back" is more than just tapping into user creativity or fostering technology acceptance through consumer feedback, as emphasized in much of the innovation management literature (Chesbrough, 2003; Hippel, 2005; Prahalad and Ramaswamy, 2004). It is a form of political participation that can help build democratic legitimacy for social interventions – or oppose them where needed (Irwin and Wynne, 2003; Stilgoe et al., 2013; Stirling, 2008). Scholarship on responsible research and innovation has emphasized the need for instruments of "collective stewardship of science and innovation" (Stilgoe et al., 2013), highlighting aspects like inclusiveness of affected publics, responsiveness towards diverse values, and reflexivity about the purpose of a technology. Test beds must tend to these political dimensions of testing societies lest they wish to run the risk of considerable public pushback.[7]

5.2. Testing emergent technologies vs. demonstrating viability: scrutinizing path-dependencies

A second tension arises between the use of test beds for outcome-neutral, quasi-scientific tests and as a vehicle for vested economic or political interests. In the scientific sense, "testing" entails some kind of expert judgement as to whether the experiment is performed according to some criteria stated in advance. This implies that the test could in theory fail and the involved actors could start again with an alternative course of action. This quasi-scientific understanding stands in sharp contrast to the use of test beds as political and corporate flagship projects that demonstrate, rather than test, the superiority of a new technology. Both of our cases had to walk a fine line between scientific investigation and public demonstration of viability. At EUREF, high visibility in Berlin and internationally, as well as internal global competition put limits on the extent to which testing could proceed open-endedly for scientific ends. Likewise, EAA was considered a trial run of the German *Energiewende* as a whole, with the prospects of the latter seeming to hinge on the success or failure of the former. EAA was also seen as a touchstone for whether other regions like Anhalt could muster energy innovation for an economic turnaround. In both cases, actors placed significant scientific, economic, and political bets on the test bed outcomes, and consequently acted in line with their interests: Companies advanced certain proprietary technologies (e.g. charging stations), at times with little bearing on scientific arguments such as the technology's relative efficacy or efficiency. Politicians occasionally pegged their career on the promise of urban or rural renewal, or sought to gain national visibility through a flagship initiative. Policy-makers hoped to reap returns on research grants and infrastructure investments through local economic growth and high-tech jobs. Researchers and engineers were eager to investigate a fruitful line of inquiry with earmarked funding. Consumers invested time and resources into adopting a technology, e.g. a solar panel, heat pump, or micro-smart grid. All these actors have a plausible interest in seeing the test bed succeed.

From a more critical perspective, this suggests that test beds help create and stabilize the very worlds they ostensibly test – or what has

[7] For example, following considerable controversy around privacy issues, Sidewalk Labs recently announced a "public engagement plan" in order to put "meaningful public engagement, collaboration, and co-creation" at the center of the Waterfront Toronto project Sidewalk Toronto (2018).

been called the "performativity" of instruments (Callon et al., 2009; Mackenzie, 1989). Once initiated, the expectations around test beds channel investments, generate shared agendas, set expectations, give clarity to roles and responsibilities among those involved or affected, and may require new infrastructures, all of which can lead to nascent path dependencies (Borup et al., 2006).

The two paradigms – scientific testing vs. demonstration of success – are not entirely incompatible. In fact, a fully constructivist account would argue that all tests, even the most remote scientific ones, are public performances, and that scientific credibility and political legitimacy frequently go hand in hand. The point here is not so much to judge whether our case studies were "real" tests or "just" demonstration projects guided by particular interests, but rather to acknowledge that there are two sides to the coin. Therefore, we must scrutinize when and how actors mobilize different registers to justify actions, for example a society-wide roll-out of technology. It also puts the spotlight on the alliances that have assembled around test beds and who interpret its activities in terms of success or failure.[8] Finally, it raises the question of how one could design test beds that truly account for the possibility of failure (in the sense of a tested sociotechnical future that turns out to be undesirable). We will return to this point in the final section. For now, it shall suffice to note that neither of our cases had a consensual vision of what they are actually "testing" or what would constitute a "failure," and different actors benefited depending on which criteria of success they applied.

5.3. Unique real-world settings vs. scalable solutions: taking situatedness seriously

The third fundamental tension facing test beds is their dual promise of drawing relevance from the unique social conditions under which they operate and, at the same time, developing scalable solutions that could serve as templates for similar transformations elsewhere once the test is finished. EUREF actively positioned itself as a model for greater Berlin (and other smart/sustainable city initiatives) – paradoxically without ever lowering the boundary between the test bed and the "real world." Partly because of this disconnect, a recent transfer effort to another German region focused on EUREF's role as an innovation hub, not as a hub for regional technology diffusion or energy transformation. In EAA, various stakeholder groups exhibited diverging commitments towards local relevance or (inter-)national scalability, with different investments in regional cultural identity, local technological needs, and economic development. Whereas local actors focused on energy independence and bottom-up solutions and dismissed the reproducibility of their experiences, federal actors were primarily interested in scalable strategies for economic revitalization. However, both test beds touted their "model" character explicitly, which resonates with observations made in other test beds.[9]

The tension between local specificity and envisioned transferability provided ample grounds for conflict. As discussed above, opinions differed as to which goal should take primacy or when to make the switch from local experimentation to global market rollout. Here, power differences among actors – e.g. between engineers and managers, or between individual local citizens and multi-national companies – played a key role in shaping test bed trajectories. In particular, growing pressure to develop standardized one-size-fits-all blueprints, which are more readily transferable, implied trade-offs vis-à-vis time-consuming participatory processes that could have enhanced local compatibility and acceptance. The aim of transferability also forced test bed participants to limit experimentation and codify their practices and technologies rather early. This forced closure stands in opposition to the use of test bed's (co-)creative settings that foster open-ended tinkering, informal networks, trust, and methodological flexibility.

Underlying the ambition of scalability is the assumption that the experience gathered in a unique local setting can be turned into generalizable, quasi-universal solutions that would maintain their validity when removed from their original conditions of production. Recent analyses of efforts to transfer complex innovation models, such as the "MIT model" or the "Silicon Valley model," indicate that the assumption of transferability might be too optimistic and miss opportunities to deliberate and articulate the social benefits of innovation (Pfotenhauer et al., 2018a; Pfotenhauer and Jasanoff, 2017). A key question for the design of test beds is hence how they envision scalability and what ought to be transferred in the first place. By extension, it challenges test bed developers exploring whether the local conditions and practices of genesis are sufficiently understood to be packaged into standardized and transferable products. This recalls a key argument by the sociology of testing that a test "always proceeds by a process of projection" (Pinch, 1993). However, in our case what is being tested and projected are not technologies but full-fledged ways of living. Envisioning test beds with a laboratory-like "placelessness" (Guggenheim, 2012) thus risks foregoing some of the benefits test beds could offer in terms of linking technology with societal needs.

6. Developing innovation and governance in tandem: implications for the responsible use of test beds as policy instruments

In this final section, we shift the focus from conceptual tensions to questions of responsible use of test beds as instruments of innovation governance. The above analysis has brought into stark relief that what is at stake in test bed innovation is social order (Pfotenhauer and Juhl, 2017), and that depending on where test bed actors stand with regard to the aforementioned tensions, test beds can entail different value propositions for society. If test beds are indeed models for future societies with a reasonable chance for broader rollout, then how and by whom are these "model societies" created and politically legitimized? What accountability measures and fail-safes do we have to prevent undesirable developments and unintended consequences? What avenues do test bed populations have to influence, or opt out of, test bed activities? And what opportunities exist to co-develop governance mechanisms in tandem with emergent technologies in real-time?

First, the observed tension between control and openness, and the divergent understandings of "success," make the question of *who* is involved in the design and governance in test beds into a sensitive governance issue. Co-creative, participatory approaches to innovation can grant broader democratic legitimacy than purely top-down, expert-driven forms of technology introduction, but they can also create new forms of exclusion. For example, the fencing-off of the EUREF campus represents a substantial (physical and psychological) barrier for public participation in the design and testing of a "future Berlin." Campus residents concede that random day-to-day interactions with the Berlin public are very limited. In effect, EUREF is testing *in* Berlin and *for* Berlin but not *with* the Berlin citizenry whose future it ostensibly represents. In EAA, power asymmetries and diverging interests between individual citizens and organized interests, and between local and national consortium partners, have revealed deep rifts in the vision

[8] This recalls an argument made by Akrich, Callon, and Latour (Akrich et al. (2002), among others, that innovation success is less about the intrinsic ingenuity of an invention or the identification of an objective need; rather, it is about the assembling of credible spokespersons as part of the project that could signal its political, economic, social, technical, and scientific trustworthiness. Test beds represent such a "microcosm … which represents through a simplified but faithful form all the forces, all the allies which will be necessary to transform an entire society" (Akrich et al., 2002).

[9] For example, Masdar City in the United Arab Emirates is envisioned as a "model city" that can serve as a blueprint for other urban developments in the Gulf region, while at the same time promising "local relevance" by fostering certain types of research and education and carrying a distinct "Emirati handwriting" in architecture and organizational design Pfotenhauer (2017). Sidewalk Labs in Toronto, too, aims to redevelop the Toronto waterfront into a "model for sustainable neighborhoods" Bliss (2018).

surrounding this test bed – to the extent governance structure ended up replicating the rift in the form of different organizational units. These experiences recall the STS insight that any participatory format is not a mere elicitation device but will also preconfigure the deliberation process in important ways and hence create, rather than consult, its publics (Felt and Fochler, 2010; Horst and Irwin, 2010).

Second, test beds are not just experiments *in* society but *on* society. At least part of the appeal of test beds rests on the enrolment of (more or less) well-defined populations as subjects of scientific inquiry and technological testing. Yet, population testing – in medical studies for example – usually needs to meet very high ethical standards and requires some form of informed consent and regulatory oversight. They also typically require the possibility of opting out. In many current test bed settings, individual consent procedures are vastly underdeveloped if not outright absent. Instead, test beds are frequently treated as infrastructure initiatives legitimized by elected representatives, even if they follow explicitly scientific goals. The necessity for better safeguarding of human lives and some form of consent procedure has become evident in the recent series of accidents involving self-driving cars in test regions (Stilgoe, 2017). As the incidents pile up, the emerging pattern points to a legal grey zone in the conception of test beds to safeguard the legal and moral differences between experimenters, test-subjects, consumers, and citizens, which will likely require greater scrutiny in the future.

Third and related, much of the regulatory construction of test beds has focused primarily on lowering local regulatory barriers (e.g. in “sandbox” settings) and tentatively allow innovative technologies to unfold their uncertain consequences in a relatively controlled environment. Yet, as indicated in the previous paragraph, a sole focus on dispensing with regulations seems mis-guided and does not make use of the potential of test beds. A more productive approach would seek to exploit test beds as an opportunity to develop innovation and new rules in tandem. To that effect, a new set of deliberative and legal mechanisms might be needed that enable test populations to take an active role in crafting these new rules and regulations, and hence strengthen self-governance and political participation by those who are most directly affected. Such smaller-scale governance forums might also allow for more agile responses, and allow them to actively shape the regulatory side. It would account for a symmetric technical and socio-political aspects of test-bed intervention.

Fourth, the aforementioned question of whether test beds are real “tests” or vehicles for interest-driven path-dependencies calls for greater accountability – e.g. through stage gates or checkpoints and potential exits, peer review procedures, or contingency scenarios – to ensure that test beds are indeed creating a desired future. At present, there are hardly any explicit criteria for the public or their political, elected representatives to judge outcomes. As discussed, what constitutes “success” or “failure” is frequently unclear and in flux. More importantly, there is usually no planning for a “failure” scenario in the first place. If test beds truly are to serve as social tests for the desirability of technological futures, then at the very least we must entertain the possibility of not passing the test as a serious option – whether for technical, economic, political, or social reasons. This also calls for greater scrutiny about whether test beds as regional or national flagship initiatives might be too politically charged to ever fail.

Finally, much of the appeal of test beds rests on their claim of scalability and transferability, both in terms of outcomes and processes. In both our cases, actors revealed considerable skepticism that their models could succeed in other places given the high degree of social embedding of the initiatives. Yet, very little explicit attention was paid to regulatory, political, or social differences between the current setting and the rest of the world. Where considered, transfer conditions between sites and societies tended to be imagined along very crude, binary criteria of similarity or difference, such as the socioeconomic status of the Anhalt region, with little sense of cultural or socio-political situatedness. More research is needed to better understand the conditions for visions of scalability to become both plausible and actionable, and how meaning of new technologies is produced in test bed settings as part of a social, cultural, and political environment.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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