Technische Universität München

TESTING TECHNOLOGIES – RE-CONFIGURING SOCIETIES:

TESTING, CONTESTING, AND MATERIALIZING VISIONS OF ENERGY FUTURES IN TWO GERMAN TEST BEDS

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ABSTRACT

This dissertation investigates how visions of future societies are tested, contested and materialized through “test beds” as an increasingly prominent policy instrument in science, technology and innovation policy. I draw on the concept of co-production to explore how test beds as situated geographical sites of experimentation and demonstration co-produce and tentatively co-stabilize new socio-technical orders. The main argument of the thesis is that test beds do not simply test a technology under real-world conditions. Rather, they “test” and reconfigure society around particular visions of desirable futures centered around new sets of technology and associated modes of governance. These sites of experimentation simultaneously intervene in local environments while also aiming to scale up these solutions to society at large. My research reveals that the processes of vision making and testing in test beds can be subject to considerable contestation and resistance around questions of which future(s) are deemed possible, viable, and desirable. Building on concepts from Science and Technology Studies (STS) and Innovation Policy, this thesis traces the role of future visions, their contestation between heterogeneous stakeholders, and the performative processes of materialization in two case studies in the domain of German energy transitions: an urban innovation campus and a regional innovation network. The empirical work draws primarily on document analysis, ethnographic participant observation, and qualitative interviews conducted between 2013 and 2018. The cases offer unique vantage points from which to examine experimentation as an emerging mode of governing innovation and sociotechnical transitions in context of discourses on “Grand Societal Challenges,” and the role test beds play in the political and economic reordering of future societies. Viewing test beds as sites of societal re-configuration raises further questions regarding democratic legitimacy, responsibility, representativeness, and participation. The co-productionist insights of this thesis serve as a stark reminder that what is at stake in innovation – in test beds and elsewhere – is social order.

The thesis takes the form of a cumulative dissertation, presenting three research articles published in three international peer-reviewed journals.

ZUSAMMENFASSUNG

Diese Dissertation untersucht „Test Beds“ als prominente Instrumente der Wissenschafts-, Technologie-, und Innovationspolitik und geht dabei der Frage nach, wie durch diese Orte zukünftige Gesellschaftsentwürfe getestet, ausgehandelt, und materialisiert werden. Mithilfe eines co-produktionistischen Ansatzes zeige ich, wie Test Beds durch Praktiken des Experimentierens und Demonstrierens neue soziotechnische Ordnungen ko-produzieren und vorläufig stabilisieren. Diese Arbeit geht über das verbreitete Verständnis hinaus, dass Experimentierräume neue Technologien lediglich unter „realen“ Umweltbedingungen testen. Vielmehr testen und rekonfigurieren sie auch die Gesellschaft auf Basis einzelner Zukunftsvisionen und der damit verbundenen Technologien und Governance-Modi. Die Experimentierräume bewirken damit Veränderungen im lokalen Umfeld, streben aber gleichzeitig an, ihre Lösungen auf die Gesellschaft im Ganzen zu skalieren. Meine Forschung macht die dabei entstehenden Spannungen und Widerstände sichtbar, sowie die Aushandlungsprozesse darüber, welche Zukunft bzw. Zukünfte von der Gesellschaft als möglich, realisierbar und wünschenswert erachtet werden. Aufbauend auf Perspektiven der Science and Technology Studies (STS) und der Innovationsforschung zeichnet die Arbeit die Bedeutung von Visionen, ihre Aushandlungen zwischen verschiedenen Interessengruppen sowie die Prozesse ihrer Materialisierung und Performativität in Test Beds nach. Der empirische Teil der Arbeit besteht aus Dokumentenanalysen, ethnographischen Beobachtungen und qualitativen Interviews, die zwischen 2013 und 2018 in zwei unterschiedlichen Fallstudien erhoben wurden: einem urbanen Innovationscampus und einem regionalen Innovationsnetzwerk. Die empirischen Fallstudien illustrieren wie der Modus des Experimentierens für die Governance von Innovationen und soziotechnischnischen Transformationen an Bedeutung gewinnt – insbesondere im Kontext der „Grand Societal Challenges“ – und wie Test Beds dadurch zur politischen und wirtschaftlichen Neuordnung zukünftiger Gesellschaften beitragen. Der Fokus auf Test Beds als Orte der sozialen Neukonfiguration erfordert auch eine Auseinandersetzung über Fragen der demokratischen Legitimität, Verantwortlichkeit, Repräsentativität, und Partizipation. Der ko-produktionistische Ansatz dieser Arbeit verdeutlicht dabei einmal mehr, wie Innovationen und gesellschaftliche Ordnung – nicht nur in Test Beds – miteinander verflochten sind.

Die kumulative Dissertation besteht aus drei Artikeln, die in internationalen Publikationen mit ExpertInnenbegutachtung veröffentlicht wurden.

For Ida

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1 INTRODUCTION

1.1 Thesis Foreword and Structure

"Welcome to Quayside, the world's first neighborhood built from the internet up. Quayside will be a new type of place, with connectivity designed into its very foundation. It will blend human-centered urban design with cutting-edge digital technology, cleantech, and advanced building materials. It will be a global test bed where people can use data about how the neighborhood works to make it work better."

(Sidewalk Labs, Project Vision of Waterfront Toronto, 2017)

"The question we need to be focused on is not how we can build a better monopoly-tech-company led, surveillance-based city (...) but the fact that we have enough evidence to know that we don't want to build that at all"

(Saadia Muzaffar, Letter of resignation from Waterfront Toronto's Digital Strategy Advisory Panel, 2018)

Instruments of public experimentation such as test beds, living labs, and real-world laboratories are increasingly gaining prominence in innovation discourses. Facing potentially disruptive technological changes and pressing societal challenges, those test beds have emerged as a go-to approach to structure and stimulate innovation by testing new sociotechnical arrangements in situ and at a meso-scale – whether in smart cities, digitized economies, energy transitions, or the future of work (Almirall and Wareham, 2011; Evans and Karvonen, 2011; Issa et al., 2018; König, 2013; Talvard, 2019). This dissertation puts the notion of test beds front and center. In contexts of smart city technologies, self-driving cars, or future energy architectures, entire districts have been developed or deemed as test beds of emerging technologies. These geographical sites of experimentation promise to drive innovation in a model – yet real-life – environment by making the particular local conditions and "ingredients" available for experimentation – and to learn from this template setting for larger contexts in society. Empirical examples of this phenomenon are mushrooming all over the world, across different countries, scales and technological domains.

The two quotes above illustrate context-specific visions and challenges around the deployment and experimentation with technology infused features and societal visions on a city-scale. They are taken from a particular prominent ongoing development in Toronto, or rather about Toronto's Waterfront called the "Quayside", that has received a lot of media attention (Sidewalk Labs, 2017). In September 2017, Canadian Prime Minister Justin Trudeau announced that Sidewalk Labs, the smart-city startup from Google parent company Alphabet, was approved to develop Toronto's Waterfront into "the most innovative district in the entire world", demonstrating of "what is actually possible but also feasible" (City Lab, 2019). They aim to experiment with ways to blend innovation with urban life to enable new froms of living, while carrying the ambition to become a model for other cities. In its first ever project on a city scale the company envisions to rebuild the Quayside neighborhood "from the Internet up". Featuring self-driving shuttles, adaptive traffic lights, snow-melting heated pavement and freight-delivering robots, the district will be deeply connected, monitored and self-regulating (i.e. "smart"). To build this new high-tech neighborhood (which should also become the home of a new headquarter for Google Canada), Sidewalk Labs CEO calls the city for its commitment to "waive or exempt many existing regulations in areas like building codes, transportation, and energy in order to build the city as envisioned" (Financial Times, 2017). For Google it is the logical next step to collect real-life data on a large scale and to translate these massive amounts of data into innovative infrastructures and profitable business models. With 3.3m square feet, the project is the geographically largest attempt to merge technology with urban planning in North America.

Yet, from its beginning, Quayside has raised criticism and questions over data protection and participation deficits. Critics have warned to hand over public entities like cities to private corporations and to the economic interests of a limited number of powerful stakeholder, who re-develop public space around their visions of data-driven and interconnected technologies: "an insidious way of handing more control – over people, places, policies – to profit-driven, power-hungry corporations" (Sadowski, 2017). As a consequence, three advisers have stepped back from their engagement with the Quayside project citing concerns about data privacy, ownership, and governance. One of them, Saadia Muzaffar, has published her letter of resignation in which she decries a "blatant disregard for resident concerns" by the project management, which "disenfranchises its residents in insidious ways and robs valuable earnings out of public budgets" (Muzaffar, 2018). Critics fear that when city leaders hand over public space to corporations and turn it into a lab for running experiments, they take away responsibility and accountability from its citizens and seemingly wipe away the local idiosyncrasies and rights of self-determination (Project for Public Spaces, 2017).

Accidents by self-driving vehicles, like the fatal Uber test car accident in Tempe, Arizona (The Guardian, 2018a), have also raised criticism and questions about the legitimacy of these kinds of social interventions and the different regulatory standards and approaches in global technology development. In 2017, Uber had extended its self-driving test program to Tempe, as they consider that area an ideal place to test autonomous vehicles because of its favorable weather and wide roads. Shortly after its introduction, one of its autonomous cars had hit a cyclist – the first pedestrian death resulting from self-driving technology (The Guardian, 2018a). However, test beds for self-driving technologies are flourishing. In the same year of the Uber accident the California Department of Transportation in collaboration with an industry's innovation hub started the "California Connected Vehicle Test Bed" in the heart of the Silicon Valley in Palo Alto (Prospect Silicon Valley, 2017). The test bed is expected to span more than 30 consecutive intersections along a seven-mile stretch of State Route 82 (El Camino Real) to provide an operational environment to test how connected vehicle technologies perform under real-world conditions.

Cities have been a laboratory for urban experiments for a long time, and the testing of technologies under real-world conditions is not new (Evans, 2016; Karvonen et al., 2014). Yet, what is striking is the sharp increase of test beds over the past few years on an international scale. The test bed-approach to innovation has made its way into national policy programs, companies' innovation strategies and transformative research agendas across various empirical domains, scales and countries by now. Thus, this is not only Google reconfiguring Toronto's Waterside into a testing site for its products and services "that will help us build cleaner, smarter, greener, cities", as Canadian Prime Minister Justin Trudeau envisions (Financial Times, 2017). All over the world, visions of greener, smarter, more sustainable or just "better" futures become performatively explored in test beds: That is for example Eco City Tianjin (China), a flagship cooperation project between the governments of Singapore and China, which is meant to be a model for sustainable development. Or Korean City Songdo, where IT company Cisco has been announcing plans to roll out 20 new cities across China and India, using New Songdo as a template: "More than anything else, this new city serves as a testing ground for what the future may have in store. Startups and companies like Cisco find Songdo the perfect clean slate for developing technologies. Built with invention and development in mind, Songdo is truly a living, breathing lab." (Cisco, 2016) One of the world's most prominent test bed examples features Masdar City in Abu Dhabi. Basing on the vision to build a global hub for the cleantech industry (with 50,000 residents and 40,000 commuters), in 2006, the project was touted as a beacon of urban sustainability. At the same time, the project was supposed to demonstrate the United Arab Emirates as an environmentally-aware, sustainable, low-carbon economy to the world, turning away from being a country dominated by its oil economy (Geographical, 2016). Ten years after its invention, managers have given up on the goal of building the world's first planned zero-carbon city (The Guardian, 2016). Still being far from completion, Masdar City is thus also an example for the intertwining between ambitious visions and the political and economic cultures they are embedded in (Pfotenhauer, 2017). "Masdar City is sustainable in as much as it manages to sustain the economic and political system that it draws on", Federico Cugurullo from Manchester University is saying while pointing at internal tensions between economic interests and environmental concerns that impede the sustainability potential of the new city (Geographical, 2016).

These examples illustrate how various stakeholders like tech companies, public authorities and citizen's initiatives deploy these sites equally as testing grounds and demonstration projects to push particular technological and policy developments. However, these different actors relate to a particular set of cultural norms, visions and values, which drive their motivations to join the test bed, and which they aim to see realized. What counts as a "better", viable or desirable future society is highly contested among different actors; yet, these contrasting visions fundamentally shape tecnological trajectories. It is of paramount importance to question the role of visions in technological development in the shaping of society and the outcomes of these configurations – and a key concern of science and technology studies. This relationship is challenged by, what I call, the "test bed-mode of innovation": Test beds re-interpret and potentially supersede "traditional" approaches for technology testing, its regulation and approaches of participation. That means they put society in a more ambivalent role than ever before. Social order is explicitly seen as up for grabs, just like a new technology, how it is developed and governed. Empirical examples reveal how the undergirding visions for the future of society are negotiated between different actors in test beds and how power and participation are (re-)arranged in these settings.

This dissertation will provide theoretical and empirical insights into the interconnected processes how technology, political and social orders are co-produced in test beds, which are designated sites of experimentation both for testing future technologies and as governance instruments. The thesis will further show how (competing) visions of future societies performatively promote innovation and shape material realities.

Throughout this dissertation, I am going to argue in particular three things. First, technologies and associated visions of the future are increasingly *tested* in real-life social settings, which place innovation activities explicitly outside the confines of the traditional laboratory and directly into society. Second, they bring to surface diverging visions of the future (here: smart city and future energy architecture visions) and highlight the heterogeneity of actors involved in innovation processes, which make these testing procedures highly *contested* endeavors and the places subjects of negotiations. Third, testing visions and the according technological developments with and within society are performative acts, in which these sites *materialize* the visions they were intended to experiment with and, as a consequence, eventually re-configure social order in a co-productionist way. This threefold interplay between *testing (article 1), contesting (article 2) and materializing (article 3) visions of future societies* is the central thread of this publication-based dissertation and each publication is dedicated to one aspect in greater detail.

The examples show that test beds are expected to serve as prominent innovation instruments that have the power to reconfigure the ways we live, behave and learn not only in future, but already in the present. Equally, visions about admirable futures tell us about both the kind of (innovation) society we aim to become and we currently live in – as Sheila Jasanoff has written, "the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we chose to live in" (Jasanoff, 2004).

Drawing on the idiom of “co-production” (Jasanoff, 2004), I explore the ways how policy-makers, scientists, urban planners, and business representatives envision, negotiate, materialize and performatively stabilize future social orders through experimental innovation projects and practices. My work builds on concepts from Science and Technology Studies (STS) and Innovation Studies. In particular, I draw on the co-productionist strand of STS alongside other established traditions in laboratory studies, sociology of testing, the co-construction of users, technical democracy, public engagement, and the (material) politics of technology and innovation. The dynamics and interrelations between innovation and societal change are a central issue in the exploration, understanding and shaping of the future. STS research goes beyond the techno-scientific aspects of innovation in that it sheds light on the practices, knowledge structures, as well as political and economic processes underwriting today's innovation-driven societies. Technologies, and even more technology testing, are integral components of social order and its social practices, norms, discourses, institutions and instruments (Jasanoff, 2004). When thinking and writing about how technologies rule society and possess the power to re-arrange the social fabric, the role of values, politics, and responsibilities cannot be left outside of discussions. Thus, the relationship between technology and society and how it is conceptually and practically staged in test beds as deliberate interventions into social order at a meso-scale necessarily requires a thorough consideration of the implications of these relationships, i.e. of our understandings of ethics, governance and citizenship.

I argue that test beds are sites of co-production and fundamentally challenge the ratio between technology and society in an unprecedented observable manner, and I aim to expose the processes, power structures and interrelations between technology, science and society investigating the recent test bed phenomena. It is the objective of my research to develop an analytic framework for this distinctive, emergent, and arguably under-theorized instrument of innovation governance and to provide empirical insights into innovation practices in test beds. I explore what "experimentation" means in both public policies and technological developments: How do test beds experiment with or re-configure sociotechnical orders? What happens if diverse or even contested visions collide in test beds? How do sociotechnical visions materialize into built form at these sites? What do these processes tell us about the role of politics and power in science and technology? How do visions and technologies tested in real-life experiments circulate to other or broader contexts?

My way of approaching these questions methodologically is through embedded, qualitative social science research as a participant observer in two test beds. I trace the ways in which they emerge, their visions get negotiated, and how those become translated and embedded into concrete material arrangements in particular social and geographical contexts – and how their material form eventually serves as an object for demonstrating feasibility. More precisely, my research draws on five years of ethnographic fieldwork, document analysis and interviews from two test bed case studies in the context of German energy transitions – an urban smart energy campus and a regional renewable energy network. From 2013 until

2018, I conducted in total 36 in-depth interviews with a heterogeneous set of test bed stakeholders, ranging from companies' CEOs, start-up founders, leading scientists, managers in non-profit organizations and government bodies to citizens and local residents.

My findings underscore that test beds indeed represent an emerging innovation paradigm of contemporary societies. They share some common conceptual and empirical ground with related concepts such as "real-world laboratories" or "living labs," for example in their experimental orientation or focus on testing in a real-life environment (Evans and Karvonen, 2013; Karvonen and van Heur, 2014). Like these concepts, too, test beds focus on user-experience and co-creation. Yet, these frameworks tend to foreground questions of technology implementation and development, not the deliberate re-making of local social order to showcase a prototypical new society with model character. Performativity here refers to a mode of innovation in which test beds help to bring about and stabilize the very sociotechnical configurations that they supposedly test. In this sense, test beds display a purposeful, directed, and performative character. In fact, they precisely try to insert an intermediate step of a "miniature society" in which such new systemic configurations can be tested, developed further, and potentially retracted.

Three original research papers are at the heart of this publication-based dissertation. They all contribute to the overall co-productionist research theme, which is the common thread of my dissertation research through all the years: How are visions of future societies tested (article 1), contested (article 2), and materialized (article 3) in and through test bed sites of innovation? And, taken together, what do test-beds tell us about the co-production and mutual stabilization of social and technical orders in contemporary innovation initiatives? This dissertation will discuss these aspects while exploring to what extent test beds mark a shift in the conceptualization of what innovation is, how it operates, and who ought to be involved.

The dissertation will proceed as follows: Section 2 will lay the conceptual groundwork for this thesis' three papers, which address test beds as sites of co-production. I will feature on the concepts of co-creation vis-à-vis co-production, visions and imaginaries of future societies, the re-vitalization of the "society as a lab"-idea, and, finally, new modes of experimental governance. The papers will each be introduced in detail in section 2.2. Section 3 provides the empirical material, the two case studies, and analytical methods used for answering the research questions of each paper. The original research articles will be presented in section 4. Finally, Section 5 concludes the thesis by first drawing together the findings of the three papers (5.1) and then discussing a set of some overall topics that emerged out of my research and which will be of interest for future research (5.2). Finally, I will make use of the epilogue for some final reflection on today's innovation but also experimental driven societies.

1.2 Overall Research Questions

This dissertation is concerned with the function, power, and performativity of future sociotechnical visions in the making and governing of today's societies, in particular with the notion of test beds and their role in shaping these processes as instruments of innovation policy.

The following research questions and subsequent papers represent more detailed and empirical approaches to study test beds and its characteristic features, practices and tensions. Three specific aspects of test beds occupy the three papers: The testing of and experimenting with future technologies and associated visions of future societies (Paper 1); their contestation in heterogeneous settings (Paper 2); and their materialization into built form (Paper 3). While all the three form the central theme of this dissertation and continuously guided my research, each of the papers features one particular aspect and related research questions. To different degrees, the papers address both conceptual questions on test beds and empirical insights gained from ethnography. The here presented research questions outline the dissertation's overall scope and interest. In section 2.2, I will then present the particular research questions of the individual articles.

Table 1. Overall Research Questions.

Key Aspect	Research Questions	Paper Reference
1. TESTING VISIONS OF FUTURE SOCIETIES	**In what ways do test beds fuse the testing of technological and social order?** What conceptual tensions do test beds characteristically face? What does this insight imply for the governance of these sites – thinking of opportunities and challenges for innovation governance?	Engels, F./Wentland, A./Pfotenhauer, S.M. (2019): Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance, *Research Policy*, 48(9).
2. CONTESTING VISIONS OF FUTURE SOCIETIES	**How do test beds serve as geographical sites for the contestation and negotiation of conflicting future visions?** Why do certain visions gain traction and eventually lead to changes of science, technology, and innovation (STI) projects? Why do different actor groups join test beds and how does heterogeneity challenge visioneering practices?	Engels, F./Münch, A.V./Simon, D. (2017): One site – multiple visions. Visioneering between contrasting actors´ perspectives, *NanoEthics*, Special Issue "Visioneering sociotechnical innovations: The making of visions", 11(1), 59-74.
3. MATERIALIZING VISIONS OF FUTURE SOCIETIES	**What are the processes through which visions become materialized into concrete technological artifacts?** Which and whose visions will be materialized in test beds, and for what reasons? How do local visions align with or relate to broader sociotechnical imaginaries?	Engels, F./Münch, A.V. (2015): The smart grid as a materialized imaginary, *Energy Research & Social Science*, Special Issue on "Smart Grid and Social Sciences", 9, 35-42.

2 CONCEPTUAL FRAMING AND CURRENT THEORETICAL APPROACHES

2.1 Test beds as Sites of Co-Production

This dissertation offers empirical insights from two case studies into the phenomenon of test beds as experimental sites for policy-making and technological development. In conceptual terms, I take as a starting point the “idiom of co-production” (Jasanoff, 2004) to grasp the mutual shaping of technological and social order, which is, I argue, a characteristic feature of test beds and how they invoke innovation on a meso-scale.

Co-production of science, technology and social order serves as my analytical lens to analyze these settings and their experimental practices and undergirding principles in order to test and perform sociotechnical futures. The co-production framework stresses the importance of contextualization to make sense of the emergence and (de-)stabilization of new technoscientific objects and orders. Through their geographical embeddedness on a local scale, test beds not only integrate “real-life” conditions into their innovation practices but rather make social order explicitly available for experimentation. Furthermore, my research reveals that test beds at once experiment with *and* stabilize new socio-technical orders in such a co-productionist manner. In line with Jasanoff’s concept, co-production is by far an untidy, uneven process and fully entangled with social norms and hierarchies, in which knowledge and its material embodiments are at once products of social work and constitutive forms of social life (Jasanoff, 2004). In line with this argument, this thesis particularly looks at the frictions and negotiations that have accompanied the emergence and design of my two test bed case studies. In both cases – the urban smart energy campus and the regional energy network – visions for a future society were subjects of enduring negotiations and contestation among the diverse actors, and those involved the purpose and material form of the actual test bed as much as the question of who should be involved in the project at all.

My research follows an interactional co-productionist approach as it directs the attention to the conflicts and negotiations that arise in test beds as proposing new epistemic and socio-political arrangements, and what happens if these interact with “existing institutions and practices, and extant cultural, economic and political formations” (Hilgartner et al., 2015).

This approach directs its focus onto the social processes of deliberation and confrontation between actors coping with the *global* grand challenges in their translation into *local* daily practices.

The belief that that all technologies are inherently social in that they are designed, produced, used and governed by people is the guiding principle of social studies on science, technology and innovation since the 1970s/80s (Bijker et al., 1987; Gibbons et al., 1994; Jasanoff, 2004; Winner, 1993). Such an explicit social constructivist approach obviously rejects the notion that technology is simply the result of rational technical imperatives. Rather, a range of social factors affects which technologies prevail, and these moments of negotiations between different groups of social actors, or even contestation, shape their material form, societal context and implications (Bijker et al., 1987; Jasanoff and Kim, 2009; Latour, 2005; Winner, 1980). In this way, technologies are crystallizations of society; imprinted by the people and social context in which they develop – and, vice versa, they are shaping societies, their ordering and hopes (Jasanoff, 2004; MacKenzie and Wajcman, 1999). The processes through which emerging technologies are developed, stabilized and fitted into the world is thus "from the outset a social one, and the practices that shape technological change also shape who is able to use emerging technologies to do what, how risks are distributed, and what kinds of lives and identities they support." (Hilgartner et al., 2015)

These conceptual STS insights are well suited for analyzing test beds and how they deliberately intervene into social order at a meso-scale. Being subject to relatively strict forms of spatial confinement (e.g. a city, district, campus, or a special testing zone) test bed activities may require the alteration of local laws and regulations, like zoning laws, privacy laws, liability regimes, or taxation. For example, the implementation of smart city technologies and concepts as in the introductory Toronto case interferes with existing relationships between local residents, digital infrastructures, material infrastructures, public services, city policies and regulations. Many of the ideas and visions outlined in the Sidewalk Labs project plan for instance interfere with governmental tasks such as sensors on public streets, the implementation of a civic data trust to manage and control its data collection, or digital connections to city services.

What is happening in test beds like Quayside Toronto is that the envisioned benefits and innovations of the test bed are tied to the possibility of testing – in a confined space – new ways of living *as if* these technological changes have already been successfully introduced and society has already adjusted to them. That means they lend credibility, justification, and visibility to specific visions of how the future could look like and tentatively materialize those. On the one hand public authorities re-invent their political identities and position themselves as innovation hubs or beacon for pressing societal challenges through the implementation or funding of public experiments. On the other hand, these experiments serve as local demonstrations and manifestations of the innovations' use and value to legitimate political action and to re-affirm the imagined political identities. This dual relationship of test bed experiments is by definition highly context-specific, constantly in flux, and fraught with tension – e.g. in terms of democratic legitimacy or the exercise of epistemic and technological power (Barry, 2001; Laurent, 2016; Winner, 1980).

Together with my colleagues Sebastian Pfotenhauer and Alexander Wentland, 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* (Engels et al., 2019). In this simultaneous co-production of new technical and social orders, experimental sociotechnical arrangements are introduced and evaluated, both in terms of their technical performance and societal uptake and acceptance. This local version of a new society is envisioned and expected to serve as a model for a set of different settings by a way of scaling up or best practice transfer (Hilgartner, 2015b; Pfotenhauer, forthcoming). This makes test beds a strategic, directed and powerful instrument in governing innovation and, by extension, the evolution of contemporary, highly technologized societies.

In the following sub-sections of the theory chapter, I will discuss four different analytical sub-aspects through which this dual relationship of test beds plays out.

2.1.1 Transformational Knowledge and Innovation Policy towards Societal Goals: The Mantra of Co-Creation

Over the last decades, the relation between science, technology and society has been changing and re-ordered driven by two major challenges: While the demand for evidence-based knowledge in policy-making is constantly growing, its legitimation, production and authority is questioned, and the guidelines for validating (expert) knowledge are highly contested

(Simon et al., 2019; Strassheim and Kettunen, 2014). It has becoming more and more apparent, that scientific endeavor is not value neutral but deeply political and socially constituted (Winner, 1980), and that the criteria for representing and certifying experts, as well as the criteria for epistemic validity and roles agreements are re-ordered.

Some scholars argue that recent developments in the name of societal transformations challenge not less than the configuration of science, policy and society (Kuhlmann and Rip, 2018; Stirling, 2015). Grand Challenges policies have to cope with "contestation, non-linearity, and bifurcations in developments", which implies that our present understandings, instruments, and practices of innovation policy are not sufficient to address such challenges like energy transitions, the future of mobility or digital permeation of all areas of society (Kuhlmann and Rip, 2018). Feeding on these current discourses and the growing insight that today's societal challenges require transdisciplinary approaches and concerted collaborative efforts, science is increasingly expected to engage in the co-creation of knowledge in heterogeneous actor constellations (Callon et al., 2009; Stirling, 2008). The ways new actors are joining policy arenas and public debates, and entering newly emerging spaces such as test beds more generally, thus exceeds the scope and involvement of "traditional" innovation policy (Kuhlmann and Rip, 2018). Whereas science and technology have long been identified as a major source of economic and social development (Schumpeter 1939), their contribution to social well-being, economic growth and prosperity is no longer taken for granted – as is the imperative of innovation (Pfotenhauer et al., 2019). For a long time, (technological) innovation has been hailed as panacea to a multitude of social problems and key to secure economic prosperity, market success and societies' progress and competitiveness in the global contest (Pfotenhauer and Juhl, 2017).

Yet, discourses are shifting towards enhanced public participation in innovation policy in which democracy is envisioned to serve society through innovation (Pfotenhauer et al., 2019). Scientific innovation processes are criticized as inadequate as they "elicit public unease and pre-empt debate on the need, direction, and desirability of innovation at large" (van Oudheusden, 2014). In that sense, boundary-crossing forms of knowledge production are receiving increasing attention across countries and different technological domains (Gibbons et al., 1994; Jasanoff, 2004; Nowotny, 2003). Under the umbrella label of co-creation, a large amount of studies discusses the practice of bringing together diverse actors in a joint innovation activity, which has been recognized as a widely desired resource and condition in current attempts to enhance innovation (Nowotny, 2003; Prahalad and Ramaswamy, 2004). Noticing the Grand Challenges paradigm, the co-creation concept emphasizes responsiveness and responsibility, openness, and a greater distribution of agency in innovation practice (Stilgoe et al., 2014). Accordingly, hopes are pinned to a more democratic and inclusive approach to innovation as local actors and local needs enter the – formerly mostly expert-driven – process. Yet, these attempts deserve an in-depth investigation to understand how co-creation practices actually relate to the social, cultural, economic, and institutional environments in which they are implemented.

These recent developments build on earlier frameworks that intend to open up science and technology to the public. Already since the second half of the 20th century debates about a resonsible and politically accountable role of science and innovation – recognizing its dual capability of producing benefits but also harm – has gained momentum (Beck, 1992; Stilgoe et al., 2013). Further concepts like hybrid forums of collaboration (Callon et al., 2009), open science and open innovation (Chesbrough, 2003), democratized innovation through user integration (Hippel, 2005), citizen science (Dickel and Franzen, 2015), or responsible research and innovation (Stilgoe et al., 2013) discuss a democratization of expertise and seek to better connect innovation – and innovation systems – to concrete social needs and concerns. Further, they reveal normative orientations and visions about "better" modes of knowledge production and technology development and what is considered robust and democratic.

This dissertation is engaged with questions that scrutinize the expectations and undergirding principles towards these heterogeneous forms of knowledge production and innovation policymaking, which I found characteristic for experimental spaces such as test beds. How are these new epistemic arrangements envisioned and used as innovation policy instruments to deal with today's societal challenges? How do actors deal with disciplinary boundaries and diverse institutional contexts in joint innovation activities under the name of co-creation? How are differences negotiated and collaboration enabled? And on a more methodological level, how can these new settings, epistemic and co-creational practices be observed and evaluated?

What makes test beds an intriguing case of studying co-creation instruments and practices, its avenues and limits, is the deliberate blurring of traditional boundaries between knowledge and technology creation and its use, bringing together diverse groups of experts from science, politics and business, consumers, local residents, and oversight bodies. I investigate two different empirical case studies – one being an urban innovation campus in the city of Berlin, the other being a regional innovation network in a rural environment – in order to understand how co-creation practices relate to the social, cultural, economic, and institutional environments in which they are implemented. Both test bed case studies are characterized by quite a heterogeneous set of actors, coming from different sectors or scales of practice, and who did not collaborate traditionally: They feature municipal utilities, civil society organizations like local energy initiatives, energy suppliers, researchers and science organizations, large (incumbent) companies and (challenger) start-ups. Such cross-sectoral connections pose major challenges for co-creation practices due to for example different, partly contradictory organizational logics or temporal orders (e.g. navigating between scientific exploration and economic exploitation) of the particular spheres they are coming from (Engels and Rogge, 2018). Thus, calling for heterogeneity of interests and capabilities, test beds bring together not only various actor groups but also complementary bodies of knowledge, technical and social inputs, regulatory and market concerns, and institutional flexibility, considered as key ingredients of (successful) innovation. However, definitions of succesful innovation and understandings what the particular test bed is for differ greatly and are themed according to the interests and stakes involved. These include scientific hypothesis testing (for academic partners); creating new avenues for integrating users into design processes (for business actors); demonstrating showcase initiatives (for policy makers and governemental actors); strengthening participatory democracy (for citizen initiatives); and many more.

Various strands of research have approached these questions of a stronger "context-sensitive science" (Gibbons, 2000) in the past. I will discuss these in a bit more detail as they offer relevant aspects to understand not only the emergence of experimental spaces across various contexts but also the motives and expectation undergirding their particular creation. Test beds speak to the so-called "Mode 2"-paradigm of knowledge production – i.e. more use-oriented, project-based, and transdisciplinary – and related calls for greater "socially robustness" (as opposed to merely scientifically soundness) of knowledge (Nowotny, 2003). Here, the public is seen as an active partner in knowledge co-creation, the role of the expert is one of facilitation instead of authority, and the touchstone of validity is robustness in the real world, not the laboratory. Shortly put, the old paradigm of scientific discovery ("Mode 1") characterized by the hegemony of theoretical or experimental science; a classification of separated disciplines; and by the autonomy of scientific knowledge and the places of its productions (the universities) has been seen as worn-out. Instead, a new discourse has evolved around a "Mode 2"-paradigm of knowledge production characterized as a cross-organizational form of knowledge production, directed towards its usefulness for various societal groups and communities who simultaneously assess its value – and which, consequently, cannot be encoded in traditional forms of scholarly publication. (Nowotny et al., 2003). While the notion of "Mode 2" is probably one of the most prominent and visible concepts to make sense of changing concepts of knowledge production, is it by far not uncontested in terms of its empirical validity, conceptual strength, and political value (Hessels and van Lente, 2008; Weingart, 1997). Critics decry a lack of distance and are concerned that Mode 2 is rather normative agenda or political ideology than a descriptive theory (ibid.).

Alternative accounts have further conceptualized the growing entanglement of diverse actors in innovation processes as a triple (or quadruple) "helix" of hybrid university-industry-government(-society) interactions in knowledge-based societies (Etzkowitz, 2008). According to them, new and emerging technologies (like ICT) induce reorganization or even transformation processes across industrial sectors and nation states, where university research increasingly functions as a locus of such knowledge-intensive network transitions (Etzkowitz and Leydesdorff, 2000). The authors argue to promote innovation through hybridization and put the state into an active, facilitating position, however, they largely disregard a critical examination of the innovation imperative at large.

Designing policy instruments such as test beds under the experimentation paradigm further relates to concrete demands and recent debates on directionality of policy intervention. Most recently, innovation policy scholars have announced a "next generation" or a "Third Frame"[1] of science, technology and innovation policy, which demands for more directionality of policy intervention and the need for policies to actively contribute to system transitions in the backdrop of major societal challenges (Edler and Boon, 2018; Kuhlmann and Rip, 2018; Schot and Steinmüller, 2016). The third framing of innovation policy calls for

[1] The third frame distinguishes from two earlier framings of "R&D" (since the 1950s) and "national systems of innovation" (since the 1980s) (Schot and Steinmüller (2016).

public policy to shift the focus on anticipation, participation, and directionality – and towards its key feature of experimentation "at a scale well beyond that of the R&D laboratory. It calls for societal experimentation." (Schot and Steinmueller, 2018) However, the authors are further concerned whether transformative change is a too ambitious goal because it involves changing a set of deeply embedded directions of society (e.g. mass production and carbon-intensity), what they call a "Second Deep Transition" (ibid. 1565).

Kuhlmann and colleagues also discuss the difficulties of driving innovation towards "Grand Societal Challenges" or towards the particular needs of emerging economies (Kuhlmann and Ordóñez-Matamoros, 2017; Kuhlmann and Rip, 2014). Often addressed through dedicated public funding, R&D and innovation in the realm of societal challenges should rather been seen as missions of the socio-economic system as a whole, they argue. According to this approach, the identification and articulation of needs into concrete demands and markets can shape the direction innovation policies will take. Orientation towards complex societal challenges (and its multiple actors, sectors and objectives) fosters the creation of a supply side (to bring about innovation) and demand side (problem-solving and responding to pressing societal needs) of innovation policy. Focusing on the demand side, studies have discussed how the role of the state is changing. Governments are increasingly seen as a major actors in shaping the directionality of innovation, acting as enabler of co-creation[2], e.g. by organizing multi-stakeholder platforms or public-private partnerships, in which the regulator is just an actor of many (te Kulve et al., 2018). The state-led activity of public procurement of innovation (PPI) might further support transformative processes through processes of articulation of societal demands, responsive development and production of new technologies, and careful selection, diffusion, and use of new technologies to meet societal demands (Wesseling and Edquist, 2018).

How emerging tensions arise from a competition between sustainability and precaution on the one side, and "competitive innovation" and "technological progress" on the other are discussed by Andy Stirling (Stirling, 2007). These tensions stem from a "range of complex, uncertain and contested choices between contending pathways for innovation" (Stirling, 2007), which are characteristic for ambiguous challenges such as a "sustainable future" or

[2] Boon and Edler distinguish between several roles of the state according to the respective need: a coordinating role (go beyond sectors), an inspiring role (go beyond incremental innovations), and a strategic role (go beyond easy solutions)." (Boon and Edler (2018).

a “sustainable society”. In my three research articles, I empirically show how these systemic tensions over contested innovation futures and their pathways play out on the concrete actors’ level in test beds. So far, little attention has been paid to these multiple expectations and how they affect micro-level practices and pose challenges for the heterogeneous actors involved in these settings. However, scholars claim that it is necessary to focus on specific initiatives, their praxes, politics and interlinkages to other experiments to better understand their nature and implications (Laurent and Pontille, 2019). Yet, these resulting dilemmas are political in nature and decisions made about them inevitably reveal priorities and choices (Karvonen et al., 2014; van Oudheusden, 2014; Voß and Schroth, 2018). This is why authors call attention that on a broader societal level, deliberate technological futures should reflect on the multi-directedness of technological progress, the essentially normative character of choices over sustainable technology, and the role of institutions and procedures – and effective discourses over the intrinsically normative and contingent character of technology (Stirling, 2007; Wynne, 2007).

Work on a more responsible science and innovation builds on STS research since the 1990s that has consistently emphasized the importance of public participation and the democratization of expertise (Irwin and Wynne, 2003; Stilgoe et al., 2014; Wynne, 1993). Debates over the social negotiation of power and social order in relation to science and technology, or put more precisely, public concern and the perception of crises related to the risks and uncertainties of new technologies, e.g. in the area of gene-modified organisms or nanotechnology, has led to the emergence of trends of public engagement in science. Wilsdon and Willis (2004) have classified three phases of this trend: From Public Understanding of Science, to a shift “from deficit to dialogue” in the positioning of science and innovation vis-à-vis its publics, to “moving engagement upstream.” What is known as the Public Understanding of Science (PUS), dating back to the 1970s, rejects the deterministic assumption that science and technology have their own objective logic to which society must adapt (Irwin and Wynne, 2003). Rather it was seen as the researcher’s professional responsibility to inform and promote the public understanding of science. For long, science and the public were seen as two opposing entities and the latter has been constructed as deficient, being unable and unwilling to understand the messages given by the “experts” (Wynne, 1993). As a result of this deficit construction, PUS was seen as a “backward looking vision” (James Wilsdon and Rebecca Willis, 2004) as UK’s Chief Scientifc Advisor had put it. In the 2000s, the climate has shifted to bring science and society into dialogue and to move engagment upstream. The concept of Public Engagment has thus argued for a reflexive, diverse and controversial engagment with science and for the acknowledgement that science and innovation fundamentally relate to public concern (Stilgoe et al., 2014; Wynne, 2006). It emerged as a way to render innovation more socially acceptable and to reconcile democracy and innovation on a broader scale. This move towards upstream innovation was imagined to allow societies to engage with questions about the direction of innovation in a more fundamental way (James Wilsdon and Rebecca Willis, 2004). However, what looks like a smooth progress towards dialogue and engagement should not distract from observations that actual practices of science remain unclear or unsatisfying in this regard (ibid.).

Other scholars have further suggested "constructive" forms of technology assessment based on ethical values and social concerns (Schot and Rip, 1997), or the possibility of "midstream modulation" and "sociotechnical integration" of technologies-in-the-making (Fisher and Schuurbiers, 2013). Pierre Delvenne and Céline Parotte raise the question of political normativities anew. For them technology assessment not only has politics, but *is* politics in the context of contemporary politics characterized by epistemic ambiguity and uncertainty (Delvenne and Parotte, 2019). Against the backdrop of populist, authoritarian, or extremist tendencies, technology assessment communities might become powerful players in upholding democratic principles in policy-making (ibid.).

Finally, the concept of "Responsible Research and Innovation" (RRI) puts the Grand Societal Challenges front and center to which research and innovation need to become more responsive by adopting a co-creation approach and shared responsibilities. It had gained particular prominence and visibility in context of research funding by the European Commission – picked up and promoted in the key claim "science with and for society" of the EU Horizon 2020 work program. The increased awareness of a more responsible approach towards innovation in (EU) policy contexts is also a reaction to deal with ethically critical policy areas and the two-sidedness of scientific and technological innovation. Thinking of, for example, gene-modified organisms that carry the potential to battle world hunger, and, at the same time, the risks of not yet known long-term effects for the eco-system's balance and the consumers' health. Further examples feature controversies around emerging technologies in the fields of biotechnology (Hilgartner, 2015b), neurotechnology (Mamidipudi and Frahm, 2019), or the design and use of Artificial Intelligence (Jasanoff, 2016). The concept of RRI stresses the need for "collective stewardship of science and innovation," highlighting aspects like the anticipation of consequences, inclusiveness of affected publics, responsiveness towards diverse values, and reflexivity about the purpose of a technology (Schomberg, 2013; Stilgoe et al., 2013). In the literature, especially two definitions have come to establish themselves in the policy realm, one by von Schomberg and the other by Stilgoe, Owen, Macnaghten and colleagues. Von Schomberg is urging for a new governance of science and technology in order to steer it responsibly according to the "right impacts" as anchored within the EU Treaty (Schomberg, 2013)[3]. While the definition by Stilgoe et al. builds on similar principles, it however leaves the definition of RI rather broad and less instrumental: "Responsible Innovation means taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe et al., 2013) The authors suggest a new RRI framework basing on the four dimensions of anticipation, reflexivity, inclusion, and responsiveness, which in practice may be mutually enforcing, but which can also be in tension with one another (ibid.). In any case, both the innovation process and the RRI framework need to be situated in a "political economy of science governance which considers both products and purpose" to be truly responsive (ibid. 1572), rather than being the action of a single innovator.

Although the concept of RRI has emerged out of a critique of mainstream innovation in order to better align innovation with society, critics decry RRI discourses as instrumental, with a lack of clarity and practicability – who would actually argue against responsibility. (Owen et al., 2012). Criticism is further directed towards the limitations or even failure of democracy talk and the unfulfilled promises raised by the popular paradigm of RRI (Irwin and Wynne, 2003; Wynne, 2001). Van Oudheusden argues that RRI plays out through "power, ends and authority" (van Oudheusden, 2014), what makes deliberative processes a political issue and raises questions about the authoritative allocation of values (van Oudheusden, 2014). This perspective on co-creation practices emphasizes more critical aspects of value extraction from the public, which is turned into a mobilized and moralized asset in order to develop and test new products, business models or modes of collaboration

[3] He defines RRI as "a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)." (Schomberg (2013).

(Delvenne, 2017; Delvenne and Macq, forthcoming). Companies or public-private partnerships, who are the major drivers and financiers behind these new innovation practices, are less concerned about a democratization of expertise or enriching decisions with citizens' insights, but rather aim to extract value from them for commercial reasons and to accelerate innovation activities through participatory experiments (Delvenne, 2017; Delvenne and Macq, forthcoming). This perspective on instrumental public engagement resonates with concerns about test beds' legitimacy and representativeness (section 5.2.2). When forms of public engagement does not challenge but in fact support existing power structures (van Oudheusden, 2014), public dialoque might be turned in its opposite, preventing other views to gain traction rather than embracing them (Chilvers and Longhurst, 2016).

These recent approaches and modes of co-creation yet need further empirical research to understand the actual deliberative practices, negotiations and power constellation, which are at play at these emerging new settings of knowledge creation. With help of my empirical material, this dissertation sets out to discuss questions of a responsible use of test beds and the role of experiments in democracy more general.

2.1.2 Envisioned and Invented Societies: Sociotechnical Imaginaries and (Vanguard) Visions

Emerging technologies, science and innovation carry visions of sociotechnical change and imagined forms of future lifes (Hilgartner, 2015b; Jasanoff, 2015d). As laid down in the previous section scientific endeavor is by far not value neutral but deeply political, contested and contextualized. Therefore, once implemented into the world, science, technology and innovation shape us as society, our (future) ways of living and how we see the world (Bijker et al., 1987; Jasanoff, 2015d). Studying the relationship between technology, its undergirding visions and their role in making future in innovation contexts thus raises questions about the direction and and formation of such – often revolutionary – visions (Konrad, 2013; Truffer et al., 2008). What does the world look like envisioned by inventors, entrepreneurs, or policy makers – not only as material change but also in terms of sociotechnical ordering and societal adoption and uptake? What do “sociotechnical imaginaries” (Jasanoff and Kim, 2013) presuppose about desirable and achievable futures? How do (vanguard) visions relate to these broader imaginaries of society and, vice versa, contribute to their stabilization? And why do some visions become plausible and others do not, i.e. which visions become marginalized or delegitimized as un-scalable, un-desirable and un-imaginable?

This dissertation explores how test beds and related concepts such as living labs serve as localized materializations of future visions in the name of innovation governance and policy-making. Empirically, I consider both case studies as model arrangements and small-scale precursors of the German Energiewende at large, which propose particular visions of desirable futures: The one by redesigning urban space around a blend of energy, mobility, and IT technologies, and the other by spearheading sustainable energy use and regional economic revitalization through a decentralized, regional approach.

In how they merge the relationship between vision- and future-making in a condensed setting, my study on test beds connects to a long tradition of STS research (Brown et al., 2000; Jasanoff, 2015a; Konrad, 2013; Nordmann, 2013), yet, adding new insights on its specific approach to innovation – that is its explicit experimentation with and re-ordering of society basing on particular visions of desirable futures. Several studies known as the "sociology of expectations" explored the impact of expectations, hopes, concerns, or "Leitbilder" on the guidance of action towards future scenarios in science and technology innovation (Borup et al., 2006; Truffer et al., 2008; van Lente, 1993). Visions and visioneering – the process of making visions – (Nordmann, 2013; Trujillo, 2014) are considered important elements of transition processes and sociotechnical change, and part of technology assessment (Grin and Grunwald, 2000) and transformational innovation policies (Schot and Steinmüller, 2016). Imagining possible futures creates opportunities for the present and enables certain spaces of action, e.g. by mobilizing resources that are considered necessary for successful innovation. Yet, visions and expectations are not only important for national policy-making at the macro-level, but also for the meso-level of innovation networks, as well as at the micro-level of individual research groups and project consortia (Borup et al., 2006; Engels et al., 2017). When companies and scientific actors think beyond their established research and innovation practices they face severe uncertainty towards the actual outcome and realization of their experimental and pioneer initiatives – a context in which shared expectations and visions can not only provide structure and legitimation, e.g. in the form of raising funding (Borup et al., 2006; Brown et al., 2000; Konrad, 2006), but also openings for new actors to set up new constellations and roles (Kuhlmann and Rip, 2018).

Insights from studies on visions and expectations and their role in governing emerging technologies and new constellations of actors inform my research on test beds and how the various actor groups articulate and negotiate different visions at these sites. In the following, I will connect these strands on visions and expectations with the analytical frameworks of (local) vanguard visions (Hilgartner, 2015b) and sociotechnical imaginaries (Jasanoff and Kim, 2013) to explore how test beds co-produce and enact technological visions and their social contexts.

Historian Patrick Mc Cray has coined the term "visioneer" (McCray, 2013) to describe single individuals or a collective of experts who are committed to imagining transformative new technologies and how they imagine, design, and popularize speculative technologies such as nanotechnologies. According to McCray, visioneering as collective action provides "valuable and hard-won space in which other scientists and engineers could mobilize, explore, and push the limits of the possible" (McCray, 2013). Whereas Mc Cray thinks of the visioneer as a forward-looking thinker with an (expert) background in natural science or technology from a techno-optimistic stance, Stephen Hilgartner introduces the concept of "sociotechnical vanguards" (Hilgartner, 2015b) to highlight the role of small collectives in the making of future. According to his concept vanguards seek to advance their visions in that they "formulate and act intentionally to realize particular sociotechnical visions of the future that have yet to be accepted by wider collectives, such as nations" (Hilgartner, 2015b). Hilgartner studies the new domain of synthetic biology to analyze how vanguard groups imagine and constitute the traits and avenues of an emerging technoscientific field. His research shows that the new field of biotechnology is not only highly contested but that the different actors also envision significant social change (ibid. 34). These insights speaks to my findings on test beds: Test bed developers make normative decisions not only about which technological changes are desirable but also about what they consider a truthful representation of society when defining a test bed. Based on these assumptions the experiments in those miniature societies constitute social interventions, which are essentially normative and political choices.

How test beds assemble new sets of stakeholder consisting of policy-makers, scientists, large corporations, start-ups, municipal utilities, citizen groups and foundations, is not only a crucial characteristic and potential benefit of these sites but equally a key challenge as those carry and promote individual visions which may differ greatly (Hilgartner, 2015b).

This is all the more true when the boundaries of emerging technoscientific fields, as in the empirical case of energy transitions, are highly ambiguous, flexible, contested and redefined in action (Gieryn, 2000). As visions are shaped by the ones involved, test beds thus become the places where vanguard visions are negotiated and temporarily materialized and eventually become objectives of political debate and public visibility (Engels et al., 2017). These processes work as public demonstrations and catalysts, and 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, 2015a). Test beds embody particular vanguard visions with the ambition to be at the forefront of change, "actively position themselves as members of an avant-garde, riding and also driving a wave of change but competing with one another at the same time" (Hilgartner, 2015b). As part of the case study of the urban innovation campus I ethnographically traced the negotiations and contestations over diverse visions about the test bed's future, how the actors envisioned the site's material design, its marketable story and its relevance in larger German energy policy. Investment strategies over certain technologies and how they are to be implemented and tested at the site have constantly been changing. Being a beacon for smart and sustainable cities was just one of the envisioned scenarios, which eventually gained traction and was collectively re-envisioned when it aligned with upcoming discourses around smart city technologies, sustainability, and clean energy – not least due to radical changes in German energy policies resulting from the nuclear disaster in Fukushima in 2011.

The correspondence or mutual influence between these different scales (the activities of local innovators and the government's policy choices) touches upon a significant relationship: The relationship between the numerous and fleeting visions of self-proclaimed sociotechnical vanguards in test beds and the "sociotechnical imaginaries" as larger, collective aspirations of societies, which are much more stable and embedded in national cultures (Hilgartner, 2015b; Jasanoff, 2010; Jasanoff and Kim, 2013). In their work, Jasanoff and Kim (2013) have discussed how visions and expectations align with larger cultural regimes and how they interact with new and emerging technologies. They define national sociotechnical imaginaries as "collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects" (Jasanoff and Kim, 2009). Although research on sociotechnical imaginaries has traditionally emphasized on innovation trajectories on the level of nations, it is well suited and applicable to study smaller scales such as urban or regional test beds and how these sites channel imaginaries into local innovation practices. To study the numerous ways in which "scientific and technological visions enter into the assemblages of materiality, meaning, and morality" and how they can be articulated by other actors than the nation state consequently requires a refinement of the traditional definition of imaginaries (Jasanoff, 2015a).

The concept of sociotechnical imaginaries differs from Hilgartner's vanguard visions in that imaginaries are "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff, 2015a; Jasanoff and Kim, 2013). This definition explicitly points at the role of public performance of future visions through projects of science and technology. That said, studying test beds as physical sites of testing and performing future visions is at once a study of the "interpenetration of knowledge, materiality and power" (Jasanoff, 2015c). Using the power of technology and innovation projects, test bed actors re-imagine and remake society, albeit at small scale. Experimental sites make explicit what entrepreneurs, public authorities and the public consider a "smart" city or a "better" architecture of the energy system in that they implement the – in their eyes – relevant technologies and adjust rules and regulations accordingly. Taking the introductory example of Toronto's Waterside re-designed by Google company SidewalkLabs, the sociotechnical imaginaries undergirding future smart city Toronto make aware that certain "cutting-edge" technologies, such as interconnected neighbourhoods or self-driving delivery robots, should support the envisioned future city and society, instead of e.g. the concerns raised by the residents regarding the storage of the collected public data (as outlined in the letter of resignation of Saadia Muzafaar). Imaginaries of digitalization "encode" the visions of what is made possible through technology, and, even further, they express how life ought to be (Jasanoff, 2015a). The integration of data-driven technologies into the social fabrics fuels hopes to solve current urban challenges in the name of sustainability, quality of life and economic opportunity. In that sense, innovation projects like Toronto Quayside can be seen as self-diagnostics of what city officials perceive to be in need of fixing (Pfotenhauer and Jasanoff, 2017a). In the Quayside test bed, however, the power to solve the diagnosed problems is given to a Google company and favours the interests of commercial actors instead of engaging with local community partners and to enrol public actors. Empirical observations like this suggest that at present, the "one-off" and opportunistic *ad-hoc* character of test beds tends to sideline the sometimes slow and laborious processes of political deliberation and public engagement.

Investigating imaginations and vision-making as social practices (Jasanoff, 2015b) allows me to follow the embeddedness of ideas into the materialities of test bed settings as publicly performed visions of "better" futures. I assume that test beds may serve as instruments to perform such processes of embedding, which allow imaginaries and visions to gain momentum and to spread beyond the actual test bed context across time and space into new contexts (Jasanoff, 2015d). In theory, the ways how revolutionary sociotechnical visions develop and re-form describes a "dynamic process" in which their advocates encounter other actors with different goals and interact with established collective aspirations and imaginations of the future (Jasanoff, 2015d). Hilgartner also suggests a dynamic approach to examine the co-production of visions of the future and the groups that advance them, which implies that vanguards can turn into imaginaries when larger and more stable groups communally hold them (Hilgartner, 2015b). That means, in order to gain support and greater relevance, ideas need to circulate outside the bounded communities of vanguard or visioneer groups to become full-fledged imaginaries (Jasanoff, 2015d). Such processes of "embedding" (Jasanoff, 2015d) describe the linking-up between ideas and concrete things, like material artifacts that can travel and generate value.

Nevertheless, it remains a topic of further research on how vanguard visions obtain or shape concrete material forms and are ascribed meaning (Jasanoff 2015). It is a key objective of STS research to unravel these processes in order to understand the undergirding power structures and actor constellations, which are eventually the designers of a new sociotechnical order. This is why it is crucial to ask, *whose* vision will be realized in and through test beds when these visions gain traction and permeate society through acts of coalition building or often "through blatant exercises of power" (Jasanoff 2015: 5).

Together with my co-authors, we empirically observed the ways how new sociotechnical visions encountered regional identities and were confronted with local traditions and self-conceptions (Engels et al., 2019). In particular, the case of the regional innovation network has revealed empirical pathways of resistance and frictions as a result of the challenges when "specific pasts and presents get connected as well as where global and local temporalities need to find arrangements" (Felt, 2015a). Further we wanted to understand how existing cultural and political predispositions and identities were re-articulated and made plausible through the re-interpretation of places as test beds (Jasanoff and Kim, 2009; Pfotenhauer and Jasanoff, 2017b). Test bed experimentation and the salient vision of its scalability are basically about the creation of plausibility of yet unknown futures (Selin and Guimaraes Pereira, 2013). Investigating how communities establish plausibility is a particularly interesting locus of concern and a means to better understand the meaning and significance of the ways individuals and communities know, explore, assess, and shape their presents and futures across time, cultures, and professional practices (Selin and Guimaraes Pereira, 2013). As test beds typically gather diverse visions about the purpose and trajectory of the test bed itself, this puts the locus of politics into the intersection of different *potential* futures. Our research confirms the dominant role of frictions, power differentials and politics in innovation activities, when expectations from actors at the national scale clash with local traditions and cultural identities.

The research papers and the upcoming discussion will further discuss and shed light on the conflicts arising in test bed governance surrounded by the negotiations about collectively held visions – their desirability, feasibility, and generalizability – and how these visions might be cast into concrete material form in the long run and across multiple sites.

2.1.3 Co-Constructing Place and Meaning: The Re-Vitalization of the "Society as a Lab"-Idea

In this upcoming section, I will introduce a set of relevant concepts to discuss how test beds resonate with notions of technological learning and traditional approaches of scientific testing, which were used to be bounded in artificial and safe environments. However, I am going to argue that test beds construct places both as sites of observation and demonstration and thus re-interpret traditional understandings of what is meant by "laboratory". Following the red line of the co-productionist relationship, technology and innovation are not merely conferred onto the places but rather get co-produced with these very places and their cultural idiosyncrasies (Jasanoff, 2004). Discussion in this section are inspired and informed by aspects of the sociology of place (Gieryn, 2000), studies on urban laboratories (Evans et al., 2015; Karvonen and van Heur, 2014), the sociology of testing (Pinch, 1993) and studies that have employed terms as "society as a lab" and the (de-)laboratization of the world (Gross, 2016; Guggenheim, 2012; Krohn and Weyer, 1988).

STS studies have shown that places as specific geographic locations refer to broader technopolitical cultures, which describe the historically rooted interrelatedness of technoscientific and societal developments (Felt, 2015b; Gupta and Ferguson, 1992; Jasanoff, 2004; Moore and Hackett, 2016). In line with the "sociology of place" introduced by Thomas F. Gieryn among others (Gieryn 2000; Henke 2000; Kohler 2002; Meusburger et al. 2008) I consider places as structured by deeply entrenched, pre-inscribed social orders. The two case studies of this dissertation offer rich empirical insights into the processes of co-shaping places and sociotechnical orders and extent the practice-based approach to local configurations of innovation. That means that place is never a "neutral" space but laden with idiosyncratic cultural differences, historical memory, and societal organization that are deeply inscribed (Gupta and Ferguson, 1992).

In his article "A space for place in sociology" Gieryn suggests three characteristic features of place (Gieryn, 2000) – geographic location, material form, and investment with meaning and value – which are relevant for my study on experimental yet real-world settings. *First*, place is described as a finite geographic location, though with elastic boundaries and at a varying scale. Test beds can differ greatly in scale, ranging from quite bounded university science parks or privately owned test sites for autonomous driving, to entire regions with rather fluid boundaries, to dispersed collectives assembled for example into a testing population (e.g. for a regulatory sandbox on financial apps). Giving a glipmse into my empirics to illustrate this point, the spatial delimitation of the urban innovation campus has created a relatively controlled environment, with the campus literally fenced off from its urban surroundings and accessible only through guarded gates. This kind of spatial delineation of the privately owned campus allows for a certain degree of regulatory and institutional flexibility, e.g. to test self-driving cars, without the interference of Germany's strict road safety regulations. In contrast, the boundaries of the other, regional, test bed are neither as clear-cut as in the campus case, nor artificially created. The territory of the test bed rather refers to the historical geographies that have formed that area over centuries, e.g. being a center of the Age of Enlightment in the 18th century.

Second, place is characterized by its physicality and material form (Gieryn, 2000). An entire strand of STS research has conceptualized places as assemblages of things (Bijker et al., 1987; MacKenzie, 1990), which point at the dual relationship between places made by people and social processes happening through the built form (Lefebvre, 1991; Winner, 1980). In recent debates, the promise of smart cities (and related concepts such as green or digital cities) advocates the use of (presumably invisible) digital technologies like smart meters or sensor technologies in order to improve life quality and to increase efficiency and productivity, however, its entanglement with the material is often underexposed (Forlano, 2013). Thus, when talking about place, it is necessary to identify the mutual constitution of place, technology and people: its visibility; its incongruity with architectural boundaries; imbued with tensions, disjuncture and frictions; and embedded within routines, relationships and practices (Forlano, 2013; Winner, 1980); in short: material-spatial arrangements embody social, i.e. power, relations (Winner, 1980). The materialization of technological artifacts in test beds and its performative character in shaping physical infrastructure are at the forefront of article 3 featuring the urban test bed: What makes technologies take the forms they have? Among others, it could been shown that urban technologies are at once the outcome of social action and collective bargaining (Winner, 1980) as well as the conditions structuring social practices.

Thirdly, places are socially constructed and invested with meaning and value (Gieryn, 2000). In both empirical case studies, the various stakeholders explicitly frame the test beds as spatially confined sites of experimental, co-creative innovation activities with the intent to spearhead an energy system transition and to serve as transferable models that hold valuable lessons for other places. Moreover, both have been featured repeatedly as flagship public demonstration ("showcase") projects. Yet, they equally invoke contested and shifting visions of how Germany's energy future ought to look like, and by which means society ought to get there. They provide empirical proof that meanings and interpretations are flexible in the hands of different people and inevitably contested (Gieryn, 2000). Test beds are, as I already outlined in the previous section, highly contested sites in which the objectives are as much up for discussion as the ways getting there. Even further, in test beds it is not only the meaning or value of the place that is labile as suggested by Gieryn, but the actual creation and testing with technical artifacts, business models and governance structures that are turned into malleable components in the name of exploring futures. "A spot in the universe, with a gathering of physical stuff there, becomes a place only when it ensconces history or utopia, danger or security, identity or memory" (Gieryn, 2000), or put it differently, one cannot think about the notion of place and technological change without considering its cultural embeddedness and qualities in ordering society (Jasanoff, 2004).

The ways in which places become test beds constitute a specific approach of purposeful place-making (Gieryn, 2006). The spatial confinement and arrangement are considered a resource for innovation as they allow for experimental tinkering at a safe space shielded from both market pressure and regulatory constraints. In this regard, test beds speak to the idea of strategic or experimental niches (Hoogma et al., 2002; Schot and Geels, 2008) in which technologies can mature in protected spaces before being rolled out more broadly. Transition studies, too, have conceptualized innovation essentially around the idea of "scaling up" through interaction between nested levels (Elzen et al., 2004; Raven et al., 2012; Späth and Rohracher, 2012). From a multi-level-perspective (MLP), test beds could be compared to protected niches that, if sufficiently aligned and reinforced, may trigger changes in existing technological regimes and the broader sociotechnical landscape (Geels 2002). Here, the potential for scaling-up depends on an interplay between the niche and the regime level, which, however, remains rather technologically determined and artificially separated. Recent studies on experimental niches have integrated contributions from regional studies and geography to suggest a "second generation of MLP" that explicitly incorporates a spatial scale (Raven et al., 2012). These studies put greater emphasis on notions of space as being relational, fluid and contested by institutionally situated actors. Nevertheless, this work pays only scant attention to questions of testing, demonstration, or performativity, which are yet important characteristics of test beds.

How test beds tentatively materialize particular visions of how the future could look like and simoultaneously lend credibility and visibility to these visions and associated practices of visioneering, they act as what Gieryn calls "truth spots": they serve at once as natural field-sites for observations, artificial laboratories for experimentation, and social sites of planning intervention (Gieryn, 2006). The combination of these three components allows test beds to strategically mobilize complementary sources of credibility – the former two based on scientific objectivity, the latter on political action for the public good.

Other studies have shown that public demonstrations as part of large research projects are less expected to serve as technological tests comparing their performances and the utility of technical devices. Rather, they constitute physical, i.e. visible, proof of the project consortium's activities and the individual project partners' commitment and participation in it (Möllers, 2016). This is also true for test beds at the scale of entire cities and regions: Taking the example of Songdo, the new metropolis in South Korea, was purposeful designed and built from scratch, aimed to serve as a model for smart cities around the globe. International ICT company CISCO makes sense of Songdo in order to "showcase the latest development of solutions co-created with partners" and to "create a vibrant partner ecosystem in collaboration with accelerators" (Cisco, 2018). This demonstration pressure speaks to a crucial aspect of test beds. Being "terrains of powers", the spatialization and demonstration serve at once as architectures of enclosure, segregation, positioning, and display: "the capacity to dominate and control people or things comes through the geographic location, built-form, and symbolic meanings of a place" (Gieryn, 2000).

The demonstration pressure however stands in partial conflict to the thoroughness and open-endedness of research, which is featured in test beds in that they are expected to test hypothesis under presumably realistic conditions. Like traditional technology tests, test beds 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. In technological testing, Pinch distinguishes between three different stages of benchmarking: Testing before a technology's introduction or roll-out, which is e.g. the case in prototyping activities; testing of current performances to identify improvements or potential failures of a technology that is already running; or, testing in retrospective, when a technology has already failed, e.g. in case of an accident or dysfunction, in order to learn about the reasons. I am going to argue that in test beds these temporal differences become partly blurred, since new technologies are tested already in a use case scenario and entailing material reconfigurations. They deliberately "wipe away" not only the boundaries of the lab and blur processes of technology creation and its use, but also give access to unfinished and potentially risky technology. This approach goes beyond traditional field tests in that it is considered the test bed's explicit purpose to gather empirical data *while* the transformation takes place.

This socially embedded approach to testing links with further conceptual STS insights from the sociology of testing as well as laboratory studies. Traditionally, scholars have regarded experimentation as an operationalization to test scientific hypothesis in an artificial laboratory environment, strictly excluding unwanted and messy conditions from the real world (Collins, 1985; Pinch, 1993). This experimental procedure and set-up typically should allow the scientists to externally control the experiment and to induce changes and treatments according to the respective hypothesis to be tested (Gross and Krohn, 2005). Yet, several studies in the sociology of science have shed light on the contingencies and paradoxes of this experimental life (Collins, 1988). Replicability, for instance, is rather a vital idea and demarcation criterion (of replicable from non-replicable phenomena) than an actual practice: it "turns out to be as much a philosophical and sociological puzzle (…) rather than a simple and straightforward test of certain knowledge" (Collins, 1985). The role of human agency, interpretation, background theories and assumptions are embedded within the very experiments and their set-ups at stake (Pinch, 1993). This is one key insight from the sociology of testing that what counts as real-world conditions for testing is never just "out there," but always subject to interpretation (Pinch, 1993). Further, 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). The idea of "testing the user" instead of technology links to my findings on test beds, which – refering to the mantra of co-creation – break with the "traditional" distribution of roles and put even greater emphasis on the instrumentalization of collectives for the innovation process (as discussed in section 2.1.1).

The blurring between testing and performing speaks to the test beds' ubiquitous promise of scalability, i.e. the ambition to develop generalizable or transferable solutions out of the experience made in a unique sociotechnical setting. These new sociotechnical arrangements are expected – presuming that they pass the "test" – to be turned into generalizable, quasi-universal solutions, which would maintain their validity when removed from their original conditions of production. In thinking local cultural embeddedness and universal scalability together, test beds in effect collapse the notions "lab" and "society", where the lab ought to resemble society precisely by turning society into a lab. STS studies introducing the idea of "society as a lab" capture the range of social and political experiments that are situated beyond the laboratory but released onto society (Böschen et al., 2017; Groß et al., 2005; Krohn and Weyer, 1988). The term was initially introduced to make sense of large-scale technologies and the threats they pose for society, e.g. in the case of nuclear power and related risks and uncertainties for the public. The concept implies a process of societal self-experimentation without clinging to a fixed setting in which technologies are per se social experiments (Gross and Krohn, 2005). This research builds on the STS tradition of "laboratory studies" (with its origins in the late 1970s) scrutinising how natural scientists pursue their research in different settings – in the field, the laboratory, at desks or conferences (Collins, 1985; Knorr Cetina, 1995; Latour, 1988; Latour and Woolgar, 1979). Aimed at understanding the process of knowledge production and the "technical core" of science they particularly consider the laboratory as a venue of scientific activity and experiments as an active mode of natural philosophy (Shapin and Schaffer, 1985). The researchers undertook ethnographic observations in laboratories to learn about the processes of scientific practice and the ways how knowledge is *constructed* at these sites (Latour, 1987). Test bed research can learn in many ways (conceptual and methodological) from the rich history of laboratory studies and its insights which have brought renewed attention to the epistemic importance of laboratories and how they construct scientific results (Lee Kleinman, 2007): They have shown that knowledge production occurs at a local level and is subject to local variation; i.e. the cultures of science, including its knowledge and objects are formed by the context in which they exist. Scientific knowledge is thus the product of contingent factors. It does not mirror or represent nature in the laboratory, rather the laboratory work transforms nature (Latour, 1988) as a mode of intervention (Hacking, 1983) by the researchers who are involved in processes of "tinkering" (Knorr-Cetina, 1981), a term introduced by Karin Knorr Cetina to describe the modification of the materials by the researcher.

This interventionist character of the laboratory life is a conceptual anchor point to study test beds as social interventions. Test beds and living labs 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 place the experimental activities purposefully into the social setting with the intention to learn quasi in "real-time" and to adopt the experimental arrangement – which can be e.g. modifications of the infrastructure or regulation – accordingly.

One could say that test beds literaly recharge the "society as a lab"-idea in an unprecedented, instrumental manner. This specific "testing of society"-approach leaves many questions open for future research. I will outline a set of crucial aspects in more detail in the discussion section. I will put emphasis on the co-productionist relations and its scalability, and I will present ideas of how to render public experiments according to democratic principles.

2.1.4 Experimental Governance through Test Beds: The Production of Epistemic and Political Authority

Whereas the previous section has emphasized the spatial dimension of test beds and their approach of testing societies, I will now highlight the political dimension of test beds, how they produce not only epistemic but political authority in that they invoke the notion of experimentation. Recently, ideas of experimentation have increasingly been employed across contexts and disciplines, finding its way into studies of geography (Kullman, 2013), urban design (Evans and Karvonen, 2013), social work (Gross and Krohn, 2005), public participation (Felt and Fochler, 2010), and governance (Voß and Simons, 2018). This section puts emphasis on the latter, considering the notion of experiment and demonstration less in terms of technological development than as a mode of governance – as often referred to as "government by experiment", "politics of experimentation" (Bulkeley and Castán Broto, 2013; Voß and Schroth, 2018; Voß and Simons, 2018), or as an epistemic mode of "collective experimentation" (Felt and Wynne, 2007; Latour, 2004). These terms describe the ways in which government and policy-making are accomplished through an interplay of social and technical practices at designated geographical locations. Research on test beds raises a number of questions how to approach this particular mode of experimentation and demonstration in contemporary societies: To what extent do test beds invoke a novel understanding of experimentation, or possibly re-interpret traditional forms of testing and producing evidence and legitimacy? How and by whom are experiments instrumentalized as a means of governance? Which implications arise related to the democracies of experimentation and their role as instruments of public engagement?

Test beds invoke quasi-experimental situations where scientists and engineers but also national governments and community-based initiatives work across disciplines and social settings and test new sociotechnical configurations at small scale in what they prominently call "living labs" (Almirall and Wareham, 2011), "niche experiments" (Hoogma et al., 2002), or “open innovation systems” (Schuurman et al., 2013). Most prominently, experiments hold considerable sway in context of energy transitions, climate change, and smart city initiatives (Bulkeley and Castán Broto, 2013; Martin et al., 2018; Späth and Rohracher, 2010) becoming central instruments in the repertoire of policy planners and governments in urban climate politics. Using the example of global climate policy, Hoffmann suggests that an “era of governance experimentation” has come, reacting to both the fragmentation of political authority and pressures of disillusionment with international policy negotiation (Hoffmann, 2011). Experiments then become symptomatic of changing structures of political authority and opportunity and serve to create new forms of political space through which policies might diffuse (Bulkeley and Castán Broto, 2013; Hodson and Marvin, 2010) – regularly beyond existing channels of policymaking (Hoffmann, 2011).

Voß and Schroth have further discussed how policy experiments within diverse social settings act as forms of polycentric governance and whether these sites perform better than the nation state (Voß and Schroth, 2018). While the rise of experiments in policy-making acknowledges limits and complexity of central control, the authors argue, it partly glosses over the embedded social processes that bring about experiments and the involved power imbalances and diverging expectations. This – again – speaks to my approach to consider test beds as sites of co-production: The design, use and dynamic of a test bed is expected to vary across different contexts with their particularities and unique challenges, mutually co-evolving with the cultural and social set-up it is envisioned to test. In this context, experiments serve as a negotiation space between different (political) positions and (scientific) knowledge claims, in which discourses and visions are rendered practical and governable (Bulkeley and Castán Broto, 2013).

Viewing test beds as an instrument of knowledge production in order to test and create epistemic as much as political authority, aligns with a broader shift in the way experimentation is understood as both an empirical phenomenon and an orientation to knowledge. That experimentation takes on meaning as a set of epistemic practices has been discussed for example by Hans-Jörg Rheinberger who has argued that experimental systems – as applied in the life sciences – are simultaneously local, social, institutional, technical, instrumental, and above all, epistemic units (Rheinberger, 1998). Further, such systems must be capable of differential reproduction in order to behave as a device for producing epistemic things whose possibility is beyond our present knowledge, that is, to behave as a "generator of surprises" (ibid. 287). This "future-making machine" (ibid. 287) generates not only the answers but also the questions to be answered – and, even more relevant for my study on test beds – the experimental system is a device to materialize these questions. "The coherence over time of an experimental system is granted by the reproduction of its components." (ibid. 291) That means that the development of an experimental system depends on eliciting differences without destroying its reproductive coherence. To illustrate this ambiguous relationship, Rheinberger compares experimental systems with labyrinths, whose walls while being erected "simultaneously blind and guide the experimenter (and) limit the space and the direction of the walls to be added (…) It forces one to move by, means of checking out, of groping" (ibid. 291). Dealing with this kind of unpredictability and uncertainty, innovation activities in test beds equally function in accordance with the principle of figuring out while doing. However, test beds fundamentally differ from what Rheinberger describes as experiments in terms of its "reproductive coherence": Unlike experimental systems with their inherent character as research arrangements and devices, experimentation in test beds has left the scientific sphere and entered society – i.e. innovation is co-produced by the social and technoscientific orders, which are neither preconfigured nor reproducible, but messy and uncontrollable embedded in cultural idiosyncrasies.

These processes are characterized by and depend on phases of stabilization and de-stabilization, which makes test beds and associated visioneering practices flexible and fragile and in need of continuous work and renewal as my empirical results suggest (Engels et al., 2017). Robustness of knowledge is hence achieved through "continual interaction – or conversion – between fact-finding and meaning-making" (Jasanoff, 2010), underpinned by processes of co-producing legitimate knowledge and legitimate power.

Drawing on the perspective that test beds co-produce knowledge and power sheds light on the conceptual tensions that test beds need to navigate when they are expected to produce both epistemic and political authority: (1) The logics of experimentation, (2) demonstration pressure, and (3) scaling up.

First, through a process of tinkering with various ingredients, "set-ups of bodies, materials and spaces", experimentation aims at once for flexible reconfiguration so as to sustain their transformative potential but at the same time flexibility is limited by a basic need for control to hold together (Kullman, 2013). This points at the paradox relation between openness and cohesion in test beds. While clinging onto some form of delineation and control, test beds at the same time deliberately seek the messiness, diversity of inputs, and unexpected disruptions that characterize real-world environments. In this paradigm, the value proposition of test beds rests in collaborative forms of innovation with non-traditional innovation actors and rapid user feedback – which, at the same time, is a potential source of conflict when to be decided whose inputs and opinions to give precedence to others

Second, actors' individual interests come along with ambitions to demonstrate success and to turn test beds into showcases of particular solutions. These ambitions stand in conflict to efforts of "learning" from the experimental activities as equivalent to scientific tests (as I have outlined in the previous section). Experiments and public demonstrations both involve – what Brice Laurent has called – "technologies of democracy" (Laurent, 2011) which he defines as "instruments based on material apparatus, social practices and expert knowledge that organize the participation of various publics in the definition and treatment of public problems." (ibid. 649) Experiments and demonstrations are two central modes of action for experts of technologies of democracy, yet, both are subject to controversies and political construction in that they construct the publics and create the citizens they envision (ibid. 651). The organization of public participation through experiments and demonstrations is thus necessarily subject of political choices which define not only what counts as a public problem but also what to be considered acceptable ways to deal with them (ibid. 664).

Already in 1999, Andrew Barry has drawn attention that the idea of demonstrations is political as much as scientific and that its conduct involves a set of technical as well as ethical practices (Barry, 1999). A demonstration is always a political matter (ibid. 77) because, first, it is an active choice to decide who is allowed to witness the demonstration and where it takes place, and, second, the conduct of a demonstration in public is always intended to have effects on others.Thinking about demonstration as an ethical and political practice through which something is made visible, demonstrations become sites "which themselves have to be made into places of political activity" (ibid. 88). This further aligns with an understanding of experimentation according to which it is not only essentially for innovation processes to envision the future but to actually realize these visions by prototyping, building and configuring practices (Hilgartner, 2015b).

In this regard, the test bed is not just a "neutral" test site for novel technologies, but evidence for the plausibility of a national policy strategy and a real-world manifestation of a certain vision for working and living. Notion of evidence and testing imply a definition about the tests' outcome, whether it succeeded or failed – whether a certain policy strategies is assessed as plausible or not. The "testing" paradigm implies further that the proposed sociotechnical arrangement could fail the test (at least in principle) and that – if taken seriously – an alternative course of action could be chosen to address the challenge. However, one could argue that the distinction between the two paradigms of success and failure is not as clear-cut as it seems. The construction of scientific facts and their acceptance outside the lab setting depends on the co-construction of (legitimated) audiences and forms of observation that attest to the validity of the observation (Shapin and Schaffer, 1985). These insights suggest that the experimental, quasi-scientific paradigm of test beds also serves a social purpose of argumentation and strategic persuasion that may grant developments made within the test bed wider legitimacy. "Whether a demonstration project, science park, or living lab, urban experimentation is increasingly being turned to as a scientific means to political ends, becoming a favored governance strategy around the world, a form of politics by other means." (Evans, 2016).

Third, taking into account the embeddednes of experimentation in test beds not only conflicts with the idea of "neutral" outcomes, but notably with regard to its scalability and transferability. The tensions between local embeddedness and ambitions of scalability requires balancing a narrow ridge between the pursuit for the best local solutions and the temptation to interfere in local arrangements and control.

The plurality of interests and the blurring of the technical and the social raises some broader questions about the role of experiments in democracy as they actively encounter with the social sphere and enroll audiences by socio-material means (Barry, 2001; Marres, 2012b). Noortje Marres has suggested that experiments as instruments of public engagement play out in at least four different perspectives (Marres, 2012b). The epistemic perspective of public experiments assigns experiments as a device of knowledge transfer between science and its public. The discursive perspective expands this view seeing experiments as a form of public politics in liberal democracies (Jasanoff, 2005). As spatial and technical arrangements, they are about staging accountability and expelling citizens into the role of witnesses. Third, the ontological perspective on public experiments goes beyond that focus on knowledge production in that it emphasizes the performativity and socio-material re-configurations emerging through experimentation. And, finally, the material perspective stemming from the sociology of demonstrations (Rosental, 2014) strongly features the material dimension of public experiments (Marres, 2012a) which are, according to this approach, participatory devices in and of themselves, engaging audiences by material means. Using the example of green living experiments, Noortje Marres argues that those initiatives are a literal attempt to "domesticate new technologies in social life" as these are directed e.g. towards the integration of smart meters in private houses.

Enrolling and reconfiguring society around newly introduced technologies establishes the latter as "passage points" for social interaction. With society serving simultaneously as a laboratory and a resource for innovation mobilized by business and political actors, test beds thus raise questions of political representation and power. The concluding chapter will shed light on the implications of test beds as experimental policy instruments for liberal democracies from the perspective of political economies of experimentation.

2.2 Situating the Articles within the Conceptual Framework

This thesis consists of three original research articles, yet, it builds on a larger corpus of papers published over the past five years. Since 2013, my research engages with the epistemic, political and sociotechnical practices of exploring future visions and associated modes of governance in the empirical context of energy transitions.

During the time of my research, not only the research subject – the test bed phenomenon – has experienced a significant increase of popularity and relevance in the political, scientific and business landscape. This thesis is also the product of an intellectual working and learning process during which my conceptual thinking about test beds has evolved over time. Furthermore, it reflects my personal journey as a researcher over the course of five years, as it covers different research projects, work environments and collaborations. In particular, since I became a member of the MCTS graduate school in 2016 my conceptual understanding and thinking has refined. I am glad that the cumulative dissertation provides the opportunity to add a new perspective on my earlier publications and to frame them in response to my latest findings and learnings. This is why I present the three papers in reverse temporal order of their creation.

The list of publications below outlines all papers that I have published on the test bed phenomenon and emerging challenges in context of German energy transitions over the course time. I have highlighted the three publications, which compose the core of this dissertation. I have chosen this particular selection since it addresses test beds and related processes of co-production in a coherent and intertwining way. Findings base on two in-depth empirical case studies, which I conducted as part of two different research projects and working contexts between 2013 until 2018.

While all the three papers reflect on test beds as emerging sites of co-production, they take different theoretical angles of analysis. The latest paper represents the conceptual heart of the dissertation, in which I together with my co-authors present an analytical framework for test beds as instruments of innovation governance and highlight their distinctive approach of *testing* technologies and society. The second paper refers to the concept of sociotechnical visions and their *contestation* and performativity in innovation policy and practices. Paper number three studies the emergence of a concrete technological artifact, the micro smart grid, which is at the heart of co-creation activities at one of my test bed case studies, and reveals the processes of *materializing* visions into technical objects.

- Engels, F./Wentland, A./Pfotenhauer, S.M. (2019): Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance, *Research Policy,* 48(9), DOI 10.1016/j.respol.2019.103826
- Engels, F./Rogge, J.-C. (2018): Tensions and Trade-offs in Real-World Laboratories – The Participants' Perspective, GAIA 27/S1 (2018), 28 – 31.
- Canzler, W./Engels, F./Rogge, J.-C./Simon, D./Wentland, A. (2017): From "living lab" to strategic action field? Bringing together energy, mobility, and Information Technology in Germany, *Energy Research & Social Science*, 27: 25–35. DOI: 10.1016/j.erss.2017.02.003.
- Engels, F./Münch, AV/Simon, D. (2017): One site – multiple visions. Visioneering between contrasting actors´ perspectives, *NanoEthics*, 11(1), 59-74. DOI 10.1007/s11569-017-0290-9
- Canzler, W/Engels, F/Rogge, J-C/Simon, D/Wentland, A (2016): Energiewende durch neue (Elektro)Mobilität? Intersektorale Annäherungen zwischen Verkehr und Energienetzen. In: Giacovelli (ed.) Die Energiewende aus wirtschaftssoziologischer Sicht – Theoretische Konzepte und empirische Zugänge, pp. 119–47, Wiesbaden: Springer Fachmedien Wiesbaden GmbH.
- Engels, F./Münch, A. V. (2015): The smart grid as a materialized imaginary, *Energy Research & Social Science*, 9, 35-42. Doi 10.1016/j.erss.2015.08.024.
- Engels, F (2015): Doppelte Komplexität von Verkehrs- und Energiewende –Wirtschaftsunternehmen als Akteure der ko-evolutionären Transformation. In: *Innovation – Exnovation: Über Prozesse des Abschaffens und Erneuerns in der Nachhaltigkeitstransformation,* pp. 63-76, Metropolis Verlag, Marburg.

In the following section, each paper will be introduced in more detail and with regard to its particular contribution to answering the overall set of research questions.

Table 2. Overview of Three Original Research Papers.

Research Paper	Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance	One site – multiple visions. Visioneering between contrasting actors´ perspectives	The smart grid as a materialized imaginary
Journal	Research Policy	Nanoethics	Energy Research & Social Science
Year	2019	2017	2015
Authors	Franziska Engels; Alexander Wentland; Sebastian M. Pfotenhauer	Franziska Engels; Anna Verena Münch; Dagmar Simon	Franziska Engels; Anna Verena Münch;
Key Hypothesis	Test beds reconfigure and “test” societies against a new set of technologies and associated modes of governance based on particular visions. Symmetric attention reveals three characteristic key tensions.	Vision about future technologies are crucial components in innovation policy and practices, yet, they are highly contested between different stakeholders. The test bed itself changes through negotiations.	Visions may materialize into technical artifacts when they (re)align with broader sociotechnical imaginaries. Even if immature and contested, they facilitate collaboration among heterogeneous actors.
Research Question(s)	In what ways do test beds fuse the testing of technological and social order?	How do test beds serve as geographical sites for the contestation and negotiation of conflicting future visions?	What are the processes through which visions become materialized into concrete technological artifacts?
Main Concepts	Co-production; Sociology of testing; Experimental geographies	Sociotechnical visions and imaginaries; Sociology of expectations	Sociotechnical imaginaries; Boundary objects
Case Study	EUREF & EAA	EUREF	EUREF
Method and Data	Ethnography (EUREF 2013-2016; EAA 2016-2018) + 36 interviews + 3 group discussions + document analysis	Ethnography and interview study (2014-2015) + 2 group discussion + archive document analysis (2007–2010)	Qualitative case study + 21 interviews + 1 group discussion + document analysis

2.2.1 Article 1

Publication:	Engels, F./Wentland, A./Pfotenhauer S.M. (2019): Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance, *Research Policy,* 48(9), DOI 10.1016/j.respol.2019.103826

The first paper of this dissertation puts test beds as a new approach toward innovation front and center. In this paper, we develop both a definition of test beds and an analytical framework for this emerging innovation paradigm, which put emphasis on the simultaneous shaping of new technological and social orders. Feeding on the popular "grand societal challenges" and transformation discourses, test beds represent an experimental approach to innovation that aims at once to test, demonstrate, and advance new sociotechnical arrangements in a model environment under real-world conditions. Our research draws on theories from both Science and Technology Studies (STS) and Innovation Policy Studies, as well as in-depth empirical analysis from two case studies – EUREF, the urban smart energy campus, and EAA, the rural renewable energy network. In total data comprises 36 in-depth interviews with a heterogeneous set of stakeholders involved in the two test bed cases and ethnography over the course of five years.

Our findings highlight three characteristic tensions that test beds need to navigate, which span across the concept of experimentation, performativity, and scalability: First, test beds facilitate an innovation practice that goes back-and-forth between controlled experimentation in a laboratory-like environment and the "messy" co-creation processes of real-world problem solving. Second, test beds merge the seemingly incompatible logic of quasi-scientific testing and staged public demonstration. Third, they face a tension between the opposing needs of local specificity and scalability, i.e. the inherent promise that the test bed outcomes can be generalized or transferred, premised on the presumed representativeness of the test bed for a future society at large. That means, this approach emphasizes place and spatial delineation, while, at the same time, conveying the promise of scalability and generalizability for a future society.

Test beds thus defy the traditional understanding of "testing": They do not test a technology against existing real-world conditions, e.g. by simulating outside environments inside a lab. Rather, they reconfigure and "test" society around a new set of technologies and associated modes of governance based on some stakeholder's particular visions of the future. This adds to an overall picture where social order is being made available for experimentation: It is society as well as technology that are the subject of testing and reconfiguration in test bed settings. In this locally confined simultaneous co-production of new technical and social orders (Jasanoff, 2004), experimental sociotechnical arrangements are introduced, stabilized, and gauged for potential problems, both in terms technical performance and societal uptake. This local "model version" of a new sociotechnical arrangement, so the hope, can then be scaled up or transferred to a wider range of settings (Hilgartner, 2015b).

This raises new challenges for a responsible use and governance of test beds as a policy instrument, including questions of participation and power, the criteria and consequences of failure (including a potential rollback of new technologies), and the contestation over diverging visions of how a desirable future looks like.

2.2.2 Article 2

Publication:	Engels, F./Münch, AV/Simon, D. (2017): One site – multiple visions. Visioneering between contrasting actors´ perspectives, *NanoEthics*, Special Issue "Visioneering sociotechnical innovations: The making of visions", 11(1), 59-74. DOI 10.1007/s11569-017-0290-9

The second paper focuses on the contestation of visions in test beds and the question how and why sociotechnical visions lead to substantial changes in projects of science, technology, and innovation.

The paper's point of departure is the significant rise of experimental niches and demonstration projects across countries and institutional fields in which the development, testing and implementation of new sociotechnical arrangements for the future energy architecture are the objective of experimentation activities. These kinds of innovation sites are framed by uncertainty since they are directed towards an unknown future, depend on rapid technological developments, address multiple actors, and are embedded in an unstable political and regulatory environment, for example, with regard to the changes to the German Renewable Energy Act (EEG).

Against this backdrop, the paper considers test beds as driven by visions and imaginaries (Jasanoff and Kim, 2013) and led by high expectations concerning their transformative power. The paper benefits from a large strand of STS studies, which have shown how visions and expectations may help to coordinate actors and enhance cooperation, provide meaning and direction, stimulate resources and support, and finally may contribute to deal with uncertainties (Nordmann, 2013; Truffer et al., 2008; van Lente, 1993) – while leaving room for diverse interpretations, modifications, or rejection.

With help of the EUREF case study, we show why and how visions of the future energy system play an important role in pioneering innovation activities. The question, why certain visions gain importance and eventually lead to substantial changes of the project in process, is in focus. Drawing on ethnography over an 8-year period the paper illustrates how controversies over concrete development processes however reveal fundamentally diverse visions of desirable futures – and the associated means to test, demonstrate and negotiate these futures. We further show how visions are produced, modified, rejected, and finally prevail within a heterogeneous set of actors, emphasizing the dynamics and temporal aspects of visioneering and its performative character in test beds.

In fact, the ethnography discloses the interweaving conditions between visioneering processes and the actual development of the site's physical appearance and its material artifacts. EUREF exemplifies how a local group of vanguards (re)aligns its different visions to a set of broader imaginaries (e.g. turning towards renewable energy and the paradigm of sustainability) and shifting political and regulatory contexts (e.g. the Fukushima accident), and how this shapes the test bed's materiality. In particular, we identified four different phases of EUREF's development, which we named "Foundation"; "Re-orientation towards renewables"; "Future city, living lab, and institutionalization"; "On stability and instability." Adopting a process perspective, we argue that the multiple transitions the site went through fulfilled respective functions of the test bed.

Our research thus underpins that the test beds' defining features result from collective bargaining and that the materialization of visions is a way of exercising power in a given setting. The material form of the campus embodies a specific form of authority (Winner, 1980) as being the subject of collective visioneering activities between contrasting actors' positions.

2.2.3 Article 3

Publication: Engels, F./Münch, A. V. (2015): The smart grid as a materialized imaginary, *Energy Research & Social Science*, Special Issue "Smart Grid and Social Sciences", 9, 35-42. Doi 10.1016/j.erss.2015.08.024.

The final (but first published) paper of this dissertation sheds light on the processes of materialization of visions in concrete technological developments.

In response to discourses surrounding on-going energy transition processes of what is known as the "Energiewende" – a large-scale experiment in itself – the micro smart grid technology has emerged as one alternative technical solution for the future energy supply, producing, storing and providing renewable energy within a decentralized infrastructure. In technical terms, a micro smart grid is a decentralized small-scale solution for future energy supply from renewable energy sources supported by information and communication technologies (ICT). However, it also represents, or embodies, the idea of a transformation into a decentralized, smarter, and greener society. This sociotechnical imaginary (Jasanoff and Kim, 2013) provides a future vision for both the design of the technological system and the citizens' role in it. According to this vision, energy will be supplied from multiple micro smart grids, consisting of mini power plants, photovoltaic systems and biogas plants, all connected via ICT – rather than from relatively few centralized sources, as it is used to be. That implies that the formerly "passive" energy consumer is envisioned to be an active market player in the future energy landscape, prominently introduced by the term "prosumer" (equally acting as producer and consumer). The politically imposed transformation of the energy system into one based on renewable sources thus requires significant changes and structural reconfigurations, equally challenging existing modes of governance, infrastructures as well as actor constellations and constructions of users within the future energy architecture.

Empirical data has been gathered from the EUREF campus, an ascribed test bed for innovation and research that represents a designated local setting combined with spatially embedded visions of the future city and energy system. Using EUREF as our example, we emphasize the question of how imaginaries are interwoven with a local test bed project and how this affects the specific actor constellation collaborating in the technological development of the micro smart grid.

Applying a co-productionist approach our study shows that the alignment between local visions and broader imaginaries is a charateristic feature of local test beds. In line with Jasanoff and Kim we argue that the energy system is shaped by collective visions of national energy choices (Jasanoff and Kim, 2013) and that the sociotechnical imaginaries of a greener, smarter and sustainable future give momentum for new technological innovations to emerge. Test beds are geographical settings in and through which such imaginaries may touch ground, and which, above all, serve to learn about the viability and desirability of particular technological visions such as the micro smart grid.

What is more, our research shows that despite the micro smart grid's incomplete status in terms of its technical advancement and reliability, it works as a boundary object (Star and Griesemer, 1989) across the specific actor constellation with plural backgrounds, interests and perspectives. Yet, not only the micro smart grid, but also the test bed itself and its feature of providing a shared, partly protected setting, facilitates collaboration and commitment across heterogeneous actor groups. Thereby, it allows various actors to find strategic ways of coping with the perceived uncertainty that is characteristic for transition processes; it enhances co-creation activities and the development of new business models across formerly disparate sectors of energy, mobility and ICT, and thus, takes it part in contributing to the energy system transformation at large.

3 CASE STUDIES AND METHODOLOGY

There is a number of studies about quantitative assessments of urban experiments (Bulkeley and Castán Broto, 2013) or about mapping the methodology of living labs "from the outside" (Almirall and Wareham, 2011; Dell'Era and Landoni, 2014) which provide an overview of the test bed landscape and their global geographies. However, these studies do neither tell us about the sites' dynamics and developments over time, why and how they emerged, or about the specific actor constellations and collaboration experiences; nor do they shed light on the rationales and contestations over different visions.

Indeed, scholars have recognized a lack of in-depth empirical case studies of specific initiatives and multi-site research which contrasts developments in different locales, and weak collaborative engagement with various stakeholders (Felt et al., 2016; Kitchin, 2015; Laurent and Pontille, 2019). They identified a need for a deeper understanding of how these initiatives are created, whose interests they serve and whose they neglect, and how they are connected to the political and economic ordering of society at large (Chilvers and Longhurst, 2016; Coletta et al., 2019; Coletta and Kitchin, 2017; Laurent, 2017).

When innovation policymaking increasingly happens through local initiatives and settings, research needs to re-orient its attention to these specific sites where future societies are envisioned, tested and realized and where sociotechnical imaginaries entangle with local conditions (Jasanoff, 2010). It is at these spaces of engagement where „traditions are made and enacted, where specific pasts and presents get connected as well as where global and local temporalities need to find arrangements" (Felt, 2015a), - and it is essential to reflect on the ways they do so. Thus, my work pays respect to the reorientation towards "the local" in order to gain insights on the particular ways in which policy missions and local specificities interact. This requires qualitative forms of in-depth analysis, in particular through the exploration of detailed case studies and a fieldwork approach to understand how the initiatives frame and unpack the projects and technologies at work as well as their wider implications as instruments of innovation policy.

In my research, I focus on two empirical case studies to explore how they have been envisioned and made into test beds for wider smart city and energy policy. I have chosen a qualitative case-study approach and engage with ethnographic and interview studies as they add rich empirical descriptions of particular instances of the test bed phenomenon. In particular, my work draws on several periods of ethnographic fieldwork over five years, three dozen interviews (single and group interviews), and extensive document analysis. Case study analysis helps me to explore the ways how technology becomes closely intertwined with complex social changes and, furthermore, to extract generalizable observations from empirical evidence to contribute to theory building (Eisenhardt and Graebner, 2007; Siggelkow, 2007). The inductive approach allows me to find patterns within and across the two cases from which to develop theoretical constructs (Yin, 2014), as we set out in article 1 suggesting an analytical framework of test beds as innovation governance instruments.

This chapter is structured as follows: After giving a brief digression to the current developments in German energy transitions, which form the empirical context of my research and in which the two case studies are embedded in and considerably have to deal with, I will state my motivation for selecting these particular cases. Then, a short description of each case follows. After that, I will share insights on my methodology, set of data and approach of analyzing data according to the overall research questions.

3.1 The Context of German Energy Transitions and Case Selection

Germany's "Energiewende" – the national policy commitment to transition to a modern, sustainable, and low-carbon energy system – has received considerable attention over the last years. Already prior to its nuclear exit, international observers and commentators have long praised the country's coordinated effort to invest into decentralized renewable energy sources such as solar and wind power, and the strong civil society backing it has enjoyed. First started in 1990, the so-called "feed-in tariffs" allowed anyone who wanted – from citizens, communities, to municipalities – to participate in Germany's renewable energy revolution. More recently, however, Germany's renewable energy leadership seems to have lost momentum, a development best described as "from leader to laggard" (The Beam Magazine, 2018). The federal government has reduced incentives for renewable energy investments and partly re-oriented its policies towards coal extraction. The country will likely miss its COP21 climate targets, set at the Paris climate conference in 2015[4], and has already

[4] At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. The agreement sets out a global action plan to put the world on track to avoid climate change by limiting global warming to well below 2°C.

lowered its climate goals. Following Germany's general election in September 2017, government coalition negotiators even agreed to abandon the emissions reduction targets. Meanwhile, other countries such as Sweden, Switzerland, and Norway are emerging as new champions in the global energy transition landscape (World Economic Forum, 2019).

While the German federal government has de-emphasized the paragon role in the global energy transition, many actors at the sub-national level have stepped up their engagement recognizing the void of a societal vision and a socio-politically sound narrative. Cities, municipalities, energy cooperatives, non-governmental organizations (NGOs), and companies insist that Germany takes a leading role in climate and sustainability policy, with several regional alliances leading the way. As a result, the country has seen flourishing local innovation initiatives to test new sociotechnical arrangements in the energy sector at a micro- and meso-scale (Späth and Rohracher, 2012). Many of the country's most powerful science and industry organizations have called for local "experimental spaces" as key instruments for future innovation and research policy (Stifterverband für die Deutsche Wissenschaft and u.a., 2017). The federal government has generally supported these local initiatives and "innovative niches as experimental spaces" across political parties and federal ministries (Bundesministerium für Bildung und Forschung, 2018).

Energy transitions have been the empirical domain where test bed approaches have initially gained its prominence, introducing terms of "real-world laboratories" and "living labs", which were dedicated to the testing and implementation of sustainable solutions for the future energy architecture. These experimental settings appeared to be a crucial part of the "Great Transformation" discourse: As one of the first, in 2011, the German Advisory Council on Global Change calls for the support of so-called "pioneers of change" (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen WBGU, 2011). Yet, the experimentation paradigm has been extended to further technical and policy domains and has become a key approach to foster innovation in general. In Germany, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety recommends the implementation of "innovative niches as experimental spaces" and promotes "testing laboratories" as a new mode of participatory design research for sustainable consumption (German Federal Government, 2014). At 2015's "innovation dialogue", experts from industry and science pointed out the importance of "test fields and experimental spaces" for developing and testing innovative applications (German Federal Government, 2015). Today, experimental spaces are at the core of Germany's economic strategy, institutionalized through the establishment of a dedicated division in the Federal Ministry of Economic Affairs and Energy, which has just published a "Handbook" for real-world laboratories (BMWi, 2018, 2019).

These examples illustrate that local test beds, experimental spaces, and real-world laboratories as means for socially embedded innovation have become a key strategy of the country's economic and innovation policy. Against this backdrop, I selected two case studies for in-depth empirical study: The first case, the "EUREF Campus" (EUREF), is an urban smart energy campus as a beacon and demonstration project for future smart city design. As a contrasting second case, I have picked a rural renewable energy network, the "Energy Avantgarde Anhalt" (EAA), which envisions a renewable, decentralized energy system on a regional scale. Both cases refer to themselves explicitly as test beds and/or living labs that have been featured repeatedly as flagship public demonstration projects. Recognizing the plurality and diversity of existing test beds, these two cases represent and illustrate the larger phenomenon in its different varieties, scales and geographies

As outlined in the beginning of this chapter, in terms of political and regulatory decisions, the German Energiewende pursues an exceptional path since it beginnings. Yet, although both cases deal with these national specifics, they offer two very distinctive ethnographic sites. They offer a set of variables along which I can proceed my analysis. On first view, they may differ greatly in some central analytic categories, in particular with respect to their spatial conditions (urban versus regional), the financial funding, the constitution process, and the involved actor constellation. The innovation campus claims to be a showcase for the future city and is initially funded as an investor project, primarily driven by economic interests and supported by strong public research funding. Considering the spatial dimension one can say that the campus was built up on a green-field site in a dense, urban neighborhood. In contrast, the regional community started as an ideological, avant-garde endeavor with loose but regional embedded connections that initiated the constitution of the network. When the bottom-up initiative received financial funding, it transferred to a defined "real-world laboratory" with formal organizational structures. Here, historically grown regional identities are confronted with national policy interests that not only affected the innovation dynamics but also group dynamics, raising the question of trust among the actors. Yet, besides these structural differences, both pioneer initiatives assemble a diverse range of actors from different sectors and disciplines, expressing diverse interests, strategies and forms of knowledge. Visions and expectations play a crucial role in both cases, which claim to be blueprints for a future energy system in a post-fossil society. Actors engage and even invest resources basing on expectations of imagined futures, which in turn are subjected to a continuous process of becoming tested and modified themselves (Felt, 2009). The two cases show how the test bed model intentionally removes several distinctions traditionally considered key for innovation. Along these lines, test beds redefine what it means to "experiment and innovate in the remaking of the world" (Evans and Karvonen, 2011).

Finally, another reason for the selection of the particular case studies is the availability to conduct in-depth empirical material in both cases over a three-year period each. Considering the fact that mostly internal power relations, motivations and interpretative patterns cannot be studied from "the outside", my methodological approach of field embedded research offers unique and valuable data to understand the mechanisms and functions of test bed innovation sites practically in the making. After introducing the cases, a more detailed description of my methodology and data analysis follows.

3.1.1 Case Study 1: The EUREF Campus

The urban smart energy campus EUREF (the acronym for "European Energy Forum") is located within the district of Tempelhof-Schöneberg in the German capital Berlin. A self-proclaimed "urban living lab for the Energiewende," EUREF aims to be a research and demonstration site for future smart and sustainable city arrangements (www.euref.de). Since its inception in 2007 following the purchase of a former gas storage facility (the "Gasometer") by a private investor, the campus has become a national flagship initiative for the integration of energy, mobility and building technologies, integrating material artifacts like electric and autonomous vehicles, charging stations, wind turbines, solar photovoltaic systems or biogas-powered cogeneration (Canzler et al., 2017).

And it has become a learning site for implementation under regionally specific, real-world conditions. 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 [..] from a legal and technological perspective, what the stumbling blocks are that one will face when bringing such ideas to market. [..] We have learned an incredible lot; perhaps we have learned other things than we initially thought, but they are no less important for doing [things].” Along the way, EUREF has received considerable public funding and has attracted several large companies and start-ups settled as tenants. As of today, about 3,500 engineers and office workers are based in the 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. Although the site has experienced some shifting of its overall story and ideology over the course of time (Engels et al., 2017; Wentland, 2016), the Gasometer as the iconic landmark has always been a widely visible (78-meter-high) symbol for energy related activities: “I never had another idea than relating to the energy theme. Insofar the project is self-explaining. So, in fact, it is logical that we deal with the energy issue at the site”, the investor and landlord of EUREF explained the site’s orientation.

3.1.2 Case Study 2: The Energieavantgarde Anhalt

The rural renewable energy network, the “Energy Avantgarde Anhalt” (EAA) was officially launched in 2014, drawing on earlier collaborations that have tried to establish the region as a pioneer for energy transitions. Recognizing the lack of tangible political action at the federal level for regional energy policies, the initiative’s vision attracted nation-wide interests from foundations, companies, and research organizations, who joined the network and helped raise funding. At the heart of the EAA vision are the local production and consumption of energy and the integration of electricity, heat and mobility as part of a regional energy transition strategy. As of today, its share of electricity derived from renewables already amounts up to 50 per cent (www.energieavantgarde.de). Since the beginning, hopes are pinned on presenting the region as a testing ground for energy related business ideas and products, for research and implementation, as well as for the socio-economic changes related to it. 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.” (www.energieavantgarde.de)

In contrast to EUREF, EAA is not a fenced-off area that was built on a greenfield site. As part of the German federal state of Saxony-Anhalt with more than 3500 km^2 and 380,000 inhabitants, EAA interprets experimentation as something that from the start ought to include various publics in its co-creation processes and regards inhabitants as valuable contributors of local knowledge. To enable formal representation and encourage participation of the public as an active partner, EAA chose to a non-profit association as its preferred organizational form, where citizens are represented alongside organized interests such as companies and government. From 2015 until 2018, the association received considerable, and almost exclusively, funding from an energy company foundation to support local innovation activities.

3.2 Methodology and Data Analysis

This dissertation and the three articles benefit from rich, qualitative data that I conducted within the two different ethnographic sites, but also in two different research projects and institutional contexts.

The first research project featuring the campus case ("D3 Micro Smart Grid EUREF") was conducted by TU-Campus EUREF, an institute of Technische Universität Berlin, from September 2013 until June 2016. The institute and we as the researchers were located at the EUREF campus, which was at once our subject of investigation. The project was part of the federal government's showcase initiative called "International Showcase of Electric Mobility (Berlin-Brandenburg)" funded by the federal government as well as by the federal states of Berlin and Brandenburg for a period of three years. The second project "Energieavantgarde Anhalt" started in November 2015 and was completed in July 2018 as a research project by the "Science Policy Studies" group at the Berlin Social Science Center (WZB). It was funded by the Innogy Foundation for Energy and Society (formerly energy corporation RWE). In both cases, I was the projects' principal investigator.

In total, this thesis draws on ethnographic fieldwork over five years, three dozen interviews, and extensive document analysis. The particular set of data slightly differs in each paper, as I will outline in the following table, which is owed to the time of conducting the projetcs as well as to the particular research approach and questions each project addresses. Article 1 covers both case studies whereas articles 2 and 3 put the campus case as a single case study at the center of investigations.

Table 3. Set of Data and Methodological Approach of Each Paper.

Research Paper	Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance	One site – multiple visions. Visioneering between contrasting actors´ perspectives	The smart grid as a materialized imaginary
Case Study	EUREF & EAA	EUREF	EUREF
Method	Ethnography (observation, participation), interviews and document analysis	Ethnography (observation, participation), interviews and document analysis	Ethnography (observation, participation), interviews and document analysis
Number of Interviews	36 interviews (23 with EUREF actors and 12 with EAA actors) incl. 3 group discussions (2 EUREF; 1 EAA)	23 interviews with campus actors incl. 2 group discussion + 13 interviews with residents	22 interviews with campus actors 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 + Archive documents for the period 2007-2010	Presentations, corporate publications, website, workshop and meeting minutes, press releases, social media
Time Period	2013-2016 (EUREF) + 2016-2018 (EAA)	2007-2015	2013-2015

This dissertation builds on empirical data from both cases, the “EUREF Campus” (EUREF), and the “Energy Avantgarde Anhalt” (EAA), and spans five years of *ethnographic fieldwork* (three years in each case with a temporal overlap). The long duration of the fieldwork and the embedded approach allowed me to conduct in-depth empirical analysis and to cover the initial moments and early struggles, constitutive moments as well as day-to-day interactions. As I was officially in charge of the “social scientific accompanying research" of the respective projects, I participated in both initiatives, which were set up as consortiums to bring together different disciplines (engineers, computer scientists, social scientiests) and sectors (companies, public utility providers, municipalities, science, citizen groups). That allowed me to take part in project meetings, workshops and informal talks, which have proved to be especially useful for mapping and understanding the consortium's discussions, interactions among the participants and the diverse set of motivations at stake.

Being part of the initiatives (and in one case even being located at the site of investigation) and participant observer at the same time was a methodological challenge and made me rethink common fieldwork practices and the forms of engagement and intervention (Estalella and Sánchez Criado, 2018). The projects were designed in a way that my research was expected to inform the project partners on a continous basis and to reflect on the insights, which I was aasigned to deliver as being the "social science researcher". This has placed me in an ambivalent position, in which I not "only" observed but produced and shared knowledge; an intervention not only through participation but collaboration (Amit, 2000; Estalella and Sánchez Criado, 2018). I engaged with my counterparts in their undertaking: in processes of technology design (developing, testing and demonstrating a micro smart grid) in the one case, and knowledge production (a region striving for ways towards a regional energy system) in the other. Paying attention to the observation that fieldwork has experienced an experimental drive and research practices have witnessed a radical opening for collaboration, Estalella and Sánchez Criado have introduced the concept of "experimental collaborations" to describe the intermingling of knowledge production with the traditional trope of participant observation that might even shape the conditions for a new form of social scientific research (Estalella and Sánchez Criado, 2018; Faubion and Marcus, 2009). Throughout the dissertation process, I took many opportunities to share my fieldwork experiences and methodological concerns within academic contexts, e.g. when I presented my research at coferences or engaged in collaborative paper projects, and benefitted from these reflections and exchange with colleagues who share similar challenges and applied particular accounts and improvisations to deal with them.

Research builds further on *interview studies*. I have chosen semi-structured, narrative-generating interviews (Flick, 2008; Lamnek, 1989) to gain deeper knowledge about the actor's ambitions to join the initiative, their expectations towards its outcome, and their perceptions about the test bed's performance. Interviews were conducted in person and informed consent was obtained before each interview. They have lasted around 1.5-2 hours and were audio-recorded and transcribed to be made available for qualitative analysis. Since the interviews transcriptions and all available documents are in German, I translated the quotations used in the articles and in this thesis into English.

In the EAA case, I conducted twelve interviews with the key players of the initiative: all members of the association's executive board, the advisory board, the head of the office, the heads of the funding institutions, and one member of the association. The interviews took place between spring and summer 2016, a period in which major tensions within the group emerged and conflicts became clearly visible. I further had access to the transcribed recordings of the initial group workshop in 2014, which was organized by colleagues of mine as part of a previous project within our research group.

In the EUREF case, together with my colleague we conducted 23 interviews between 2014-2015 with representatives from companies, start-ups, and research organizations, located at the campus. Two of the interviews were group discussions with the project consortium working on the micro smart grid's development. The sample covers the heterogeneity of the cases, in particular, the range of different sectors, and different organizational sizes, including both long-term participants and newcomers. In detail the sample comprises the following entities: five start-ups and newer small companies, three big internationally active corporations, three Europe-wide organizations, two European public-private partnerships across sectorial boarders (energy, mobility, ICT, science), four mid-sized firms with occasional international contacts, one scientist, the developer of the campus and architect, one small handicrafts company, and two gastronomy services. Regarding the duration of tenancy, two companies were already on the site even before the campus was being developed, eight companies and actors belong to the "early settlers", and the other companies and organizations have located there over the last four years. Another research organization was represented in the group discussions. Research focuses on interviewees in leadership, chief executive officers, or people with equivalent status who answered questions regarding strategic decisions such as the move to the campus or becoming part of the joint research activities at the site.

Besides the interviews with campus tenants and officials, we further conducted 13 interviews with local residents who live in close neighbourhood of the campus. We wanted to understand how the development of the campus has affected the district's general development and how the people living there perceived these changes. These insights are both a fruitful contrast and completion to the interviews with the campus actors and contribute to the overall understanding of the site's evolution and its role in urban development.

I have coded the interviews with help of QDA software. Therefore, I adopted an inductive, iterative approach, while working through the material. I began with a list of analytical themes derived from relevant theoretical and conceptual work on experimental spaces, sociotechnical visions and imaginaries of innovation, among others (as laid down in the theory chapter), which guided my research and had also inspired the preparation of the interview guidelines. In line with grounded theory methodology, which shaped not only the analysis of my data but also the interviewing process, interviews were open-ended, but framed and focused allowing the interviewees to tell their story. Furthermore, as the research projects run one after the other (though with a short temporal overlap), data collection in one case and data analysis in the other have overlapped, which allowed for flexibility in data collection procedures so that my research remained open to new ideas or patterns that emerged throughout the process (Charmaz and Belgrave, 2007).

To understand the characteristics and tensions of test beds and to rendering conceptual understanding from these data, I identified recurring themes across the data sets covering the following aspects: The actors' definition of a "living lab" and what they see as its necessary components; the general aim of the initiative and how it should be achieved; the individual expectations to become part of the initiative and whether those have been fulfilled; the reasons why expectations possibly have not been fulfilled; their perspective on German energy policy at large and the role of the respective test bed in it; tensions they perceive and which strategies they apply to deal with the tensions; experiences in dealing with the heterogeneous set of actors.

The theoretical concepts and previous studies have served as initial sources for building codes, but I integrated additional codes, modified existing ones, as gaining deeper knowledge of the empirical cases. I thus condensed the analytical themes into a set of codes and sub-codes, such as "definition of success," "definition of failure," "testing approach," "vision of scalability," "competing visions," "organization of actor network," "heterogeneity," "understanding of participation," "role of the user," "local challenges," "perceived tensions," and "process dynamics," among others.

I 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 following the principles of grounded theory (Berg and Lune, 2012; Glaser and Strauss, 2017; Mayring, 2007).

Next to my field observations and interview study, research builds on extensive *document analysis* which covers press releases and further materials, like websites and presentations from (internal and public) meetings. For article 2, together with my co-authors we traced the campus' genealogy for what we required additional sources of documents. In particular, we needed further and more detailed information and knowledge about earlier phases of the site's development, dating back to the conceptual stage. Therefore, we conducted further documented data and interviews with contemporary witnesses. We had access to both kinds of sources: first, to 40 protocols and meeting minutes from the first assessment and fundraising process in 2007 and to 29 of the second assessment process in 2008–2009. The analysis focused on a) information about former visions of the place, b) which kind of actors were involved and how they related to the visions in question, and c) technical information regarding the site's development. These documents turned out to be rich sources tracing the – partly relatively tough – negotiations about the strategic orientation and its funding as well as the lines of argumentation and reasoning. Second, we had informal talks with two actors involved in the assessment processes at that time. Furthermore, three of the interviewees from our sample cover information regarding the period 2007–2010, namely the project developer, one of his architects, and one early settler.

I related the interview data and statements from the field notes to the results generated in the document analysis. As described above, I have organized and sythesized all data materials through coding and category building and prepared it for the analysis with grounded theory methodology as introduced by Glaser and Strauss (Charmaz and Belgrave, 2007; Glaser and Strauss, 1967; Glaser and Strauss, 2017). I have chosen grounded theory due to its open and inductive approach which allowed me to move from thick descriptions of the specific cases to more general explanations of the test bed phenomenon – "ground up" from the data (Bryant and Charmaz, 2007).

4 THE ARTICLES

4.1 Franziska Engels, Alexander Wentland & Sebastian M. Pfotenhauer: 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.

Keywords: Innovation governance; test bed; living lab; experimentation; scaling; co-production

I. 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)[5]. For example, 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" (Financial Times, 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 (ibid). 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" (ibid).

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

[5] 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.

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 Schot and Steinmueller (2016) call 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 governance. 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 scaling up. This symmetric focus on social intervention and reconfiguration raises important questions about the responsible use of test beds as vehicles for innovation as well as their potential as instruments of innovation governance.

II. 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 (ibid.).

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 biothreats (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.[6] 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

[6] 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).

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" (ibid.: 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.

III. 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. 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, 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.

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

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.[7]

IV. Testing future energy systems: 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

[7] 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.

years,[8] 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.

IV.I. 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) – 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 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

[8] 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.

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 3,500 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.[9] 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

[9] 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).

> "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 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 upscaling 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 (WAZ, 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.

IV.II. 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 socio-economic 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 3,500 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.[10] At the same time, many local actors underscore that 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

[10] 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."

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."

V. 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 socio-economic 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 dis-rooted, 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 framework that raises crucial design questions for test beds. We summarize the main results of this discussion in Table 2.

V.I. 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.[11]

V.II. 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

[11] 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).

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 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.[12] 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.

[12] 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" (ibid.).

V.III. 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.[13]

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

[13] 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" Sidewalk Labs (2017).

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.

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

VI. 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 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.

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4.2 Franziska Engels, Anna Verena Münch & Dagmar Simon: One site – multiple visions. Visioneering between contrasting actors´ perspectives

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ABSTRACT

Visions of and narratives about the future energy system influence the actual creation of innovations and are thus accompanying the current energy transition. Particularly in times of change and uncertainty, visions gain crucial relevance: imagining possible futures impacts the current social reality by both creating certain spaces of action and shaping technical artifacts. However, different actors may express divergent visions of the future energy system and its implementation. Looking at a particular innovation site involving multiple stakeholders over an eight-year period, we empirically analyze the collective negotiation process of vision making, its shifting over time, and how visions eventually unfold performativity. Adopting a process perspective, we identify four different phases and the respective functions of visions and visioneering related to the site's development by exploring the question: Why do certain visions gain importance and eventually lead to substantial changes of the project in process? Qualitative data from documents and interviews analyzed with reference to science and technology studies show the interweaving conditions that influence the visioneering and the linkage to the actual development of material artifacts. Against the backdrop of innovation projects, this paper explores visioneering as an ongoing, transformative and collective process and reveals its moments of (de)stabilization.

Keywords: Vision; visioneering; innovation projects; performativity; material artifacts

I. Introduction

The German energy system transformation is an ambitious challenge that has created a pressing need for an alternative energy supply on the basis of renewable energies. According to its policy goals, Germany is still trying to adopt a leading and pioneering position within the international climate debate (Morris 2014; Ohlhorst 2015). Currently, we are observing a significant rise of experimental niches and demonstration projects all over the country where the development, testing and implementation of new sociotechnical arrangements for the future energy architecture are the objective of innovation activities (Evans & Karvonen 2014; Bulkeley & Castán Broto 2012; Späth & Rohracher 2012). Showcase or demonstration projects, often referred to as “living labs” or “real-world laboratories”, are intended to manage the current sociotechnical challenges on a smaller, feasible scale. These innovative activities go beyond technological developments while also addressing new business models as well as intersectorial and interdisciplinary cooperation in research and development. The presented case study of an urban innovation campus represents a particular geographical site where coalitions of actors, including business and research institutions, carry out innovation projects addressing a “smart” and “green” future energy system. Yet, these kinds of innovation sites are framed by uncertainty since they are directed towards an unknown future, depend on rapid technological developments, address multiple actors, and are embedded in an unstable political and regulatory environment, for example, with regard to the changes to the German Renewable Energy Act (EEG).

Against this backdrop, “test bed sites” are usually driven by large-scale visions and imaginaries (Jasanoff & Kim 2013) and led by high expectations concerning their transformative power as “seeds for change” (Kivisaari et al 2004: 224). With help of our empirical case study, we will show that visions of the future energy system play an important role in pioneering innovation activities. Social studies have shown how visions help to coordinate actors and enhance cooperation, provide meaning and direction, stimulate resources and support, and finally may reduce uncertainties (van Lente 1993; Dierkes et al. 1996; Nordmann 2013; Truffer et al. 2008). One can say that visions provide sense to innovation activities that are directed towards an uncertain future. We argue that inherent uncertainties, characteristic of sociotechnical grand challenges such as energy transitions, even reinforce the role of visions and expectations[14] as an important instrument for decision-making. Then, expectations work as "narrative infrastructures" (Truffer et al 2008: 1361) to bridge the present and the future status while leaving room for diverse interpretations of the long-term and large-scale visions. The anticipation of sociotechnical developments by visions is a way of articulating possible futures (van Lente 2012), since narratives or stories make visions explicit. Therefore, they are important tools in the framing, explanation, motivation, and understanding of actors' strategies (Janda/Topouzi 2015). Being normative in character, visions can be the outcome of collective foresight processes but also the product of individual actors to support particular interests (Eames et al. 2006). As this study explores, different actors may express divergent visions of the future energy system and its implementation.

The conscious act of vision making, its distribution and use is lately described by the term "visioneering" (McCray 2013). Taking heterogeneity into account, visioneering and experimentation within the urban arena entail the negotiation of diverse expectations of possible futures, as well as the "re-making of social relations across chains of actors involved in or influenced by transitions in socio-technical regimes" (Evans et al. 2016: 5). The performativity of visions and visioneering and its interrelation with the negotiation of contrasting visions between different actors, yet, have not been investigated by scientific studies so far. In this paper, we empirically explore the performativity of visions at a particular geographical place, which is a mix of lab and demonstration project in the context of the energy transition. We conceptualize visioneering as a process of collective practice that enables the integration of new actors with diverse interests and forms of knowledge over time, which may lead to new sociotechnical arrangements and artifacts. The aim of the paper is to understand: Why do certain visions gain importance at a specific time and lead to substantial changes to a project in process?

To answer the research question we focus on the strategic use of various narratives about the development and the negotiation processes at a former urban gas storage facility turned innovation campus between competing interpretations. Different actors express divergent

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[14]Borup et al. use the terms "expectations" and "visions" almost synonymously, describing expectations as "real-time representations of future technological situations and capabilities." Visions are "largely overlapping with 'expectations' but emphasize to a higher degree their enacting and subjectively normative character" (Borup et al. 2006: 286).

or even contrasting visions of the future energy system and its realization, and they compete for interpretations. We aim to show how visions are produced, modified, rejected, and finally prevail within a heterogeneous set of actors gathered at a common site, emphasizing the dynamics and temporal aspects of the process. Visioneering is both the subject and the outcome of negotiations; it can set parameters and open up room to maneuver. As collective action, visioneering provides "valuable and hard-won space in which other scientists and engineers could mobilize, explore, and push the limits of the possible" (McCray 2013: 10–14). Referring to the notion of performativity, we shed light on the interrelation between visions and the actual development of the site, and finally onto the threats that may arise when both dimensions diverge.

Looking at the innovation campus involving multiple stakeholders, we observe that vision making is a contested process and that the vision is shifting over time as a consequence. These processes, we argue, may contribute to stabilization or, conversely, destabilization of the vision that guides the ongoing development of the site. This paper[15] is an empirical based contribution to the making, changing and performativity of visions in innovation projects in the field of energy transition. Thereby our research contributes to the understanding of both the time dimension and normative dimension of visioneering. The notion of temporality in innovation activities is addressed in our conceptualization of visioneering as a process of several phases reflecting on the changing landscape conditions and actor constellations. By paying attention to the temporal order, we apply a time-sensitive perspective to understand how temporalities matter in the making of visions and the formation of sociotechnical configurations or artifacts, as "time becomes aligned in a specific manner when constituting a phenomenon or an artifact" (Felt 2015: 8).

II. The role of visions in innovation projects

Visions are prominent in the discourse on emerging technologies in the backdrop of current grand challenges, like the energy system transformation (e.g., Grunwald 2012). Several studies from science and technology studies, like the sociology of expectations, show that

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[15] This paper is based on the presentation by Engels/Münch 2015: "One site – multiple visions. Visioneering between contrasting actors' perspectives" at the First International Conference on Anticipation in Trento (Italy), 6.11.2015.

in times of social and technological change, visions gain crucial relevance and unfold a performative power: imagining possible futures impacts the current social reality by creating certain spaces of action and the making of technical artifacts. Expectations, hopes, concerns or risks provide guidance, structure and legitimation of activities, define roles and duties, and help to mobilize resources (cf. Nordman 2013; Borup et al. 2006; Brown et al. 2000) – and thereby may unfold a performative character. One can say narratives, like visions or imaginaries of the future, are constitutive since they affect decision-making and actions in the present (van Lente 2012: 772), for example by creating obligations. These theoretical strands support our research on visionary practices in innovation settings.

The qualitative data analyzed with reference to these concepts reveal the interweaving conditions that influence the negotiations on contested visions and place-specific expectations. First, uncertainties impact the creation of visions, which derive from both landscape conditions as well as from factors inherent in the project, as we are going to show. Landscape conditions not only refer to radical changes in energy policy or field-related accidents, like the nuclear disaster in Fukushima, but also to further external shocks like the global financial crisis. The case study analysis explores how the actors notice these kinds of macro-level shocks and how this in turn impacts the site's development. Furthermore, with help of our empirical data we unpack uncertainties that emerged within the project.

Second, visioneering is influenced by the changing constellation of actors at the innovation campus who articulate divergent viewpoints and interests. We focused our investigation on this second point: the heterogeneous actor constellation represented at the site consisted of scientists from various disciplines, engineers, practitioners, entrepreneurs, business representatives, and the project developer. They each settle down with their organizations and firms at the campus, some also engage in joint research projects – and all contribute to the creation of the campus identity, albeit in very different ways and with varying degrees of intensity. Patrick McCray described visioneers as a hybrid "combination of futurist, engineer, and promoter" who undertake future-directed activities (McCray 2013: 14). His definition underlines the active and mobilizing character of visioneering being a practice: Visionary agents "articulate designs for the future with considerable technical know-how and sometimes in astounding detail" (Nordmann 2013: 89). By creating scenarios or stories, visioneering opens up the space beyond the status quo for innovations, change, and development. It is the "compelling causal link" (Nordmann 2013: 89) between the present and the future.

Against the backdrop of experimentation as a rapidly emerging field of practice in times of transition (Evans et al. 2016: 1), the campus under investigation represents an example of the broader empirical phenomenon of sites of experimentation. Today, its purpose is to be a test bed and futuristic showcase project demonstrating “the urban district of the future”. It is driven by the idea of showcasing an innovative new generation of energy independent architecture. These kinds of projects gain traction all over the world as a mode of governance to stimulate alternatives and steer change (Bulkeley/CastánBroto 2012).

To understand the power and performativity of visions, it is important to note that the creation of a micro energy system via smart grid technologies entails a process that is extremely ambitious and demanding in many respects: Referring to 1) the technological requirements, 2) the structure of the site’s ownership, and 3) the practices of collective actions. First, the installation of a smart grid as a core component of the campus depends on the research and development of technological requirements, for example storage, capabilities for volatile energy sources and the interconnectivity of multiple renewable energy sources and components (wind, solar, batteries, etc.) via information and communication technologies (ICT). Second, we consider the campus to be an experimental test field characterized by testing procedures and intensive constructions at the site. Testing implies physical modifications, like the installation of cables, setting up wind turbines or building up a solar carport. Consequently, the structure of campus ownership and regulatory provisions may support but also may inhibit these kinds of activities and therefore constitute a relevant factor investigating the campus development. Third, the installation of a smart energy system, due to these multiple challenges, requires actors from various disciplines and sectors to come together to achieve a joint task, each providing plural forms of knowledge, practices, and support of the project.

Referring to the ambitious and heterogeneous character of the project, we ask how stable and robust a vision actually can be for the implementation of its promises. We use the case of the urban innovation campus to document the dynamics of visioneering, to show how the guiding vision of the future energy system is flexible and constantly reinvented, and how visions must be grounded and implemented in the local context if its promise is to become realized (see Eames et al. 2006). Our qualitative research covers a period of eight years from 2007 until 2015.

The paper is structured as follows: First, we present our methodology and the empirical data of the case study. We identify four different phases and analyze each along the specific state of actor constellation involved, landscape condition, and vision proclaimed at that particular moment of time. Building up on this we highlight several aspects of the process of visioneering between contrasting actors' positions. Second, we discuss the role of uncertainties for the project's development. We then consider the way the actors take up on this, focusing on the actor constellation and negotiations process. Third, we reflect the interrelatedness of vision, action and divergence. And finally, we show why visioneering needs to be understood as an ongoing process due to the vision's fragile character and the project's permanent need for stabilization.

III. Methodology and data

To describe and analyze the visioneering process from its early stages to the present, we chose a qualitative mixed methods approach (Flick 2008), including an interview study we conducted in 2014/15[16] with actors located at the site of interest and a document analysis regarding the time period 2007–2010. With our qualitative interview study we sought out knowledge in the following three interest areas: first, the motivation and expectations for the different actor groups from diverse scientific and economic fields to settle down at the innovation campus; second, their actual assessment of what they found, how far their interests and expectations were met; third, their knowledge of the technologies, particularly the micro smart grid as it developed at the place, their stakes in the respective project and their assessment regarding the technology on the whole. We chose semi-structured, narrative-generating interviews as our research method (Lamnek 1995).

Out of a list of 60 campus tenants we selected 23 companies and organizations according to the following criteria: We wanted to cover the range of different branches, of different organizational sizes, and to include long-term tenants as well as newcomers. We focused on interviewees in leadership, CEOs, or people with equivalent status who were able to answer questions regarding strategic decisions, like the move to the campus or joining a

[16] Our study is being conducted within a research project that gathers different actor groups who are working on the development and operation of a micro smart grid including electro-vehicles.

cooperation project. In the end 21 interviews were carried out as well as two group discussions with the scientists and economic actors working on the micro smart grid's development. For the latter we used the method of group discussion Kühn and Koschel have developed (2011).

In detail our sample comprises the following entities: five start-ups and newer small companies, three big internationally active corporations, three Europe-wide organizations, two European public-private partnerships across sectorial boarders (energy, mobility, ICT, science), four mid-sized firms with occasional international contacts, one scientist, the developer of the campus and architect, one small handicrafts company, and two gastronomy services. A more detailed description of the interviewees quoted in this paper is presented in the list of interviewees in the acknowledgements. Regarding the duration of tenancy, two companies were already on the site even before the campus was being developed, eight companies and actors belong to the "early settlers," and the other companies and organizations have located there over the last four years. One further scientific organization was represented in the group discussions. This sample makes it possible to gain insight into the motivations, the relatedness to the vision, and the development assessments from various perspectives. Thus, approaches and strategies regarding the activities and interests on the local scale of the campus as well as the attitudes towards the transition process of the *Energiewende* and beyond become apparent.

To gather information and knowledge about earlier phases of the development of the vision of the site one needs further documented data or contemporary witnesses. We had access to both kinds of sources: first, to 40 protocols from the first assessment and fundraising process in 2008 and to 29 protocols of the second assessment process 2008–2009, which we analyzed as documents (Lamnek 1995) focusing on a) the information about former visions that can be gained, b) which kind of actors were involved and how they related to the vision in question, and c) what information can be gathered regarding the ongoing process and development. Second, we had informal talks with two actors involved in one of the assessment processes; in addition, three of the interviewees from our sample described above produced information regarding the period 2007–2010, namely the project developer, an architect, and one early settler.

IV. Multiple visions in the making

The case study provides a good example to analyze the ways visions are created and the effects they have, since the site experienced substantial changes in the past and is still “in the making.” Imaginations and expectations were closely attached throughout the entire process (Engels/Münch 2015). In particular, we identify four different phases of visioneering by illustrating how visions where stabilized (produced, materialized, institutionalized) and destabilized (rejected, modified, transformed) over time.

a) Visioneering as an ongoing process – the four phases

Phase I (2007–2008): Foundation

At the beginning of the first phase, we found several framing conditions: In 2007 a project developer and investor purchased a former gas storage facility, distinguished by a technical monument with a high symbolic value and a turn of the twentieth-century brick building. The site contained its own separate grid construction that left a certain level of residues in the soil. The developer and his team previously had an acknowledged reputation for the conversion of former industrial sites with historical buildings. Together they planned to restore the historical buildings and to build several new buildings with a high total floor area for offices, a hotel, and apartments at this centrally located site within the city. This caused not only excitement but also concerns and resistance against the conversion of the site, against both the developer himself and the planning in detail from citizens, politicians, and local government. Profiteering and dishonesty were some of the accusations uttered by critics. The credibility of the developer, the local government, and the political supporters was questioned, which also raised media attention.

So, at the very beginning of the project, there were already different stakeholders challenging the business case as visioneered by the developer. It is not possible from our data set to state when the plan of adding value to the project has actually been developed. The story being told emphasizes the beginning of the planning. In retrospect, seven years later, the architect and the developer reflect:

There were doubts that we really would carry through this kind of use as a platform, a university that exists nowadays. But this is normal. People are suspicious of all large-scale *projects ... I appreciate that.*[17] *(I2)*

The number of initial actors was low, but increased quickly. This is interdependent with the visioneering process, which began with the vision of an international forum at the symbolic site. The aim of the forum was to provide a platform for all questions regarding energy. This forum was founded shortly after the purchase, and in its wake the number and variety of actors grew as the visioneering developed further towards the vision of an international university, now including stakeholders from various companies, operating nationally and internationally, as well as internationally reputable scientists.

I never had another idea than relating to the energy theme. Insofar the project is self-explaining. So, in fact, it is logical that we deal with the energy issue at the site.... I was thinking how to get people onto this site. Then I said to myself, there is this landmark, I am building something on the site that is suitable for events, climate protection, energy, universities. (I3)

The vision was outlined as an international university with an interdisciplinary focus on energy, emphasizing Russia as a strong partner and nuclear energy as one main topic. The university was designed to include eight professorial chairs with the right to award doctorates, initially providing master's programs for economists and engineers and establish itself as a think tank for politics and communication. The project was to be realized in cooperation with scientific institutions in Germany, Russia, Norway, Sweden, and Spain; also the Gulf States were observed. The idea was to set up a foundation, supporting the university with sufficient capital.

One national scientific institution came on board as scientific adviser, organizing a needs and market assessment as well as the funding process. Furthermore, in 2008 a reputable scientific advisory board for the proposed university was constituted, listing the majority of the scientists who work internationally and lead in their fields of energy and beyond. This act of performativity is very unusual. The foundation of a scientific advisory board normally follows up after the foundational process is completed. Both the assignment of scientific consultants as well as the constitution of the advisory board can be understood as acts of bonding reputation with the vision, thus with the whole development project.

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[17] All interviews are originally conducted in German and translated by the authors.

The variety of partners and the political significance of the vision was soon recognized and accompanied with publicity. The protocols show that from April to July 2008 there were fundraising activities to collect money and engagement among leading energy corporations. In September 2008 the framing conditions shifted: The global finance crisis marked a radical turn and a setback in activities by many of the actors involved. The main scientific adviser dropped out, corporations called off their commitments and other scientific institutions followed. Without the scientific basis the project collapsed and the guiding vision disintegrated. Our data does not allow for any conclusion as to whether or not the vision dissolved due to the financial crisis or because its outline would have been simply too big and therefore unrealistic. Interviews and informal talks support both explanations.

To a certain degree the vision had proved to be functional: It produced more acceptance for the realization of the development plan. Thus, the dissolution of this guiding vision affected the whole site development.

Phase II (2008–2009): Reorientation towards renewables

Imagined futures play a central role in the development process, e.g., as they justify investments: novel technologies do exist "only in terms of imaginings, expectations and visions that have shaped their potential" (Borup et al. 2006). If they cannot be fulfilled, uncertainty arises on both sides – the developer's as well as the public administration's — which increases pressure to act. Thus, the developer needed an alternative plan at that time. The science institution was a fixed part of the proclaimed special mixture at the site. So at this point the credibility of the developer vis-à-vis investors, supporters, political partners, local government and citizens was at stake and the search for an alternative to replace the former vision marks the start of a next phase of visioneering.

When the developer contracted a small group of scientists from a German research institution for consulting; a new actor group entered the field, inserting a vision fundamentally different from the former, as we will show in the following. Again, this assignment of scientific consulting is being used to bond or reconnect reputation with the project, thus enhancing or at least stabilizing its acceptance. Other actors involved included the developer and his team, then the stakeholders from business and the sciences who were consulted, and — towards the end of this phase — a third actor, the first major tenant at the site.

Regarding the former guiding vision, this second needs and market assessment carried out in winter 2008/2009 also collected feedback. Interestingly enough only months after the first assessment, it brought up critique directed at the former concept. As the protocols and field notes of these scientists show, most of the stakeholders they spoke with now thought the old concept had been *"way, way too conservative regarding nuclear power"(P1)*. Also in size, capital and regarding the claimed right to confer doctoral degrees – it all seemed unrealistic to these stakeholders.

The resulting recommendation suggested a reorientation of the vision, focusing on downsizing the organizational form, and renewable energies as main topics. Instead of the envisioned university, a small size institute in cooperation with one local university was offered as an alternative. This institute was to focus on research and energy related master's programs, offer a platform for dialogue to bring together science, industry and energy corporations; it was also to establish a platform for electromobility. Overall its outstanding feature was to be renewable energies with an interdisciplinary perspective on the transformation process. These plans, however, produced disagreement between the developer and its team. Many objections were uttered against such a paradigm shift, often even in a highly emotional manner, e.g., in the form of accusations against scientists of being ideologists. Actually, this setting of priorities had a normative character, which is in general a feature of visions (Borup et al. 2006: 286). The suggested vision was highly unstable and fragile at this time, because the framing conditions did not offer clear direction for where energy production and innovations would head. Hence, this vision could have dissipated too.

In the end, the concept prevailed, mainly due to the actual pressure and the first tenant, a consulting institution in electromobility and renewable energy with a clear vision regarding the mobility and energy transition in general and the site potential in particular. The developer needed and accepted this new actor as a partner in visioneering, taking action to build the campus and bring about the suggested vision. This cooperation led first to transformation as well as stabilization of the vision.

So the first aim was to bring people to this site. Then we started to win over the first tenants for this topic, there was .... [the first tenant], a very, very significant motor, which [brought in] the topic electric mobility, car-sharing and so on. (I3)

Years later, the architect comments this critical change in a rather relaxed way:

The [technical monument] offers plenty of connecting factors to put it on the market ... New actor constellations always come with new thinking, not to be stuck with a strict concept ... to go new ways with a lot of partners. (I2)

Phase III (2009–2014): Future city, living lab, and institutionalization

After the phase of reorientation, the next phase in the visioneering and development process started in 2009 with the further expansion of the site: restoring and building old and new buildings and creating a space for and with innovative actors working on the realization of the vision. The unfolding of the vision's performativity was accompanied by a certain degree of uncertainty: Could the vision prevail? The accident in March 2011in Fukushima, Japan and the declaration of the German *Energiewende* in its wake marked a big shift in national framing conditions and highly influenced the negotiation process. On the micro-level of the site's development it put an end to the internal discussion process of accepting or disagreeing with the renewable energy vision. From there on the different stakeholders did not question this vision any longer. This shift led to a substantial change to the project in progress and affected the structure and size of the actor group on the site. In the first two years of this phase, the activities on the site were characterized by an engagement in innovation processes with a high amount of idealism among the first tenants, mostly small firms and some branches from institutes or NGOs. In interviews with several of these actors, they describe themselves as early settlers, a small group of people who all knew each other. In addition, the fact that they were all coping with the heavy construction work going on at the site, materializing the vision while engaging in innovation processes with a high level of uncertainty in producing stable business cases created a "*community with a siege mentality"* (co2).

The sudden and substantial shift brought the site into focus as a "living lab" for future solutions within the city. The site's attraction for other actor groups, like international companies, scientific research institutes, smaller innovative companies, and start-ups to become part of a community working on solutions for the *Energiewende* was increasing and thus more and more of these actor groups moved to the site. The developer selected these new tenants in consultation with the first major tenant and co-visioneer, appointing the reference to the concept of sustainability to a common standard; a further advancement of the local materialization of the vision:

In principle you can only become a tenant on this campus, if in the widest sense you have got something to do with the vision. So if you were a call center for telephone networks, I would tell you to search for someplace else, here you are wrong. (I3)

Some of these new actors engaged actively in developing the site and its vision and contributing to its stabilization. Master's programs were developed at the newly established on site science institute and the first students came to the site, proving and legitimizing the proclaimed character as a campus. Cooperation between science and business was now actively developed and established in terms of publically funded joint research projects. Such projects characterize the innovation campus as a living lab and showcase project within the energy transition.

The storytelling of the guiding vision, what this site already represented and how it was going to develop in the future, expanded too. One main actor described the attraction of the site as "*a practical example and an urban 'place' for connecting all those complicated processes that, so far, no one dares to address" (I4).* Within the local context, allocating scientists, business representatives and interdisciplinary research projects, visions and expectations all together help to coordinate between those diverse actor groups and "serve to bridge or mediate across different boundaries and ... dimensions and levels" (Borup et al. 2006: 286). For example, the original micro grid infrastructure of the former gas storage site was being redeveloped within such joint research projects into a test bed for a micro smart grid as an alternative technical solution for producing, storing and providing renewable energy within a decentralized infrastructure. Alongside the micro smart grid's function as a boundary object (Star/Griesemer 1989), which was being actively and jointly created and constructed, the envisioned ideas of it already produced a communitarized perception of the future that unfolded a binding force between the multiple actors from disparate social worlds working in the nexus of energy, mobility, and digitalization. As we have analyzed elsewhere, the materialized micro smart grid vision has a powerful impact and an integrating effect on the functioning and success of cooperation (Engels/Münch 2015). This materialization of a vision is also a mechanism to cope with uncertainty. Yet, the vision itself also needed an object, like the micro smart grid:

You need to have a vision and a plan on how to get a whole bunch of people together. And I believe the only formula to develop is the vision. They want to work jointly to save the world, I'd say. And for that, you need items to show and demonstrate that. (I5)

Thus, such objects function as representations of future solutions for sustainable energy production and use within a smart city – produced collaboratively by visioneers, developers, scientists, companies, organizations, and sponsors. They stabilize the vision even more when being institutionalized in terms of scientific research projects with the aim to establish a business case on the basis of the outcome and experience. Such scientific research projects have an intermediary function: they integrate different actor groups while focusing on a clear vision, thereby leading to a further stabilization of the vision.

At the end of this third phase, the micro smart grid part of the vision was being institutionalized: two of the main campus actors — namely the co-visioneer, a consulting institution and an international technical supplier for smart energy solutions — started a direct cooperation with the foundation of a collective society to bring the innovative business model to market.

Phase IV (since 2015): On stability and instability

It poses an analytical challenge to draw the line between the third and fourth phases. The attraction of the site is still growing, new tenants are being sought for the second new building, and more actors from the described actor groups of the third phase are settling down. Yet, there is visible development that gives hints to the processes going on "inside" the campus, namely the ongoing visioneering, its fulfillment and the gaps in between.

From our perspective, another institutionalization marks the next phase within the visioneering process adequately: multiple stakeholders from business and scientific institutions, active in a joint research and development project, founded a non-profit organization. The developer, still one of the main visioneers and driving forces, is part of this non-profit organization, claiming a strong voice in governing the campus. The organization aims to realize the German energy transition by pushing to change the whole mobility system along with the energy supply system. This step of institutionalization, an outcome of a publicly funded research and development project, contributes to the stabilization and expansion of the vision, as well as to its internal and external visibility. The vision is being developed further, now serving as a bridge between two formerly separated sectors, energy and mobility:

We are about to continue the campus's development and we will make it more transparent, but we will try to make its identity externally visible through devices and structures... but how do we ensure that nuclear power plant operators don't suddenly come here? ...In the past, people from all the different thematic areas were brought here because everyone thought: I'll go there because I want to do something with electric mobility, with science, with the Energiewende. But that, of course does not contribute in the long run...And yes it will be one of our tasks to jointly develop these premises. (I4)

When analyzing the interviews with the tenants in 2014, two primary gaps became visible regarding the development process of the site: Actors who were stronger involved in the technical development named *"fulfilling the promises the story contains"* as one major challenge for the nearer future, which implies, for example, actually achieving the climate goals. A second gap tackles the problem that derives from the narrative of the proclaimed campus culture with its informal opportunities to network and cooperate despite massive expansion: Between 2011 and 2015 the number of people working on the site more than doubled from 650 to 1,550. When the next building is finished in 2016 there will be about 500 more, and further buildings are planned (according to the homepage and several news-letters). We assume that whether the guiding vision will help solidify the campus culture further or whether the vision will vanish depends on the actor constellation. Depending on how they find their way to the campus, these new actors can have a stabilizing or destabilizing effect on the vision and its realization: Actors who subscribe to the *Energiewende* imaginary also contribute to the stabilization. However, the arrival of several actors to the campus because of its attractive office spaces and thriving environment bears the risk of destabilizing the vision. Already the interaction between diverse and plural actor groups, accompanied by different visions and expectations regarding the storytelling as well as the narrative of the campus culture produces conflicts. As some experiences demonstrate, some of the developer's ideas contradict the tenants' ideas and vice versa, according to their respective systems of reference and interests. Thus, the development of the campus culture is also about the development of power relations and about the further development of the developer himself. In chapter d) we will further pick up on the threats that arise when vision and action diverge.

The description of the four phases highlights several factors that have been influencing the visioneering process. To give a more profound answer to our research question, we discuss some external aspects that also play into the process of visioneering between contrasting actors' positions in the following.

b) Uncertainties within the project and from landscape conditions

Within any visioneering process uncertainties play a central role (Berker 2010), they are structural to innovation processes (Böhle 2011) as we have discussed in the introduction. On the micro-level of the campus in development a major cause for uncertainty is that a real estate investor and developer is crossing a border and is entering the world of science and scientists, deciding to settle down at the site and promote the guiding vision. With his idea of establishing a university the developer moves into foreign territory, while still trying to control what is happening to his initial idea – which more and more develops within a field he cannot control. So instead, he tries to oversee and manage what is happening on the ground owed to his particular strategic interests. As our research reveals, the structure of the site's ownership and regulatory provisions — the question of who has the authority to decide — is a relevant factor, which can have a high impact on innovation activities at these kinds of test fields. Furthermore, it explains many of the conflicts regarding the visioneering and the negotiation process vis-à-vis how the vision is put into action at the particular location, e.g., when it comes down to the authorization of construction measures. The twofold border-crossing poses a source of uncertainty.

As the empirical investigation in chapter a) showed, on the landscape level uncertainty derives not only from accidents and crises but also from crisis-induced shifting framework conditions. The global financial crisis in 2008 at least finalized the dissolution of the university vision in phase I. At the end of phase II no one knew if the development would really head in the direction of renewable energies. Nonetheless some visioneers started working on sociotechnical solutions and products, sticking to their vision of a sustainable, carbon-free energy future. The nuclear accident in Fukushima in March 2011 led to massive protests in Germany against nuclear energy. In the end the German government reacted by proclaimed the *Energiewende* with two main goals: By 2025 Germany aims to produce 40–45 percent of its electricity from renewable sources and 55–60 per cent by 2035; and by 2020 1 million electric vehicles ought to be on the streets. But to achieve these political targets, several problems and uncertainties concerning the grid infrastructure became apparent. Uncertainty, however, has not only increased with respect to technological innovations, but also on the micro-level of the economic actors' strategies since traditional business models are eroding in the face of the paradigm shift. And yet there is neither a standard for innovative solutions nor is it possible to predict what the standards will be like. Being perceived as a possible alternative, the guiding vision of the site as a test bed for decentralized independent production and supply of renewable energies rapidly gained relevance and public attention.

Another impact factor on the landscape level are shifting state regulatory legal frameworks in the wake of climate change: The liberalization of the German electricity market in 1998 and the Renewable Energy Act (EEG) passed in 2000 and its latest amendments in 2014 led to a change of the regulatory framework with far-reaching consequences for the German energy sector. As a consequence, numerous kinds of self-organized local and regional energy initiatives have emerged so far, presenting alternatives and thereby initiating a bottom-up process to innovate and test solutions for locally based future energy supply on a small scale. This process was brought to a hold by the latest amendments in 2014. These changing framework conditions also affect the leading companies' investment strategies, business models and modes of cooperation. Our study explores, the move to the innovation campus by companies, from start-ups to internationally established corporations, constitutes a coping-strategy in dealing with uncertainty, presenting oneself still as active in a showcase on site.

c) Changing constellation of actors

The actor group constellation has changed towards more plurality and differentiation – with science and business actors from different sectors – including different reference systems and interests. Since visioneering is conceptualized here as the subject and outcome of negotiations between the actors on campus coming from "disparate social worlds," mechanisms of cooperation come into play despite heterogeneity. A vision may enable commitment and cooperation among the actors striving to produce and show innovations "as representations of future solutions" (Star/Griesemer 1989: 396). Its function as a boundary object is a stabilizing factor for the constellation of actors and simultaneously affects the reformulation of the vision – but it can also be destabilized quickly. In the discussion we focus on the fluid and processual character, since boundary objects "act as anchors or bridges, however temporary” (Star/Griesemer 1989: 414). So without having consensus, the diverse actors at the campus work together. “These common objects form the boundaries between groups through flexibility and shared structure – they are the stuff of action” (Star 2010: 603). Against this backdrop, one interviewee describes the place’s potential to create an identity across sectorial borders:

So, energy and mobility are already the central issues through which the campus is perceived, and what we communicate to the outside world. It is already a spectacular place, solely by the buildings, how it is realized. This place already creates an identity, which is something special, in the center of the city. I do believe that it connects people via the two thematic blocks. (I7)

The actor groups present are showing different degrees of involvement. Only the main actors are involved in the visioneering due to close cooperation and institutionalization, i.e., storytelling, reinventing, and developing the vision as well as the realization and implementation through cooperation between economic actors and scientists in certain projects. Despite the very diverse interests, these main actors attempt to collectivize the vision. Setbacks, e.g., due to bureaucratic hurdles from the municipal building authority or differences in interest between project developer and tenants, have forced the major players to develop conflict-solving strategies to restabilize the relationship, e.g., close and rapid communication or leaving the site as the sphere of connections and influences, meeting on neutral ground. One interviewee mentioned the emergence of “trust” as one unifying factor within the core group:

There is already a structure of trust grown between the key players, which is tested daily, I would say, because there are numerous points of friction. But when I look at the story we created together, it is a story of success that is unifying ... what we achieved so far led to a core community, even if there might be improvements and so on. (I4)

In this quotation, the interviewee describes trust and the existence of a core community to be the result of the collective creation of a common story. As recent studies on interdisciplinary collaboration have shown, interpersonal trust in interdisciplinary projects is a prerequisite for group bonds and for the exchange of ideas (i.e., Parker/Hackett 2012; Boix, Mansilla et al. 2015). However, trust as well as the vision seem to be the outcome of a process of collective action. Meanwhile, over one year after this statement was made, even this structure of trust seems to run the risk of exhaustion, as interviewees tell us on an informal basis. The loss of trust can be ascribed to the perceived gap between visions and its local materialization that comes along with a decrease of credibility.

In many cases, the translation from vision into action and material form shows divergences, like in terms of management decisions or in the way the power constellation forms. This is one source of conflict that might destabilize the guiding vision. We will further discuss the relation between vision and action in the following.

d) Interplay between vision and action and the case of divergence

In the following we touch upon the relationship between visions, the local materialization of visions and in how far a gap between both could be a source of conflict. We observe two interrelated developments from our empirical research. The constellation of actors has been in constant change since the beginning. This is due to the ongoing growth of the campus, both in terms of the number of tenants and the progress of the built environment. Our interviews show that new actors come with specific expectations that they want to see fulfilled in their settling down at the site. They seek to make a business case, benefit from the campus network, take part in joint projects, or gain public visibility. The campus's topics at the nexus of energy, mobility, and ICT attract research institutes as well as companies:

[I]t is a topic that is relevant to us, like I just said. We are actively joining in and want to figure out how we can contribute, without having an exact product idea right away, but we want to learn, we want to contribute, we want to work jointly. It's learning, relationships, networking, that's why we're doing it, and we want to implement. For us that's a key thing; we want to take all that we are doing and implement it. (I6)

Expectations circulate among businesspeople, engineers, and researchers – they are "part and parcel of all professional practices" (van Lente 2012: 769). When actors follow or orient themselves to the expectations, expectations have a structural effect or may achieve stability. Change, for example, in terms of new sociotechnical arrangements, is often the subject of conflicts, however, since new expectations may clash with established expectations.

Compared to visions, expectations refer to "less formalized, often fragmented and partial, beliefs about the future" (Eames et al. 2006: 362). They may be inscribed and made explicit in forms of business strategies and stories for communication. As we learned from our interview study, the actors base their organizations' strategic decision to settle down at the campus on particular expectations and beliefs. These, again, are promoted and triggered by the current articulated vision and story of the campus's future expansion:

[The owner] has promised us that there will be more here and so we're building, of course. But fine, finish what's here first. But we would indeed very much like to continue ramping it up. (I6)

This paper traces the hypothesis that the continuing growth and diversification of the campus, as shown in the case study, challenges not only the campus's attractiveness and cohesion but also the vision's stability and performative power. One reason for this is that various actors hold divergent expectations regarding the active shaping and scope for design that they seek to be supported and even become materialized and grounded in the actual context of the campus's development. The actors at the site influence the interpretation and creation of the vision consequently. They actively engage in shaping the future they envision by building coalitions, starting joint ventures, or installing several components of the renewable energy system in the micro smart grid. The interviewee's frame the vision and its physical representation as a coherent identity:

So, you have to find a place that has these roots, which is suitable for mythologizing of course, and to form an identity. Insofar the site turned out well. And it is done very physically via the former gas storage facility or the buildings, which are very well renovated. (I7)

That would speak to me for a vision that you just really consider an overall concept, and when you say "it is 100 percent renewable," that one can really check what it means exactly and where the energy actually comes from? Just to make it clear how this campus works. (I8)

However, this interrelatedness implies the question of what happens if expectations are not met and, as a consequence, the imagined future and its realization in material form diverge. As our data analysis revealed, this is where we find one major source of conflict: The vision becomes collectivized and modified, but single decisions are made based on investment strategies that may contradict the visions objectives. When promises and expectations remain unfulfilled, this poses a major threat to the site's future development in terms of credibility.

Then, a certain fragility of a vision becomes obvious: “While expectations are needed to start a project or a program, they also introduce vulnerability when projects and programs bring other outcomes than expected” (van Lente 2012: 774). In the case of divergence, a gap between the dimension of imagination and material implementation emerges and poses a threat to the campus identity. The realization of an innovation project, like the implementation of a decentralized micro smart grid, unfolds a relation between materiality and what is imagined. The material dimension comprises material interests, products, processes, i.e., the making of technical artifacts, the grid construction and investments. The meaning of the vision “city of the future” remains vague, as that allows for it to be “actively promoted by a broad range of actors and interest groups” (Eames et al. 2006: 371). Translated into a story it becomes an effective communication and promotion tool. When we asked the interviewees about their motives for moving to the site they reproduced and referred to the story. The empirical phases show an interplay between both strands, which influences the making of the vision and its shifting over time. It is the co-creation between both dimensions that creates new reality and arrangements.

Our study disclosed the following mechanisms: As long as visions remain in an uncertain state, they unfold interpretative flexibility for diverse interests. Similar to boundary objects as introduced by Star and Griesemer (1989), visions are also abstract and plastic enough, so they can have different meanings in different social worlds and act as bridges. The empirical periodization has shown that each phase was labeled by particular “umbrella terms” (Nordmann 2013; Rip/Voß 2013) that were broad and flexible enough to unfold a conceptual framework that carried the campus development forward. Umbrella terms mobilize the variety of diverse actors since they serve to encompass a broad range of activities and interests thanks to their flexible and interpretative character. According to Rip and Voß, umbrella terms work as mechanisms of governance, which “link up and translate discursively patterned practices” (Rip/Voß 2013: 40). But when they become realized into concrete physical and artifactual developments, i.e., when it comes down to materialization, the inherent contested nature is disclosed (Eames et al. 2006). In our case study the translation into action within the spatial context consequently uncovered these contested interpretations; it is a source of conflict. The credibility and attraction may decrease consequently. The actors themselves perceive a field of tension, being part of the campus community on the one hand, and pursuing individual targets, on the other:

Of course, we're a big corporation and, of course, we want to reap the benefits, otherwise we would be lying. However, we believe that it works best in such an environment, and we hope that there won't be any restrictions there. (I6)

From this, we conclude that the vision is in need of continuous development and discussion between the actors. In addition, it needs to be translated and put into practice, as illustrated in the following quote: *"the only way to survive is, if we make facts credible, and not just a backdrop"* (I4)

e) Visions are in need of stabilization and have stabilizing effects

The campus's guiding vision is being contested and challenged by the various actors, and has consequently experienced several modifications over the years. Visionary practices often are located at the "blurred boundary between scientific fact, technological possibility and optimistic speculation, which often leads to their claims being contested and challenged by others" (Trujillo/Yenisa 2014: 202). They can exercise their performative power as a bridge to the future through discussion and confrontation with them. The empirical results suggest that visioneering is an ongoing process in need of continuous work and regular renewal since visions themselves remain flexible and fragile in their basic character. The field of energy transition is a contested space in which actors imagine and work to constitute the properties of a future dramatically different from the past. Revolutionary sociotechnical visions develop and re-form through a dynamic process in which their advocates encounter other actors with different goals and interact with established collective aspirations and imaginaries of the future (Jasanoff 2015). There exist many ways in which visions enter into the "assemblages of materiality, meaning and morality" and how they gain "traction through blatant exercises of power or sustained acts of coalition building" (Jasanoff 2015: 5). Our research is a contribution to understand the ways of how visions become materialized and to what extent this is linked to power relations.

Our research has revealed that visions fulfill different functions in innovation activities and may occur with various nuances. They offer certain temporary cohesion but remain unstable in their nature. This volatility also brings benefits since the abstract vision enables adaptive capacity for the vision to undergo modification along with the project's development. On the other hand, this characteristic implies a high potential for conflict when the vision goes from the abstract to the concrete.

Despite its contested nature, the vision has a guiding and collectivizing function since it behaves like a "floating signifier of semiotic theory, defined for specific debates, but largely left open as alignment and agenda building takes place" (Eames et al. 2006: 367). The more general the formulation is, like "the city of the future," the easier consensus can be established (Dierkes et al. 1996).We further argue that cohesion within innovative projects, which exhibits vulnerability from within as well as from outside the project as demonstrated in the beginning, also evolves through continuous work on a common identity. Even though they are contested and vague, they may offer a momentum of stabilization to innovative projects. The necessity for a renewed vision is presented in one interviewee's expression to pass over from "*campus 1.0 to 2.0*" (I4) and in the following quotation:

... that one says, okay, up to the first step towards a campus, and in fact when its infrastructure is finished, that is just buildings, then, the paper of the research projects and this whole story of the Energiewende goes up till that point ... And then, once we've achieved that, what we've simulated today and built up. But even beyond that, this campus won't be finished; rather, with the new actors that are at the campus, with the new networks that have been created, we want to enter into new projects, which will further develop this campus, that this always remains at the heart of it, this activity. I believe that then this whole construct carries itself, I will say also among the companies, a whole lot better, when they know that they can continue to do their research here forever into the future, as far as I'm concerned, at this location, that this will always be a place for it, that they can tamper with the infrastructure, with or without the support of the investor or with or without funding. (I4)

Our research has shown that visions of different dimensions of effectiveness exist. How powerful and performative they are, depends on the interplay between visions and changing conditions, and on how this interplay is unfolding over time. Since they are basically fluid and fragile, they need a steady reproduction and renewal, which describes an on-going process. This is part of visioneering as a joint, collective activity (Nordmann 2013):

[Campus name] 2.0 clearly means more community building, not to leave it to the project developer but to force him into it and to demand more from the tenants (I5)

It is basically the bottom-up approach of visioneering in this case that unfolds the most power for the project to precede and its success since the actors tailor the vague vision to the local context. The shared space functions as a common object that “forms the boundaries between groups through flexibility and shared structure –they are the stuff of action” (Star 2010: 602f.).

V. Conclusion

On the basis of our empirical data we investigated the practices of visioneering and the way the performativity of visions unfolds over a certain time period. We have shown how a particular setting as an interplay of actors and landscape conditions affects the visions and their making of the site. Our study over an eight-year period uncovered the interwoven relation between the temporal material stabilization of the vision, which is in constant flux, as is the site “in the making.” The development of the urban innovation campus is an outcome of visioneering activities and the local materializations of what the actors envisioned. Our case study revealed how visions become artifacts and shape sociotechnical innovations like the micro smart grid in the context of energy transitions. Looking from a perspective inspired by science and technology studies enabled us to analyze the materialization of the vision as a way of exercising power in a given setting (Latour 2005). The material form of the campus, i.e., how it is constructed, embodies a specific form of authority (Winner 1986), as subject of collective visioneering activities between contrasting actors’ positions.

We conceptualized the campus as a local “test bed,” an envisioned mix of lab and demonstration project, for sociotechnical configurations to capture the uncertainties inherent in the project. We disclosed the negotiation processes of contested visions to show why certain visions gained importance at a certain time and consequently led to substantial change of the project. The various actors hold diverging expectations and pursue individual strategies by settling down at the campus to respond to economic imperatives, like greater visibility and participation in collaborative research and innovation projects. By pursuing these objectives, they try to imprint the campus identity according to their organization’s individual strategic goals. The collective negotiation process and the increasing integration of further actors over the years hereby contribute to the further development and modification of the site’s vision while likewise challenging it. Actors compete for the interpretation of the site and make it a “contested terrain.” The observed constellations appear to be fragile in their character and provide only temporary stabilization.

At the same time, disputes and discussions in turn contribute to the general stabilization of the site's vision. We refer to this observation as "the instability of imaginary stability." This feature is an integral element of visioneering.

One factor of stabilization are competing narrative themes or umbrella terms that leave room for "interpretative flexibility" (Eames et al. 2006: 362). It is due to this quality that multiple and diverse actors could engage at a common site of interest although holding different interests and expectations. Actors make use of the vision and consequently contribute to its modification. In case of divergence between the campus's story and its realization, the vision needs to be (re)stabilized by rituals of renewal and conflict-resolution and is consequently changing over time.

Generally, our study points at the processual quality of visions and their need for renewal and change. Our research contributes to the understanding of both the time and normative dimensions of visioneering, looking at the actors' motivations and social practices in innovative endeavors. We have shown the factors that influence a shift of a vision in accordance with its performative power. This again underlines the visions' roles in transformation and innovation processes. Future research on visioneering should take into account that visioneering is a fragile and ongoing process and that it needs to be analyzed as such.

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Appendix A. List of quoted interviewees and documents

Code	Position of the interviewee	Date of interview/protocol
P1	Manager, international energy organization	11/2008
I2	Architect, part of the development team	07/2014
I3	Investor and developer of the site	01/2014
I4	Manager, consulting company, "early settler"	04/2014
I5	Scientist and manager, consulting company, "early settler"	10/2014
I6	Manager, international communication company	02/2015
I7	Manager, public-private partnership in the ICT sector	07/2014
I8	Manager, public-private partnership in the climate sector	08/2014

4.3 Franziska Engels & Anna Verena Münch: The smart grid as a materialized imaginary

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ABSTRACT

In technical terms, a micro smart grid is one solution for future energy supply from renewable energy sources with the aid of information technology. However, it also symbolises the idea of a transformation into a low-carbon, non-fossil-fuel society. This paper analyses that the micro smart grid works as a sociotechnical imaginary and boundary object across a specific actor constellation with plural backgrounds, interests and perspectives. Empirical data has been gathered for this study from an urban innovation campus in Germany, an ascribed living lab for innovation and research that represents an especially designated place combined with spatially embedded visions of the future city and energy system. Here the micro smart grid imaginary is closely interlinked with the place and becomes materialised: It is argued that despite the micro smart grid’s incomplete status in terms of technical advancement and reliability, the imaginary already generates cooperation and commitment across actor groups and sectors. The place provides a shared, protected experimental space as well as boundary objects, thus, first, enabling the actors to cope with the perceived uncertainty in the transition process. Second, it fosters innovation, new business models and forms of cooperation, and thereby, third, contributes to the energy system transformation.

Keywords: micro smart grid; uncertainty; energy transition; imaginary

1. Introduction

Today we are facing complex challenges in transitioning the entire energy system in Germany due to the proclaimed nuclear phase-out. The distribution of renewable energy throughout the country is one of these challenges. Wind energy is produced mainly in the north of Germany while the vast majority of energy-intensive industry is located in the south. Building new major long-distance high voltage lines through Germany is the favoured political answer to this challenge. Beside the extensive costs these plans evoke protest and resistance among those citizens affected. Another challenge for the electricity grid is the large number of power generation installations connected like rooftop photovoltaic installations. A modern electricity grid must not only transmit energy in one direction, from the transmission grids through the distribution grids to the end user – it must also cope with transmissions in the other direction as well.

In the wake of this discussion and in response to this challenge of the on-going transition process of what is known as the "*Energiewende*", sometimes called the "energy turnaround", the micro smart grid technology has emerged as one alternative technical solution for the future energy supply, producing, storing and providing renewable energy within a decentralised infrastructure. This sociotechnical imaginary (Jasanoff/Kim 2013), the term we are going to introduce below, provides one future vision: energy will be supplied from multiple micro smart grids, consisting of mini power plants, photovoltaic systems and biogas plants, all connected via information-communications-technology (ICT) – rather than from relatively few centralised sources, as it is the case today. This transition process is not only a change in technical terms or one of energy sources; it is of sociotechnical character since it affects rather various areas of society, as several studies from a social science perspective have analysed recently (e.g., Schippl/Grunwald 2013; Dolata 2011; Schneidewind/Scheck 2013; Geels 2007). The politically imposed transformation of the power generation system into one based on renewable energy means significant changes and structural reconfigurations, challenging governance, novel infrastructures as well as actor constellations and their ability to adapt their own patterns of behaviour. The term "prosumer", originally coined by Alvin Toffler in his book *The Third Wave* (1980), for example attracts once more high attention as it describes the new active role of the user, who is consumer and producer of energy at the same time and thus an important actor for a future energy architecture basing on multiple micro smart grids.

Since previous decision-making processes and power structures of the energy system have been brought into new and uncertain terrain by turning away from the traditional generation-transmission-distribution-consumer model, established practices and routines are going under scrutiny, challenging path-dependent organisations (cf., DiMaggio/Powell 1983; Sydow/Schreyögg/Koch 2005). At the same time, opportunities arise for technological innovations to emerge, like the micro smart grid. Those may gain crucial relevance leading to substantial structural, institutional and organisational changes, such as sectoral adjustments between formerly disparate sectors of energy, mobility and ICT (e.g., Dolata 2011). Thus, the *Energiewende*, being a large-scale experiment and sociotechnical transformation, is characterised by a high degree of uncertainty with which the actors in the field have to cope (Böhle 2011, Berker 2010).

In times of change, visions and visioneering (Nordmann 2013) gain crucial relevance: imagining possible futures creates opportunities for the present and enables certain spaces of action. Analysing visions as future concepts of innovations is a key element to understand (technological) change (e.g., Borup et al. 2006; Schulz-Schaeffer 2012). Visions of the future in the form of expectations, hopes, concerns or risks (e.g., Skjølsvold 2014; Schulz-Schaeffer 2012) provide guidance, structure and legitimation of activity, define roles and duties and help to mobilise resources (Borup et al. 2006) – and thereby may unfold a "performative" character: vision's promises may give rise to social change (Schulz-Schaeffer 2012). A shared vision enables cooperation among innovation actors from "different social worlds", striving to produce innovations "as representations of future solutions" (Star/Griesemer 1989: 396). In turn such innovation activities create a "direction" or conviction "of 'what the future will bring' " (Brown/Rappert/Webster 2000: 4). In addition to visions, sociotechnical imaginaries are collective visions of attainable futures produced by science and technology and apply as an instrument for co-production (Jasanoff/Kim 2013). Such imagined futures play a central role in the development of technical artefacts for the future energy system, e.g., justify investments: Novel technologies do exist „except and only in terms of imaginings, expectations and visions that have shaped their potential" (Borup et al. 2006: 285).

Our study focuses on the micro smart grid technology as a materialised sociotechnical imaginary in the realm of the future energy system. Our case study on a micro smart grid currently underway at an urban site innovation campus sheds some light on the question of how economic actors and scientists work together on a concrete technical solution to deal with the transformation-induced uncertainty and sociotechnical pressure to change and to innovate. In particular, the visions present within the innovation process of the micro smart grid as defining feature, i.e. “representation” (Star/Griesemer 1989) of the innovation campus will be analysed. Thereby, the case study focuses on the specific innovation campus, described as a living lab by the actors interviewed, which is being built to create and test future technologies in the field of energy. We hypothesise that the micro smart grid represents both, a concrete technical point of reference for the actors – even in its early stage of development – as well as a sociotechnical imaginary for the future energy supply, thus enabling cooperation across boundaries and diverse interests. The combination of a shared imagined space and concrete space for opportunity contributes to a reduction of perceived uncertainty and thereby supports the sociotechnical transformation. This is what we intend to present here.

In this paper, we argue that the micro smart grid is not only a technical artefact but a sociotechnical imaginary as well, materialised as a boundary object (Star/Griesemer 1989) at a designated place in process (1) and we describe the function it fulfils for scientists and economic actors wishing to contribute to the *Energiewende* and striving to create a business case in doing so (2). The outline of this paper is as follows: First, the case study and the empirical material drawn from interviews conducted at a designated innovation campus are presented. We then shed light on the characteristics of the transition process in Germany, the *Energiewende*, putting emphasis on the inherent uncertainties – also with regard to the perceived uncertainty from our empirical data. We discuss our research propositions, showing that the micro smart grid is a sociotechnical imaginary and how it is materialised. Basing on our research we then show how it contributes to coping with uncertainty for the actors, focussing on the constitution of place and space and on its function as a boundary object for coordinating different actor groups.

With our empirical findings, we want to contribute to the field of research while strengthening the social sciences’ point of view on micro smart grids as decentralised small scale solutions being part of the on-going sociotechnical transformation process. The complex system of energy in the fields of electricity, mobility and heating represents a crucial infrastructure of modern, industrialised societies that rely on the constant availability of energy - now the traditional architecture is changing. Besides its technical feature for the future energy supply, the micro smart grid symbolises the idea of transformation into a decentralised, low-carbon and non-fossil society that Germany is presently striving towards.

2. Method: A qualitative case study

At the centre of our empirical case study is the innovation campus that proclaims to be an urban living lab for the *Energiewende* in Germany. Participating scientists and economic actors are trying to shape the transition process by creating new business models, services and products related to the field of micro smart grids and beyond, with a clear focus on energy efficiency and sustainability. Among the economic actors, we find established actors like international corporations, co-working projects, organisations and start-ups. Co-operations between science and economy are actively developed and put into action in terms of publically funded joint research projects. Our study is being conducted within such a research project gathering different actor groups who are working on the development and operation of a micro smart grid including electro-vehicles. This project is part of a publically funded promotional programme.[i]

With our qualitative case study we sought out knowledge on the following three interest areas: first, the motivation for the different actor groups from diverse scientific and economic fields to settle down at the innovation campus; second their actual assessment of what they found, how far their interests and expectations were met; third their knowledge of the micro smart grid as it developed at the place, their stakes in the project and their assessment regarding the technology at all. We chose semi-structured, narrative-generating interviews as the research method (Lamnek 1989, Flick 2006).

Out of a list of 60 tenants we selected 23 companies and organisations according to the following criteria: We wanted to cover the range of different branches, of different organisational sizes, and to include long-term tenants as well as "newcomers". We focused on interviewees in leadership, CEOs or people with equivalent status, who were able to answer questions regarding strategic decisions, like the move to the campus or joining a cooperation project. In the end 21 interviews could be realised as well as one group discussion with the scientists and economic actors working on the micro smart grids' development. For the latter we used the method "group discussion" Kühn and Koschel have developed (2011). The majority of our interviews were conducted in 2014 (see also the appendix).

In detail our sample comprises the following: five start-ups and newer small companies, three big internationally active corporations, three Europe-wide organisations, two being cooperation projects of European economy across sectorial boarders (energy, mobility, IC-technology, science), four mid-sized firms with occasional international contacts, one scientist, the investor and developer of the innovation campus, the campus architect, one small handicrafts company and two gastronomical services. Regarding the duration of tenancy, two companies were already on the site even before the campus was being developed, eight companies and actors belong to the "early settlers", and the other companies and organisations have moved over the last four years. Within the group discussion, one further scientific organisation was represented. This sample makes it possible to gain insight into the motivations and development assessments from various perspectives. Thus approaches and strategies regarding the activities and interests on the local scale of the campus as well as the attitudes towards the transition process of the *Energiewende* and beyond become apparent.

3. Uncertainties within the energy transition process

To understand why established companies, start-ups and also scientific organisations gather themselves together in a specific place, engage in the innovation campus and in joint research projects like the micro smart grid development, we need to have a closer look at the transition of the German energy system currently underway.

Innovation in general has to deal with uncertainty, Berker stated, "it is one of its defining characteristics, since innovative activities are always directed toward an uncertain future" (Berker 2010: 65). The *Energiewende* holds a future vision – the country's independence from nuclear and fossil fuels by midcentury –, while offering some direction with clear goals: By 2025, Germany aims to produce 40–45 per cent of its electricity from renewable sources and 55–60 per cent by 2035. To achieve the ambitious targets a reliable, economic and environmentally sensible energy supply is required. Thus the energy system turnaround represents a politically imposed system change, announced and repeated like a belief with great impact on society, policy and economy. The governmental decision to shut down all of the country's nuclear power plants may not be stable come another election. After all it was the dominating party, the Christian Democratic Union (CDU) currently in charge of the government that – only months before Fukushima – had reversed the previous government's plan for nuclear exit of which they themselves did not approve. Additionally, public discussions and criticism regarding increasing costs, the security of supply and uncoordinated governance of the *Energiewende* have emerged. The plurality of expertise and possible scenarios (Schulze-Schaeffer 2012) enhances the uncertainties that actors are dealing with on many different levels within this transition process. With Lane and Maxfield these uncertainties belong to the third kind of uncertainty they have distinguished: the "ontological uncertainty" (2005: 10) of what is reality and what is possibility. In case of the *Energiewende* this ontological uncertainty seems to be at least threefold: First, it is not clear whether the proclaimed vision will be achieved. Second, the actual gap between the scheduled goals announced by the government and the sociotechnical state of the art produces high pressure on innovation processes, though no one knows if it can be bridged. Third, the still shifting political and regulatory interventions mark the German energy transition as being very fragile.

Political and regulatory interventions play a crucial role within this transition process, since they have a great impact in altering a field or sector's environment. One of our interviews, a department manager of an established energy company, reflects on the effects of such interventions and the current regulatory changes:

> *"The company's strategy is different for every country, depending on the regulatory frameworks as well as public acceptance . . . Looking at nuclear power, one could have seen the policy shifting, and the impacts for investments and investment safety and the consequences of it. Companies but also politics have to cope with it." (co1)*

Uncertainty exists not only at the level of political decision making but also has strong influence on the micro level of the economic actors' strategies since traditional business models are eroding in the face of the paradigm shift. Notably the liberalisation of the German electricity market in 1998 and the Renewable Energy Law (EEG) passed in 2000 and its latest amendments in 2014 led to a change of the regulatory framework and had far-reaching consequences for the German energy sector. Numerous kinds of self-organised local and regional energy initiatives have emerged so far, presenting alternatives and thereby initiating a bottom-up process to innovate and test solutions for locally based future energy supply on a small scale. The changing framework has also affected the leading companies' investment strategies, business models and modes of cooperation. One of those actors that is engaged at the innovation campus, calls it "*the most challenging time right now":*

> *"Absolutely, Energiewende is the big issue for us since it impacts the whole business, it determines the company's focus, as it does for all the energy companies, because business models had to be changed completely. It has extremely serious impacts, the energy market is changing entirely, and we have to adapt. Like it was 20 years ago, we had planning security looking at the returns, that's not the case anymore. […] Sure, it's producing an extremely high level of uncertainty. If you are used to stability and continuity for decades and only slow changes; and now one change after the other, clearly that's creating uncertainty." (co1)*

Next to institutional challenges, companies have to deal with several challenges related to the technological development. Looking at the volatility of the energy sources and the inequitable regional production, a major technical task is to balance the energy supply and demand – at the present moment however any technological solutions is far from being in practice. The micro smart grid emerged to be such one future solution for the distribution and coordination of renewable energy.

As analysed above, we note that the ontological uncertainty surrounding market developments and highly competitive environments is profound, leading to great cost pressure from the established technologies that have dominated the market so far. Cooperation in innovation processes at the interface between different sectors of energy, mobility and digitalisation, thus creating business cases across formerly separated business areas and traditional sectoral borders does not seem to make it easier at first sight. While taking a closer look these activities not only enhance risks but also opportunities (Böhle 2011: 24) and can be interpreted as coping strategies to deal with uncertainty, as we are going to show. Accepting the fact that "uncertainty can never be completely removed" rather is a "structural feature", in particular when it comes to innovations, Böhle (2011) suggests a coping strategy to overcome uncertainty: acknowledge limitations and use uncertainty productively within innovation management (24 ff.). After taking a closer look at the innovation campus, we will then analyse how the business actors and scientists cope with the uncertainty surrounding the micro smart grid and given their differing ideas surrounding the technology.

The campus was established in 2008/09 and is still under construction. It is being expanded with new buildings, projects and tenants – and will continue to do so for the next few years. Historical buildings have been restored and new buildings with high-energy efficiency are being built around a huge technical artefact that offers skyline character, important for orientation and identification. The micro grid – not smart yet – already in place is one object of development and invention but of diverse expectations, due to heterogeneous groups of actors gathered at the innovation campus: One, there are influential economic actors or interest coalitions, facing the paradigm shift towards a sustainable energy supply. For many of these established actors, their former model of business and strategy has evaporated with the *Energiewende*. They are searching for new ways to re-establish or at least stabilise themselves. Small companies and start-ups can be defined as a second actor group, occupying less privileged innovation niches, which are now of new importance. Scientists, working on campus with a highly practical orientation, constitute a third actor group. They engage in research projects together with economic actors but also in courses of study at the university institute on campus.

Most of the actors we have interviewed in our case study feel like being part of an innovation network. One interviewee, an "early settler", describes the first years of the campus like a "*community with a siege mentality (Wagenburgmentalität)*" (co2). Although coming from different "social worlds" (Star/Griesemer 1989) with different individual approaches and strategies, cooperation is possible and varying visions do overlap at this physical place. In the following we will take a closer look at the micro smart grid being a sociotechnical imaginary.

3.1 The micro smart grid as a sociotechnical imaginary

The micro smart grid is a technical demonstration object: Separate from the normal power grid, the micro smart grid is only connected at transfer points. Physically it has its own cable and pipelines, connecting power generation sources, like small wind turbines, photovoltaic panels to batteries as well as electric vehicles for storage, with the goal to power buildings. This is tested and implemented at the site. The goal is a micro grid that is "smart", setting up multiple generating and storage systems to tackle volatile renewable energy sources. Smart then means integrating IC-technologies like software, special algorithms that collect and interpret data and regulate supply and demand based on this data.

To study the micro smart grid's quality as an imaginary for the energy transition, we rely on the concept of sociotechnical imaginaries, which are defined by Jasanoff and Kim as "collective imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects" (2013: 190). In this approach, collective visions help shape social responses to innovation, where sociotechnical imaginaries describe attainable futures whose realisation is accompanied by risks and instabilities. Comparing national energy imaginaries in Germany to those in the U.S. and South Korea, the authors found out that uncertainty is "the gravest risk in the German imagination", formulating the need for "predictability and order at moments of significant technological change" (ibid.). Germany appears to be lagging behind America's pragmatism, speed and flexibility, showing pervasive risk-consciousness and risk-aversion when dealing with new technologies – the authors argue in reference to theoretical reflections on the risk society by Beck (1992) in which a perspective of risk and uncertainty has become a defining feature of contemporary society. This perspective is in line with Böhle's idea of accepting uncertainty as given and a "potential to be harnessed" (2011: 21) we introduced above. According to Böhle Germany's former strength, the industrial societies' key features of planning and control, is becoming its weakness since uncertainty must be regarded as structural of innovation processes (2011: 24). In line with Jasanoff and Kim we argue that the energy system is shaped by "collective visions" of national energy choices. Imaginaries then help to produce collective systems of meaning that enable the interpretation of social reality. Whereas Jasanoff and Kim focus on the broader political levels and the national energy imaginary, we emphasize the question of how imaginaries are interwoven with a local project and the imaginary's role within a specific actor constellation cooperating in innovation processes like the construction of the micro smart grid. Considering the perceived uncertainty and the shaky political and regulatory landscape we presented above, a shared imaginary on a particular artefact among the actors can be analysed as a mechanism to manage uncertainty and is thus considered to be an important element in the analysis of innovation and sociotechnical transformation processes. The research's qualitative data show that the development and implementation of the micro smart grid – as well as the development of the innovation campus as a "living lab" – is influenced in particular by such imaginaries, which we define as the actors' perceptions, expectations and assessments towards possible solutions for the future energy system. Based on this, we found that the micro smart grid imaginary develops while the concrete technical artefact, is under construction and at the same time materialises the vision of the future energy architecture. The micro smart grid imaginary and the technical artefact being a demonstration object are interwoven with the visions projected on the innovation campus. One interviewee described the starting years of the campus and the search for a common vision strongly tied to the place:

> "*There was nothing but promises, and we were about to move in. So, the search for identity was now important, you know . . . It's crazy, but you need such objects and places to establish the identity*." *(co2)*

Here the function of the micro smart grid as a boundary object (Star/Griesemer 1989: 393, Star 2010) becomes apparent. Adapting Star and Griesemer's prominent concept, then boundary objects are produced, when visioneers, developers, scientists, companies, organisations, sponsors and so on collaborate to produce representations of future solutions for sustainable energy production and use within a smart city (Star/Griesemer 1989: 408). Among these boundary objects are technical artefacts like the micro smart grid itself but also energy efficient buildings, the campus newsletter, projects of cooperation between scientific and economic actors, which characterise the innovation campus as a 'living lab', and serve as common objects through flexibility and shared structure (Star 2010: 603; Star/Griesemer 1989: 404). At the campus' micro-level with scientists, business representatives and interdisciplinary research projects, visions (and expectations[18]) help to coordinate between those diverse actor groups and "serve to bridge or mediate across different boundaries and [...] dimensions and levels" (Borup et al. 2006: 286). Besides the micro smart grid's function as a boundary object, which is being actively and jointly created and constructed, the imaginary is understood by us rather as a communitarised perception of the future that can unfold a binding force between plural actors from disparate social worlds working in the nexus of energy, mobility and digitalisation within the transition towards the post-fossil fuel society. The materialised micro smart grid imaginary has a powerful impact and an integrating effect on the functioning and success of cooperation, therefore,

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[18] Borup et al. (2006) use the terms "expectations" and "visions" almost synonymously, describing "real-time representations of future technological situations and capabilities", however visions are "largely overlapping with 'expectations' but emphasise to a higher degree their enacting and subjectively normative character" (286).

it is a mechanism to cope with uncertainty. Yet, the vision itself also needs an object, like the micro smart grid:

> *"You need to have a vision and a plan on how to get a whole bunch of people together. And I believe the only formula to develop is the vision. They want to work jointly to save the world, I'd say. And for that, you need items to show and demonstrate that." (co2)*

Striving for a specific vision especially in an intersectoral context of plural actors with diverse strategies and interests helps to bridge borders.

Under the conditions of fragile economic and political structures on the macro-level, experimental niches and protected on-site test environments appear to be a crucial matter of the energy transition. Several studies already put emphasis on the importance of local mobilisation efforts (e.g., strategic niche management by Schot/Geels 2008). The momentum of change and flexibility then opens up certain margins for action and opportunities, particularly to local or niche actors. Our empirical data also points towards the significance of local efforts:

> *"Before waiting for any environmental conditions and great decision to apply, it actually would be quite good to focus on those matters that one can influence themselves. The micro smart grid or other decentralised solutions are ideal for focusing on for going forward. In that regard the campus is doing quite well, presenting visible results relatively quickly and relatively clearly." (co3)*

Developments of local technology-oriented initiatives as small experimental niches or urban living labs may deeply affect the energy transition process, possibly even more than radical decisions by policy makers. To analyse places with spatially-concentrated innovation activities and the vision's role in those spaces, the combination of sociotechnical imaginaries with conceptions of place, space and identity provides fruitful insights. Implementing the micro smart grid in smaller urban areas has the benefit of testing under laboratory conditions and experiencing learning effects. The technology may be constructed, tested, evaluated, monitored and finally optimised on a small scale. However, the stability of the laboratory in-vivo situation on the micro scale is still quite limited – mirroring the macro-scale system transition – and thus arises the need for mechanisms and objects to cope with that situation.

3.2 The materialisation of the micro smart grid imaginary

The actors on the campus strive to create a business case at the concrete place, either through cooperation or by making use of synergy effects the place and its representation offer to them. Places are needed to establish identities: Without the place, the innovation network realising the micro smart grid would not "take place", since it is the place itself that enables the concrete cooperation of innovation networks: "*The on-going digitalisation is putting emphasis back onto the physical space . . . There is a need to know where the campus starts and where it ends, for it to have an identity*", *(co2)* an interviewee describes the importance of the place and its borders for shaping identity. A place like the innovation campus can be analysed as an articulated moment within a network of social relations, experiences and understandings, those being constructed mostly on a macro-level, so that one can speak of a global sense of the place (Massey 1991). Several interviewees refer to these links between the local and the global, emphasising that a large number of interested people from all over the world visit the campus to view a showpiece project pretesting and realising future technologies for a sustainable and low-carbon society. The development of the campus is being explored and watched closely not only in Germany but in Europe and in wider parts of the world. This in turn strengthens the true significance of the place for the different campus actors as well, who strongly believe in the campus's leading position:

> *"A very important, crucial and not to be underestimated role of the campus is . . . [that] it is a practical example and an urban 'place' for connecting all those complicated processes that, so far, no one dares to address. And the campus is a showcase, a microscope under which we look at the different sectors, like energy, ICT, mobility. The campus is a magnifying glass for all that." (co4)*

This quotation displays one vision of the campus being a "microscope" but at the same time reveals a perception of uncertainty referring to the existence of "*processes no one dares to address*", and it reflects on the attributed audacity and courage of the actors involved. One start-up company decidedly moved to the campus because of these links between the local and the global that promise opportunities of cooperation with actors from different sectors located at the site. This puts the emphasis on the place being constituted, conceptualised and tied together through social interactions, which are in process, as is the place itself (Massey 1991). That shifts the focus towards the on-going "place making", towards the construction process of the campus' identity, especially the construction of difference – because identity evolves as a “mobile, often unstable relation of difference” (Gupta/Ferguson 1999: 13): Several interviewees refer directly to the campus’ specificity and to the necessity of further development, to define and strive for an “identity”, from an economic perspective the unique selling point:

> *“We are about to continue the campus’ development and we will make it more transparent, but we will try to make its identity externally visible through devices and structures . . . but how do we ensure that nuclear power plant operators don’t suddenly come here? . . . In the past, people from all the different thematic areas were brought here because everyone thought: I’ll go there because I want to do something with electric mobility, with science, with the Energiewende. But that, of course does not contribute in the long run . . . And yes it will be one of our tasks to jointly develop these premises.” (co4)*

In connection with the designated place such contexuality and “identity” can work in two ways, both internally and externally: Internally, the joint project is based on a clear target and object, the realisation of the micro smart grid. This is even strengthened by the intrinsic motivation of the actors involved, who formulate the expectation to complete “our tasks”, as stated above. Externally, the visions are merged into a story that is told again and again (“make the identity visible”), like a promise of technology, that also delivers docking points for external interests. The interviews confirmed the national and international external visibility and reputation of the campus, delivered by the story’s attractiveness. The process status enables flexibility and responsiveness on the one hand; but on the other, this fragility requires points of reference and orientation. The micro smart grid as a technical device as well as a sociotechnical imaginary serves as a steady constitutional part of these references and reproductions of the place:

> *“The theme [of the campus’ identity] in sum has to be such a great attraction that it naturally becomes a standard . . . The micro smart grid. That is our theme. And also in the way we are implementing it, we want to be independent. That is one of our location themes: no combustion engines, no tropical wood on site . . .” (co3)*

This quotation also puts a finger on the fundamental questions that arise within the process of defining and constructing the identity of a place: In the face of diverse interests the actors quarrel about the campus’ present development, whether it should be a window for innovations, a living lab versus a real estate site. And what about possible futures, like a decarbonised place with an ascribed commitment? Although these contrasting interests exist, the campus characteristics and its smart city vision, "the theme", prove to be open and adaptable to individual interpretation and use (Star 2010: 602), "robust enough to maintain a common identity across sites" (Star/Griesemer 1989: 393), and to maintain coherence across the actor groups.

However, these conflicts are not only internal in nature. As a living lab it is located in an urban neighbourhood, which means it is operating within the public space and thus subject to external influences, which might hinder developmental activities regarding the micro smart grid. In dealing with conflicts like barriers or frequent modifications, i.e., construction work, the cooperation between the specific actors working on the micro smart grid develops binding powers:

> *"I believe that external factors cannot be influenced. You can just try to build the internal structure as robust as possible. I think, on campus we developed the unique capacity to deal with every stone that was put in our path and even turn it into something successful and presentable in the end." (msg1)*

This bonding can be regarded as identity-shaping and therefore as crucial for the entire innovation process of developing and testing the micro smart grid. The central coordination mechanisms to deal with barriers like frequent modifications appeared to be on the one hand the specific network of actors ("internal structure as robust") that "developed the unique capacity". On the other hand the existence of a material artefact or product facilitates cooperation since the pure materiality creates obligations, e.g., in financial terms, and is therefore a binding factor that solidifies commitment.

In fact, for economic actors, coping with uncertainty is relevant in particular with respect to investment strategies, the expected return on investments and investor reports. If an economic actor develops a new technology or chooses a specific path of innovation, he is facing various uncertainties: in regard to the access to information about the technology; the development process of the technical product and its economic and commercial success; the existence or establishment of a market; the users' acceptance and possible side effects; the technology's profit and capital investment; and finally its legal compatibility, to name just a few: Innovations exist as a chain of closely interlinked decisions, forming a "circle of uncertainties" (Rammert 2008: 16). In particular for start-ups, uncertainty in the face of limited resources underlines the need for strategic cooperation with established actors in the market for learning effects and networking, which is – next to the national and international awareness in public and among subject-specific experts – the reason to settle down at the campus. This is what interviewees from relatively new established companies stated. Those start-up managers also embody the habitus of "men of action" who strongly believe in the paradigm of future sustainability, by turning their conviction into a business case, striving for "impact", "change" and "influence":

> *"In fact, we are quite innovation driven, that means, we have plenty of ideas that might impact and change the energy market massively, ones that can promote and influence electro mobility and renewables." (co5)*

For them campus culture is the combination of "*closeness to the emotion that comes from the shared theme everywhere, plus the loose network*." However, innovations are driven by competition: "*without competition, there is usually not nearly as much innovation*" (co5). All the same, while competitors foster innovation processes, smaller companies still fear the dominance of big players who settle down at the campus as one founder expresses his concerns: "*We could just be blown over in the shortest time with reasonable money and reasonable resources" (co5)*. The established stakeholders themselves however, struggle with the new challenges imposed by the energy paradigm shift and the need to apply modified market strategies themselves and thus strive to participate in innovation processes by partaking in research projects, like the micro smart grid. The cooperation in research projects "*plays a crucial role in providing 'areas of action' for every project partner.*" (co4) In particular established stakeholders often face locked structures in their own organisations, this is what other actors observe:

> *"In general large companies have difficulties with such places: to keep pace with the required speed and scope of the place, that's true for us and for our shareholders. They still don't bring in the desired involvement. But let's say, it is getting better every year." (co4)*

For established organisations it takes a long time to adapt or react to a new situation or even to seize opportunities compared to a start-up's mobility. The established actors are indeed searching for new business activities, expanding or changing their strategic objectives, e.g., by creating new business units or shifting the focus within the organisational structure. The level of commitment might vary greatly with some companies only setting up innovation departments, "*centre of innovations",* with just one or two employers, as we observed. One start-up manager interpreted the motives of "*such big names that choose to come to this location simply as a strong signal*":

> *"It means they want to be close to innovations, learn how to innovate and be part of it. They just want to have an eye on smaller, younger companies. Most of them do not come so much for production or development but they have their centre of innovation here, so that they can present themselves and learn." (co5)*

The strategies mentioned, "*representation"* and *"learning"*, underline the interest in and need for innovative actions. After all established actors have even greater cost pressure with their responsibilities to shareholder within the organisation. But the interests, power and size of established actors also run the risk of influencing and dominating experimental niche-protecting spaces like the campus, as one interviewee warns: "*We definitely do not want the campus to become an ordinary office location."* However, "*[m]ore and more big players are settling down at the campus*" (co4) who could possibly undermine the distinguishing features of the campus, the creative potential and openness and most of all the flexibility and "*speed*". The following quotation illustrates how one out of the diverse actor groups on campus tries to define the boundaries (Star 2010: 605), referring to big companies moving to the innovation campus:

> *"Someone should give them a site code, like a constitution: Welcome to the campus. You can not only present yourself and shine here, but your contribution counts. It is desirable to fulfil the promises of the campus for yourself as well as the community that has been working here to create a framework for action. But in the long term we all have to save the attractiveness of the site as a working, living and creative space." (co4)*

Conflicting interests are assumed to be balanced out or at least coordinated by the campus "*code*" or "*constitution"* to preserve its attractiveness as an innovation network. The interviewees agree on the fact that the specific mix of tenants is crucial for the innovation culture and campus success even though not all actors are directly involved in the micro smart grid's realisation. Yet, attempts for "standardisation" (Star/Griesemer 2006: 614 ff.) by implementing a *"framework for action*" become obvious in this quotation, contradicting obviously the individual interests projected on the place we presented earlier. We found that to balance these tensions cooperation is marked by mutual trust among both big and small as well as scientific and economic actors, even so in the absence of consensus. In innovation networks, the risks and knowledge are shared between the actors, which requires loose but bonding cooperation (Rammert 2008):

> "*Because we are a very tight-knit little community here that knows, by now, how to deal with each other, and how to respond*." *(msg1)*

The open interdependence and medium-term trusting cooperation in the research project are suitable specifically for partnership and cooperation between those heterogeneous actors. This is particularly true in conditions of instability, as one interviewee commented:

> "*There is already a structure of trust grown between the key players, which is tested daily, I would say, because there are numerous points of friction. But when I look at the story we created together, it is a story of success that is unifying […] what we achieved so far led to a core community, even if there might be improvements and so on." (co4)*

Negotiations, about the way to handle "frictions", turned out to be of great importance and a prerequisite for the mentioned "*campus culture*". The spatial materialisation of the micro smart grid imaginary is characterised by these complex negotiations between the investor of the campus, the responsible public authority and the actors who have been working on the micro smart grid from the very beginning. However, through collective action as well as collective struggle, the negotiation process turns out to be a bonding force on the one hand. On the other hand the "work in progress"-status, the campus in flux and the open spaces of action helped to handle "*differences*". The actors involved build the place jointly and taking responsibility for the achievement of common objectives.

> *"The entire smart grid topic is characterised by the numerous stakeholders and their various roles, which are not yet fixed. We've learned a lot about the interplay and functioning of the stakeholder-specific matrix in the face of the differences related to the site." (msg2)*

One empirical outcome of the institutionalisation and stabilisation efforts is the formation of a joint venture between an international cooperation and an established "early settler" on campus. The organisation of economic interests aims at the utilisation of results and consolidates cooperation. Existing structures and institutions of sectoral systems become successively renewed through competitive conflicts and power struggles (Dolata 2008), even in the truest sense of the word: Historical buildings at the site, above all, the technical artefact with skyline character, have been enhanced and given new components like wind turbines or photovoltaic systems as visible artefacts:

> *"That's the campus's unique selling point, the mix of virtual things and real things, like industry. Plus the content connection of the micro smart grid that shows the whole range of the issue: energy supply, storage and distribution. You can make it understandable here. That is quite rare for such a location, to make the entire value chain visible. That is my personal goal as well as the uniqueness." (co3)*

Our empirical research bears one additional finding that is important for understanding the innovation dynamics and strategies chosen by the actors to exploit the momentum of change and the testing environment offered by the campus. As the quotation above "that is my personal goal" reveals: The interviewees are decision makers in their organisation and can be described as "makers" or "doers" or even visionareers (Nordmann 2013: 89) in how they make use of the experimental space: "*If there is no one who is the driver, it will not work – the kind of driver who has a vision as a driving force. Everything else is just theory*", *(co3)* one interviewee reflects upon himself.

4. Conclusion

We have found that even if the technical realisation and reliability of the micro smart grid is as of yet incomplete, the sociotechnical imaginary of it already generates a common understanding and commitment among the scientific and economic actors working on it. Place is closely interlinked with the smart grid imaginary. It is a prerequisite for the emergence of cooperation and understanding across different social worlds as it provides a protected experimental space and enables both niche and established actors to collaborate, to test new business models like setting up a joint venture and forms of cooperation – and thereby to become or remain part of the system transformation: For niche actors like small companies and start-ups, the campus works as an incubation space that enables the development of technological innovations and defends these fragile early stage innovations against the selection pressure of market mechanisms. For established stakeholders, it offers participation in innovation processes. Both of these groups are holding on to the imaginary:

first, for strategic reasons like setting up a business case; and second, for dealing with perceived uncertainty by hanging on to a certain vision of the future with performative character. By imagining possible or attainable futures, actors can create opportunities for the present reality and initiate dynamics of change. The empirical data reveals a specific constellation of actors and their constructive interaction at the campus, working on the technical realisation of the micro smart grid while sharing an ideal type representation of the campus, referred to as "the story". This serves as a means of communicating and cooperating symbolically (Star/Griesemer 1989: 410).

It is not only the "revolutionary process" (Rammert 2008: 1) of innovations and the creative action that produces deviations and goes along with uncertainty and fragility. Basically it is the open-ended Germany-specific transition process of the *Energiewende* that scientists and economic actors both have to struggle with, we tried to show. With that in mind, the materialised micro smart grid imaginary became a boundary object for the diverse actors to hold on to – even though being in technical terms work in process itself. Additionally, the campus site works as a representation of solutions for the future smart city and energy architecture, leaving enough space for individual autonomy and identification, considering the existence of the divergent perspectives and interests. At the place, search and selection processes are carried out with help of negotiations and cooperation in research projects that serve as "shared space" according to the concept of boundary objects (Star 2010: 603).

Dynamic developments like the sociotechnical transformation are generally accompanied by perceived uncertainties and disruptions. But, at the same time, the momentum of change opens up certain margins of innovative actions. The qualitative data indicate that the imaginary links the technical artefact with the new energy paradigm and serves as a coping strategy. Thereby it is an instrument for identity-creation in terms of direction-sharing, which seems to be even more important in times of change, providing a point of reference and thereby point of departure towards the post-fossil fuel society.

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Appendix: List of interviewees

Code	Function	When
co1	Manager, international energy company, early engaged	01/2015
co2	Scientist and manager, consulting company, “early settler”	10/2014
co3	Manager, set up several start-ups, “early settler”	06/2014
co4	Manager, consulting company, “early settler”	04/2014
co5	Manager, start-up, new tenant	08/2014
msg1	Project manager, micro smart grid project, group discussion	06/2014
msg2	Project manager, micro smart grid project, group discussion	06/2014

5 CONCLUSION

The three articles explored the particular ways in which test beds can serve to bring into being new and emerging technologies as collaboratively performed visions tied to distinctive geographical sites of test beds. My research has shown how test beds are less about purely testing technological performances in "real world" contexts. Rather, these sites test and performatively re-order societies and their sociomaterial arrangements based on these undergirding visions related to future technologies. The concluding discussion puts the empirical cases into dialogue with the theoretical concepts spanning across the three articles.

My discussion will center around questions that put the notion of societal reconfiguration and the broader interest of technology's role in governing modern societies front and center. They build on co-productionist approaches in order to grasp the interplay of technological and societal change and the ways in which knowledge and technological artifacts equally shape and are being shaped by social order. According to this analytical lens, I consider test beds as projects through which visions of science, technology and innovation are explored, tested and eventually performed and materialized.

The conclusion chapter has two parts: First, I will offer comprehensive discussions of the empirical findings across the three cases (5.1). Along the lines of STS insights, I will discuss how both cases formulate, test and re-define visions of desirable future societies and how they align their particular visions with broader sociotechnical imaginaries (5.1.1). I will emphasize how actors interpret test beds as policy instruments basing on the paradigm of experimentation (5.1.2). Finally, I will address questions of how actors envision and construct scalability (5.1.3).

In the second part (5.2), which I call "future research program", I will interrogate in more depth the conceptual and practical challenges facing test beds when increasingly serving as policy instruments. These challenges refer to the co-productionist character of test beds and associated challenges of scalability (5.2.1); the emerging paradigm of experimental policy-making and its neoliberal underpinnings when not only governments but increasingly private sector actors engage in the provision of public goods (5.2.2); and a responsible use of test beds and potential ethical concerns, when social order is up for grabs (5.2.3).

5.1 Discussion of the Case Studies

5.1.1 Conflicting Visions of Future Societies

The empirical cases provide insights on the relation between different local vanguard groups and the partly incongruous visions that they hope to realize. They also cast light onto broader sociotechnical imaginaries at play in the articulation of vanguard visions and the realization of test beds. In particular, drawing on the "real-world laboratory" framing EUREF and EAA exemplify how relatively unstable vanguard visions and may align with culturally deep-seated and collectively shared imaginaries in test beds, and how this alignment – or realignment – contributes to the physical and ideological shaping of the test bed itself. As discussed in the theory section, vanguard visions can be like seeds which might become an imaginary if they are shared by larger collectives and institutionally stabilized (Hilgartner, 2015a). To constitute a group of supporters, and to build coalitions are processes through which visions are modified, advanced, or partly rejected. Basing on my empirical data, I argue that test beds are privileged geographical sites at which these processes take place and, even further, they performatively co-produce the sociotechnical futures they are ostensibly designed to test.

My research thus suggests that future making is a constant process of rearranging collectively imagined forms of social life with localized and culturally situated vanguard groups, and that processes of alignment work as contested practices between various scales, like a seismograph of what is possible and what is desirable in society.

Imaginaries of sustainability, digitalization, participatory governance, and smart urban infrastructures highlight what EUREF and EAA actors consider a well-functioning organization of the future energy system while re-ordering the social arrangement of the traditional consumer-producer relationship. At the same time, the case studies reflect the interpretative flexibility of the test bed framing: Innovation is expected to solve problems linked to technical efficiency (EUREF), economic competitivenss (EUREF), public participation (EAA), socio-economic revitalization (EAA), and political agenda-setting (EUREF and EAA). As test beds become negotiation sites about desirable or "better" future (frequently along the lines of established potential conflict lines), they thus provide us with insights on how contemporary societies envision and negotiate their future through projects of science, technology and innovation, and the contingent ways of getting there. My test bed case studies thus bring to light the trajectories of strategic behavior in reference to the different scales, sectors, and audiences these sites appeal to.

Ethnography of EUREF’s emergence and development has shed light on the strategic use of various narratives about the development and the negotiation processes at this former urban gas storage facility turned innovation campus between competing interpretations (Engels et al., 2017). While looking for support and constituting a critical group to advance particular visions, these visions might be changing or reshaped, Stephen Hilgartner has shown with his research on the Human Genome Project (Hilgartner, 2017). How visions are produced, modified, rejected, and finally prevail within a heterogeneous set of actors gathered at a common site substantially depends on their interplay with and ability to adjust to broader sociotechnical imaginaries, and channeling those into materialized reality (Engels and Münch, 2015; Wentland, 2017). Over the course of eight years, EUREF has shown how localized vanguard visions repeatedly aligned to different imaginaries (from conventional energy sources to secure safety, turning towards renewables, and finally becoming a smart city demonstration site) and how this has stabilized and materialized particular visions, and has rejected others. The frequently changing physical appearance of the campus is indicative of continual struggles not only over the purpose and direction of the test bed, but over competing visions of future societies.

In order to understand how these processes work in practice, i.e. how visions translate into agency and strategic behavior, and eventually, how they contribute to the test beds physical appearance, I traced the materialization and utilization of a particular artifact, the micro smart grid[19], which is at the heart of a number of R&D projects at EUREF (Engels and Münch, 2015). In the wake of discourses on the German Energiewende and its manifold technical but also societal challenges, the micro smart grid technology fueled hopes as being an alternative solution for the future energy supply, producing, storing and providing

[19] A micro smart grid is a localized small-scale power grid that can operate independently with its own power resources, generation and loads. Hopes are pinned on purposes including cost reduction, enhancing reliability and autarky. The intelligent grid vision describes a network of integrated micro grids that can monitor and heal itself, and in which the citizen performs as an active prosumer (Marris, 2008). Yet, a number of questions regarding e.g. ownership rights, its modes and responsibilities of control, data collection, and data use remains open.

renewable energy within a decentralized infrastructure. Energy will be supplied from multiple micro smart grids, consisting of mini power plants, photovoltaic systems and biogas plants, all connected via ICT – rather than from relatively few centralized sources, as it used to be the case. Further, the smart grid technology allows having forms of flexibility in the energy system. This is where electric vehicles come into play: Using bi-directional chargepoints, battery-powered cars could serve as mobile storage devices to match up supply and demand at the local level. Different vanguard groups, consitisting of engineers, mobility experts and self-proclaimed innovators, call this future scenario "Vehicle to Grid (V2G)" (Wentland, 2017). This term hints at the merging of the previously separate economic fields of renewable energy systems, transportation, and ICT in order to become sustainble societies (Canzler et al., 2017; Wentland, 2017). The electrification of transportation with energy from renewable sources is considered to be key to reduce emissions from transportation and to contribute to the countries' efforts to become green, smart and sustainable. In the particular case of Germany, these vanguard visions challenge long-existing and taken-for-granted regimes of automobility and energy, which are closely interwoven with the country's economic success and well-being. Particularly the automobile and the entire automobility system are deeply embedded in Germany's cultural identity, which have been signifiers of wealth, success, family values, and self-determination for decades (Canzler and Knie, 2016; Wentland, 2017)

While the transition towards a more sustainable, decarbonized society has become an urgent matter not only in Germany but globally, imaginaries of digitalization, sustainability and smart urban infrastructure encode – or inspire – visions of future technologies, such as the the micro smart grid. They trickle down as the actors' perceptions, expectations and assessments towards possible solutions for the future energy system. And, the other way around, the micro smart grid helps imaginaries at national scale to touch ground and to evoke relevance and plausibility for a wider range of actors (Engels and Münch, 2015). This leads not only to the convergence of different technological spheres but is also prompting the formation of new corporate alliances and business ideas – which, however, remain an objective of R&D projects and expert discourses so far.

Not only the smart grid technology but also EUREF at large taps into the popular "smart city" imaginary. In Germany, EUREF became the go-to-side for innovation demonstrations related to the nexus of energy, mobility and ICT, where the full range of new technologies (from its technical performance to regulatory modifications) can be tested and made visible – though being under permanent construction: “It’s crazy, but you need such objects and places to establish the identity,” one interviewee described the strive to localize and materialize sociotechnical visions to help them touching ground. EUREF conveys a vision of the future society that stands for the blending of technology creation and use environment at one and the same location, featuring technologies considered requisite for smart, sustainable and innovative societies. Next to the micro smart grid comprising different technologies, EUREF showcases the operation of autonomous vehicles, a variety of charging stations to test different charging infrastructures, mini wind turbines installed on the roofs of several buildings, solar photovoltaic systems or biogas-powered cogeneration. EUREF’s vision of a cosmoplitan smart city rests upon the idea to merge the development and demonstration of such technologies with the working and living environment[20] of the engineers and entrepreneurs, featuring e.g. a fitness center and a volleyball court.

The reason why today’s smart city vision is proliferating and funded across various countries and domains is that it merges different popular discourses, as argued by Martin, Evans, and Karvonen (Martin et al., 2018). Specifically, the smart city vision converges three visions: the digital city, the entrepreneurial city, and the sustainable city, as the authors argue. Smart city visions are fueled by related techno-centric policy discourses centering around the respective social problems, which are to imagined to be solved through the deployment of digital technologies in order to contribute to economic growth in parallel with citizen participation and decarbonization. Smart city advocates expect the deployment and application of smart technologies such as blockchain, robotics and artificial intelligence on a city scale to trigger economic growth substantially and to “unlock” a city’s potential (Smart Cities World, 2018). This neoliberal understanding is also inscribed in the European Commission’s Smart City strategy (European Commission, 2013), which prominently features this framing referring to the healing power of technological solutions addressing deficient societies.

[20] Initial plans to build up to 120 private appartments into the Gasometer (Berliner Morgenpost (2015) however have been put on hold (and up to now it is not clear whether these plan will ever be realized). Instead the Gasometer is currently used as a space for exhibitions and host for prominent political and business events (e.g. the Future Mobility Summit or the G20 Africa Summit).

Entrepreneurial and scientific agents who engage at EUREF largely mobilized this narrative that smart technology not only fosters economic growth but also, subsequently, that society at large will benefit in the long run (Pfotenhauer et al., 2019). This re-invigoration of the myth of trickle-down innovation stems from the belief that innovation starts with economic investments and will then trickle down to solve societal challenges (Joly, 2017). “I think that for EUREF it is a stroke of luck that I live in a different world than usual. If we do not bring the energy transition to people who are decision-makers and who may be living in other social spheres, in other urban districts, but who have the power to make decisions, the energy transition will not work”, the investor explains his investment strategy and belief how innovation works; namely, that it needs powerful decision-makers like successful entrepreneurs and investors to initiate societal change for the better.

EAA empirical insights represent another example of how different vanguard groups envision the energy landscape’s and society’s future, and which strategies they apply to enact that future. At the heart of the EAA vision are the local production and consumption of energy and the integration of electricity, heat and mobility as part of a regional energy transition strategy. Yet, our data reveals that this general idea conceals a larger set of partly contrasting visions, which are assembled under the living lab framework (Engels et al., 2019). Most of the local participants of the EAA see the region’s interpretation of being a test bed as a means to revitalize the region’s economic prosperity and to address the needs of local communities. At the same time, from its beginnings the local network has attracted the interests of national (policy) players who have been quick to recognize the chance to establish the region of Anhalt as a hub for the Energiewende, in response to a perceived lack of noticeable results from the federal level for regional energy policies. EAA exemplifies the frictions that may emerge when national interests encounter local social and cultural identities. In other words, challenges emerge when collectively performed visions on a national scale are to be transferred and materially enacted at a situated and established “real-world” setting, here, the region of Anhalt in East Germany – and vice versa.

In contrast to the strong identification of local actors, for most national actors EAA is merely a testing ground for visions of a decentralized energy grid as being the future solution for a digitalized, more efficient, and more participatory energy system. Similar to EUREF, EAA stands for a decentralized energy system basing on renewables. Yet, in contrast to EUREF’s technological centred visions, EAA’s decentralized approach nurtures visions of a more democratic, equal, and participatory society in that individual citizens or organized collectives are imagined to be “empowered” as “energy managers”, getting rid of an energy system dominated by the monopoly position of a handful of providers. In the minds of those responsible for EAA, this revolutionary new energy architecture is made possible through the opportunities of digitalization. EAA actors draw on elements of the powerful sociotechnical imaginary of digitalization, which is considered to both re-order energy infrastructures through “smartification” and the citizens’ role vis-à-vis large energy corporations. The envisioned re-organization into localized grids through the application of smart technologies thus comprises a particular vision of the citizen: One scenario promoted by national EAA actors entails citizens as entrepreneurs who are enabled to manage their individual energy use and supply.

Further, Berlin-based EAA actors aim to position the region of Anhalt as a national exemplar and best practice for energy system transformations reconciling economic and societal interests. They believe that “if everything we tried failed to make any significant progress (…) then the Energiewende will not succeed either,” as one non-regional manager explains the EAA’s function as a national showcase initiative. This perspective featuring the region and its inhabitants as local proof for national policies stands in sharp contrast to the regional actors’ vision of what the regional test bed should be and aim for. This major source for recurring conflicts basically centers around the question who gets to decide about the region’s future and whose visions are represented and promoted in the test bed.

In constrast, local EAA actors dismiss the idea of becoming “guinea pigs” and their region to be a replicable model, one interviewee stated. They rejected to cite their own research and testing activities into “so-called model projects and model regions,” because these are “not transferable outside the model structure. That is, it 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.” This quote from a local EAA actor underscores the strong sense of regional embedding and identity among the local core group of actors, which has initially triggered the formation of the network and has been a driving force throughout the development process. The region is blessed with a rich cultural heritage and features three world heritage sites, and self-consciously portrays itself as a spearhead of modernity full of innovators and visionaries. The test bed vision of local EAA actors is nurtured by the belief that the region's cultural identity is committed to the region's tradition, which has the potential to once more serve as a driver of transformation.

These insights point at the difficulties of creating entanglements between more widely held imaginaries and their local articulation and uptake, when vanguard groups challenge and disconnect from supposedly collectively shared imaginations of the future. Societies mobilize their cultural identities and inscribed hopes and fears when they encounter the possibilities – or threats – of emerging technologies. When test beds become the go-to-sites to articulate and materialize vanguard visions of future technologies, they become also the sites where societies decide which future they aim for.

5.1.2 Conflicting Interpretations of Experimentation

My research has shown that test beds straddle opposing paradigms of knowledge creation in the way they interpret "experimentation," oscillating between a mode of controlled experimentation in spatially confined settings and a "messy" co-creation process open for a variety of actors and "real-world-"influences. On the one hand, test beds turn actual places into sites of experimental manipulation and testing, whose value proposition is to create a research-setting equivalent to traditional laboratories, which allows for modifications and tinkering in order to improve the technology's performance and to observe possible defects. On the other hand, there is an interpretation of test beds that embraces the diversity of inputs – such as diverse publics – coming from "chaotic" or uncontrollabe environments as these are considered valuable sources for "better" innovation outcomes, e.g. in terms of being more responsible or inclusive. According to this experimentation-in-the-wild-approach, test beds turn co-creation into their dominant epistemic paradigm (Engels et al., 2019). The simultaneous belief in two oppositional paradigms of knowledge creation is yet a potential source of tensions as my empirical case studies have shown. Consequently, conflicts occur around interpretations of what precisely a test bed is, how it should be organized and what should it aim for.

In case of EUREF, control is invoked through the clear spatial delineation of the privately owned campus from its Berlin environment, which allowed for a certain degree of regulatory and institutional flexibility, e.g. to test a self-driving mini bus and its operability as a shuttle service without the interference of Germany's strict road safety regulation. As another example, various models of charging station designed by different energy providers and new companies entering the market (all located at EUREF) were installed in order to compare and test not only their design process but also their performances in use. Infrastructural modifications and co-location are the key components of EUREF's aspirations to make a showcase of the feasibility of integrated smart urban energy infrastructures – not only in technical terms, but to demonstrate what they aspire to be an innovation friendly environment and how national policies and regulations should be adjusted. However, delineating the campus from its urban neighbourhoods has been a subject of contestation over years. Contrasting visions center around the general question whether future innovation should be made accessible to the public, or whether technological experiments should be conducted shielded from the public. For example, the campus owner has explained to put up the fence in order to protect the offices and garages from theft and vandalism (which have happened in the past), establishing a kind of a 'safety zone for innovation'. In contrast, one of the early settler organizations that has contributed to the sites development and strategic positioning from the beginning argues against the fence to allow pedestrians to pass through the campus and to better integrate the campus into its neighbourhood as a whole.

This latter perspective speaks to the other interpretation of experimentation, plugging EUREF's mission into the co-creation mantra. One of its key features is the mixture of different stakeholders, covering business and research partners as well as start-ups and renowned companies, and technology projects in an explicit attempt to foster co-creative innovation activities. Most of the start-ups occupy niches between the traditionally segregated sectors of energy, mobility and ICT and therefore appreciate the campus character, being close to potential business partners or investors and at the same time profiting from the site's visibility in media and politics, and from the diversity of visitors being constantly around (Canzler et al., 2017). The diversity of inputs however puts limits on the extent to which scientific activities can be controlled or even anticipated. Taking the example of the installation of different charging station models for electric vehicles, I observed how the project partners were in a constant process of negotiation about the construction and placement. While most research partners argued for a variety of technologies to be tested, business partners formulated clear ideas of how to arrange and design the charging stations as part of EUREF's general showcase concept. This resonates with another element of EUREF's demonstration character, which is its decisive getting-there-first attitude regarding energy innovation vis-à-vis international developers in demonstrating the viability of smart technologies and in positioning German companies in international competition.

Here again, conflicting interpretations of the test bed's role in innovation policy come to the fore. The demonstration pressure stands in partial conflict to the thoroughness and open-endedness of research: Research and testing arrangements are facing constant internal pressure to give way to more tangible and visible forms of demonstration and materialization, even if the technology is still immature. That means, test beds are as much about testing technologies as about their staging in front of diverse audiences and the demonstration of its viability and success. However, it is at times unclear what exactly is or should be demonstrated as expectations and interests have been shifting over time (Engels et al., 2017).

In contrast to EUREF, EAA strives towards the co-creative paradigm of knowledge-creation. It has interpreted experimentation in a more inclusive and open manner from the start, striving toward an active integration of the public. Interpreting test beds as means of participation resonates with EAA's more 'porous' spatial delineation. EAA is not a fenced-off area like the EUREF innovation campus but understands experimentation as something that includes more space and various publics in its co-creation processes. In order to encourage participation of the public as an active partner, EAA chose a non-profit association as its organizational form, whereby citizens are formally presented alongside organized interests such as companies and government. Embracing instruments of direct citizen participation, EAA carried out a series of public events to provide a form for exchange and dialogue. Despite these good intentions, however, only few citizens joined the association as members. Instead, the core group consists primarily of experts and professionals from regional organizations such as energy suppliers, public utility companies, and municipalities, as well as also supra-regional organizations like non-profit foundations, research institutions, and the country's central federal authority on environmental matters. At regular meetings of the association, it is primarily this expert group that is engaging in and running the debate about future projects and next steps.

Within this imbalanced representation, diverging interpretations collide as to how open or controlled the test bed should be. While some accept that co-creation can be ungovernable and unpredictable at this scale, others see EAA rather as a "project" in business terms that requires a concerted "effort of management and coordination" like any other project. These tensions are further intensifies by the aforementioned conflicts between local and non-local EAA members about who gets to decide about the future of the region. Repeated controversies over the degree of inclusiveness, the scope and governance of the test bed have hardened rivalries between local and federal interests and even resulted in an organizational split-up into a local branch office in Dessau and a project office in Berlin. A regional EAA member describes this perceived 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." Further, in the eyes of some local actors the fact that the funding for all activities is almost exclusively provided by a private company foundation establishes an imbalanced distribution of power and allows for an unilateral pursuit of interest. This empirical insight speaks to another finding, which is the changing role of intermediary organizations in these experimental settings related to Grand Challenges discourses. Research funding agencies may go further than their traditional role by becoming "brokers, playing a role in defining and/or managing concerted actions" (Kuhlmann and Rip, 2018).

What EAA further exemplifies is that experimentation within geographical boundaries goes hand in hand with the choice of, and control over, a designated local "test population". Here, the designated "real-world laboratory" comprises almost 400,000 inhabitants who are considered to be valuable local innovation resources, yet without any formal declaration of consent (I will further discuss this point in section 5.2). While EUREF keeps "lay people" literally out and constructs users as part of technological testing, EAA demonstrations happen not only towards the public but in public, by the public. In test beds' actual physical environment, experimentation and technological testing are thus linked with the configuration of users and publics, a process of co-construction. How EAA and EUREF construct its publics and users (allowing for interference or not) reveals once more that test beds are different interpretations of how controlled innovation in test beds should be.

Test beds serve above all as physical locations of negotiations between diverging interpretations of experimentation, strained between control and co-creation for innovation, and related concepts of participation, strained between instrumentalization and opening-up. And, finally, they raise questions of how local or global the innovation ambitions should or can be.

5.1.3 Conflicting Ambitions of Scalability

My data casts light on how test beds are utilized as means of governing and serve broader patterns of policy-making, while equally carrying hopes to create more effective or applicable solutions when innovation becomes localized. Studies on political experiments have shown that these sites function both as instruments to gain knowledge about something that is yet unknown *and* analytical concepts to deal with uncertainty and to legitimate action in the making of decisions (Laurent, 2016). Equally, test beds speak as instruments of policy-making and knowledge-making to both politics and science. Since government, industry and private foundations – or mixtures of these – fund test beds, these sites are expected to be applicable to the particular needs and to construct plausibility to the various interests. Like innovation at large, test beds thus contribute to the making of meaning, mobilizing visions and creating a sense of collectivity in order to give rise to change (Pfotenhauer and Jasanoff, 2017a). Their demonstration character further allows for framing, staging, and articulating the particular visions to various audiences[21], which are expected to circulate across multiple locations.

Ambitions of transferability lie at the heart of the test beds' model character and inevitably invoke notions of scalability (Engels et al., 2019). Although for different reasons and based on individual rationales, EUREF and EAA exploit experimental practices with the goal to produce generalizable findings that can be projected onto further sites or use scenarios: What is tested and applicable at one site – so the hope – should be adaptable at another, given similar conditions or needs. By now, few studies have addressed related aspects of scalability, like the scalability of collaborative forms of governance (Ansell and Torfing, 2015), the scalability of particular technologies that have been tested in experimental niches (Naber et al., 2017), or, more generally, imaginaries of standardized and transferable innovation (Pfotenhauer and Jasanoff, 2017a).

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[21] Through their strategic use and the various interests they are expected to serve, test beds function as a kind of boundary organization, which are "able to project authority by showing its responsive face to either audience" Guston (2000): "Like Latour's Janusian visage of science itself, the boundary organization speaks differently to different audiences. Latour's science is able to project authority by appealing to either face in a strategic fashion, for example, by claiming that science is a messy, creative process and also by claiming that it is a neat, rational process."

My research illustrates the tensions related to the contrasting ambitions of scalability. They arise when test beds carry the dual promise to draw relevance from the unique social conditions under which they operate and, at the same time, to develop solutions that could serve as templates for similar transformations elsewhere. More precisely, my case study research contributes to understanding how actors envision the proposed solutions to scale up or out of the experimental test environment and how they perceive and eventually deal with this dual (policy) challenge.

EUREF navigates various challenges of scalability and its leadership role in German energy and smart city policy. Being a reference point for the country's transition towards a smart and sustainable future, for many campus actors testing in EUREF is equivalent to testing in a city (at scale). In the eyes of many, the self-contained EUREF campus serves as a miniature future city, representative of how to integrate various technologies, energy-efficient buildings, and new forms of work in the knowledge economy. In order to position the campus as a model for greater Berlin and these new paradigms at large, it requires to experiment on both the level of technological development and the policy level of regulation and governance. Empirically, that means, developing the micro smart grid technology goes hand in hand with legal and regulatory questions of how to make a business case out of it. Here, two of the most powerful companies located at EUREF, the German railway company and energy company Schneider Electric, have teamed up as a joint venture. The newly established company "Inno2Grid" aims to turn the micro smart grid technology and the relevant knowledge and experiences from the R&D project into a marketable business model that can consult and implement energy and mobility solutions at different areas. Furthermore, technological and regulatory questions come together in case of the smart grid's interconnectivity. At EUREF, experimentation entails testing with different levels of interconnectivity built into the elctrical grid to learn about different options that might become common standards and that will help to implement the technology in various contexts.

Not only the micro smart grid is envisioned to travel beyond its site of demonstration, also the campus pushes the active transfer of its model to other geographical regions. Although it features some Berlin specific characteristics holding close links to Berlin politicians and the city's business development agency, EUREF strives to replicate its general concept at further locations. Plans to actively transfer and reproduce the campus concept at the former coalmine industrial site ("Zeche Zollverein") – a world heritage site – in the city of Essen (North Rhine-Westphalia) however failed as it turned out that construction plans have not been compatible with the rules of the protection of the local historical buildings and monuments (WDR, 2019). Shortly after, EUREF leadership announced plans to build a "EUREF Campus Düsseldorf" in the city of Düsseldorf (also North Rhine-Westphalia), even bigger in size and with more investment than in Essen (NRZ, 2019). Exactely as planned in Essen, as kind of a visual connection, the symbolic dome roof of the Berlin gas storage facility was announced to be transferred to the new campus, along some other key features such as food trucks and a fitness center for employees. City officials state their support as the campus settlement and its projects on future mobility, digitalization, and resource-friendly production presumably fit well with strategies of federal economic policies and the city's image of being a "start-up city", as explained by the mayor (Westdeutsche Zeitung, 2019). The establishment of the innovation campus in Düsseldorf is tied up with the promise to install 100 companies and to generate about 2.500 new jobs, and to meet Germany's 2050 climate targets in order to keep the country's "environmental promise," the EUREF investor announced (Westdeutsche Zeitung, 2019). This example illustrates, first, the deployment of test beds as a means of economic vitalization and (energy) policy making. Second, this (quick) change of plans (from Essen to Düsseldorf) is yet another illustration of EUREF's ambition to transfer rather its "test beds as templates"-approach than its specific technologies and their local diffusion. It stands for the general best-practice model character of test beds, which are envisioned to be plugged in and to drive innovation wherever requested.

In case of EAA, the network draws on both promises related to the test bed's scalability. That is, to serve as a replicable model but at the same time to tailor innovation activities to the concrete societal needs and use contexts. The latter aspect is particularly mobilized by local actors, who envision the test bed to serve the concrete societal needs of the entire region, that means, to develop specific local solutions for the specific local challenges. However, expectations towards the regional network have been ambitious and diverse from its beginning regarding the general revitalization of the ageing and economic weak region as well as some very specific and current investment strategies of the region's public utility company: "In the end, you are always expecting an economic advantage, which can be customer growth, or renewable energy projects to be part of," a manager of a local company describes his motivation to join EAA.

At the same time, actors from the national level envision the regional test bed as an interchangeable testing ground for the feasibility of energy transitions at large. For them, the region of Anhalt is just one geographical location where they found a group of actors and a certain willingness they could operate with to investigate broader questions related to the vision of a decentralized energy system. In their eyes, EAA is above all a spatial context in which supraregional actors can test strategies and ideas for sustainability, technological advancement, and prospective energy concepts. If this context has not been the region of Anhalt, they would have promoted any other location that posseses the features they think are suitable for experimentation and demonstration. In their eyes, Anhalt's important features are equivalent to those of many other rural German and European regions: the disappearance of local industry, continuing major job losses, an aging and declining population, and the absence of a credible vision for the future of the region (although these challenges might be particularly pronounced in the German East). From a federal perspective, the EAA test bed in Anhalt is thus as much about placating calls for regional economic development as it is about developing strategic resources for Germany's energy policy future. More than just a local showcase, EAA actors expect the initiative to have a catalytic function for Germany's Enegiewende. Visions of a smaller-scale stand-in for Germany's transition challenges at large result in diverging commitments to local relevance related to national scalability, identity building, technological needs, and local economic development, and highlight the connection between regional and national success of the Energiewende.

EAA and EUREF's empirical insights illustrate how these experiments create new realities in ways that are always active and guided by particular interests, but never neutral or innocent. This is what makes test beds inherently political and contested characterized by processes of constant adjustments and iteration (Engels et al., 2017): "Experimentation with representative claims on collective interests, for generating political authority, legitimizing norms, and mobilizing collective agency, is a constituent component in the remaking of collective orders" (Voß and Schroth, 2018). Decisions related to the inclusion and exclusion of particular actors, local bottom-up ideas against national ones, core actors against new actors, they all comprise social and political components in all modes of experimentation and have long-lasting ordering effects(Voß and Schroth, 2018). The question how, by whom, and for whom decisions are made in these experiments and about what needs to be known, is also a question how certain interests are addressed and negotiated with each other and, on a more general level, why societies do want to know some things and others not. In this light, the observed tensions of scalability in both of the empirical cases – between local networks, regional identity, and concrete needs on the one hand, and claim-making for federal policy and transferable models on the other – shed light on the tensions between bottom-up and top-down approaches to public policy. Empirics indicate that struggles over local identity and control put limits on the extent of experimentation and its exploitation as a means of governing. That means, while test beds proof to be suitable places for contestation and dialogue about the viability of desirable futures, they equally point to the limits and pitfalls of experimentation and the scalability of innovation practices.

5.2 Future Research Program (Outlook)

The thesis considers test beds not as stand-alone solutions or detached innovation projects but components of wider trends and rationales of (urban; innovation; economic) policies. They ways in which experimental practices interfere with the assemblages that constitute social life, they thus raise questions of how they are connected to the political, economic, and social ordering of the city, region or nation (Jasanoff, 2004; Laurent and Pontille, 2019). The upcoming and final section of this dissertation therefore sets out to reflect more broadly on the co-productionist relation and potential policy implications if societal reconfiguration is the flipside of technological change. I will approach test beds from a political economy perspective to raise concerns related to such aspects of societal re-configuration (5.2.1), democracy and citizenship (5.2.2), and a responsible governance (5.2.3).

Although recent STS work on experiments has provided a basis for rethinking the terms, practices and consequences of experimentation (Evans and Karvonen, 2011; Laurent, 2017; Lezaun et al., 2017; Voß and Schroth, 2018), further research is needed in order "to identify the ways in which experimentation is structured through political economies operating at different scales and through different circuits of power and finance, and to consider whose interests are served through these processes." (Bulkeley and Castán Broto, 2013) The study on test beds contributes to our general understanding of the interrelations between science, technology and society in the making of our future, and helps to explore new territories of experimentation and their attendant means of reproducing or reconfiguring the world.

5.2.1 Testing Technologies, Imagining Futures, Reconfiguring Societies

Beyond urban experiments in contexts of smart cities, the logics, procedures and rationales of testing and experimentation are increasingly applied to a wide range of areas: Beta-testing of face recognitions softwares in public spaces (e.g. in London in 2019), field trials of autonomous vehicles (e.g. Uber in Tempe, Arizona, 2016-2018), or universal basic income experiments on a nation-wide scale (e.g. in Finnland from 2017-2018), are just some examples. Yet, what most existing studies on field trials, living labs or real-world laboratories miss is the co-productionist character of these test beds, i.e. the processes of how the spatial embeddedness shapes innovation activities as much as the test bed shapes its context on both the local scale but also on broader contexts. Both, technology as well as society are thus the subject of testing and reconfiguration in test bed settings. Applying such a co-productionist lens, the aforementioned examples constitute avenues of intervening in society and affecting public life, though in varying ways and depths. In the following, I will raise a number of governance challenges, which I think are crucial in order to understand and deal with this co-productionist character of test beds.

First, test beds release technology onto society while still containing bugs and faults, i.e. technology is still in its beta stage of development. Then, it is up to the "beta-users" (Dratwa, 2017) to test these technologies and to learn at once about their performances *and* about their shortcomings and potential risks in practice. Even further, users not only have to learn *about* these things but also how to deal with those faults which potentially affect their lifes. Testing technologies in their beta versions (e.g. trying out new or unstable devices like autonomous vehicles) is a process through which imagined futures (here: a future governed by algorithms and machine learning systems) become materialized into concrete artifacts and interfere with existing social relationships that are tacitly relied upon and often legally codified (here: autonomous vehicles intervene with urban infrastructure, local residents, road users, and traffic regulations). Referring again to the example of autonomous vehicles, the large number of experiments in place brings self-driving cars already on the streets although the technology is still far from being mature. Car manufacturers and ICT companies started a race in the development and marketization of self-driving technologies, supported by politicians who have rushed to allow car companies to use their jurisdictions for beta tests (Huffpost, 2019). Studying the Tesla crash in 2016, Jack Stilgoe has shown that while companies still learn about the algorithms and the various technological challenges of autonomous vehicles, the self-driving car makes in effect life or death decisions (Stilgoe, 2018).

Second, through the release of beta technologies onto society, test beds thus turn society at large into a beta-stage basing on particular visions of future societies. In such a "beta-test society"[22] it is not only the emerging technologies and technological arrangements but also the undergirding relationships that are ordering social life and social being, e.g. through law and regulation, which are put to the test. Such a beta testing of society actively shapes social order and tentatively invalidates rules and regulation that limit what technologies can

[22] Inspired by the terms and concepts of the Open Beta Society (Dratwa (2017), the test society (Callon et al. (2007), or the experimental society (Haworth (1960).

do, indicating a laissez-faire attitude towards potentially harmful societal implications of technology (Marres, 2017).

What is more, harmful technologies and potential bugs might become materialized and stabilized in the social infrastructure, which is highly path-dependent and cannot be retracted easily, or even not at all. In her resignation letter from Sidewalk Toronto, Saadia Muzaffar states: “(…) a resident shared their serious concern with me about the fact that Sidewalk Toronto materials and soundbites thus far do not address the blast radius of making mistakes on a city-scale. That is, a city’s infrastructure has an obsolescence of many decades; it is not like a new phone that we can change in a couple of years if we find it problematic.” Her quote speaks to the performative character of experiments and exemplifies how potential errors might become persistent once inscribed into infrastructures. In order to emphasize aspects of performativity, Halpern and colleagues have coined the term “test-bed urbanism” as a new form of epistemology, which is not about making facts or representative models but rather about creating models that *are* territories (Halpern et al., 2013).

The model quality and transferability promise depict another governance challenge related to the scalabillity of test beds’ co-productionist character. As test beds intervene into the organization of society they create local model realities that are deemed scalable. This finding begs conceptual questions of how co-production and scalability interrelate. If test beds tinker with and eventually re-configure social order under the guise of technology testing and demonstration, how is it even possible to scale up this this locally confined simultaneous shaping of new technical and social orders to other or broader contexts? Attempts of scalability show similarities with rollout practices, as known for example from the start-up sphere where companies first introduce their product or service to a selected market or niche, and then steadily expand to other or larger markets. Yet, in case of test beds, the value proposition – a promise of value to be delivered – is not a single product but an innovative social order, i.e. ways of living, which is imagined to further roll out. This means, first, that it is in effect the co-productionist relation between the technical and the social, which needs to scale. And. second, the test bed’s performance inevitably depends on its ability to scale up exactly that co-productionist character.

I hypothesize that the mutual evolution of technology and society is scalable, yet, to a limited degree. That would imply that a stabilized social order bears the risk of breaking down if stretched too far. So, the question for future research is; what are the conditions and parameters for cohesion? In this thesis I have introduced a set of parameters – such as the allignment between vanguard visions and imaginaries, or between local needs and national policies – which indicate to play a role for the test bed's coherence. Accordingly, I assume that the test bed is most successful as long as it reconciles existing political and epistemic cultures as a nation's cultural identity only allows for a particular way of dealing with technologies (Jasanoff and Kim, 2013). Then, the simultaneous configuration of technoscientific and sociomaterial orders is not only the analytical core of test beds but also a signifier for its performative power in designing future societies.

Finally, processes of mobilizing support and coalitions for particular visions to scale into collectively shared facts constitute key moments in the politics of experimentation. When the outcomes from locally configured findings get turned into a transferable good to travel out of the confined space, this is where "micropolitics of experimentation turn into macropolitics" (Voß and Schroth, 2018). Yet, test beds are at once micropolitics to be scaled up *and* geographically localized macropolitics, testing out collective policy claims. My research has shown that this dual relationship is a source of severe tension and that the ways in which a test bed deals with these tensions is key to its design, performance and relevance – both in technological development and serving as a policy instrument. Both of my test bed case studies transformed in ways that exceeded the original visions of their architects. In particular EAA has experienced some "disciplining effects of neoliberalism" (Peck and Theodore, 2015): stepped up to transform the region from the bottom and highly ideologically motivated, it has been taken over by funding institutions and project management rules, recognizing the endeavor's potential as a test bed for national energy policy claims[23]. Marked by a deep distrust among local and national actors, these tensions have never been explicitly addressed and finally ended up in an organizational split-up and unsatisfying outcome after the official funding period`s end after three years. This finding implies that the test bed's adaptive capacity is limited to reconcile the dual challenges of

[23] The ways in which national actors have engaged and eventually adopted the regional test bed according to their interests and visions also results from a deep cultural divergence between both the urban and the regional, and the West and East Germany. What has started as an open-ended, regional experiment in which everything was negotiable (or, in other words, undecided) has turned into a "real-world laboratory" idea, increasingly imposed from outside in the service of managerial and funding institutions' interests.

micro politics to be scaled and macro politics to be localized. This might provoke the test bed to collapse, when innovation processes disconnect from local idiosyncrasies in favor for assumed success stories. Even further, it might overrule the strengths of local, subjective engagement and of democratic deliberation. This points to, what Peck and Theodore call, the “limits of radical localism in a neoliberalizing world” (Peck and Theodore, 2015).

If technologies are the devices with which societies explore and create designs for future living (Jasanoff, 2016), articulating hope and dreams, then, test beds are both the physical sites of (re-)aligning the plurality of possible designs vis-à-vis the plurality of visions for the future and performatively testing their plausibility and feasibility in social contexts. This is yet bounded by the strong co-productionist relations, which make explicit both the interacting modes *and* its limitations of future-making, imaginations and their mobilizations in concrete claims, practices and spaces.

5.2.2 Political Economy of Test Beds

A less benign and more normative reading of the emergence of test beds and experiments is, of course, possible. If test beds truly act as social experiments and instruments of governance, questions emerge related to broader concerns on democratic legitimacy and potential new forms of exclusion through power asymmetries and diverging interests in test beds. To that end, I apply perspectives of political economy to raise questions on how test beds are framed and promoted, how they (re)produce particular formations of power and regulation, and how they shape patterns of economic development (Coletta et al., 2019; Laurent, 2016). I take the opportunity to discuss test beds and their intruding neoliberal and subversively authoritarian implications that could potentially manifest[24] – as “never before in history cities have been subjected in such scale to the technocratic visions and trials of a few anonymized global companies.” (Halpern et al., 2013). Acknowleding that the choice,

[24] It should not be overlooked here that some scholars have pointed at the dualistic character of discussions particularly surrounding smart city test beds, e.g. by Kitchin (2015); Talvard (2019). The two poles tend to be either too idealistic, seeing smart cities as technologically optimized democracies, or too critical, lacking nuances and rich empirical insights.

design and deployment of technology is deeply political and moral, test beds offer analytical avenues to study the organization of democratic life in the realm of participatory deficits and neoliberal tendencies.

First, empirical data points at a privatization of public problems and goods in test beds. Test beds and public experiments in general often rely on close cooperation between public bodies and private entities, i.e. they are increasingly occupied both by national politics and by corporate interests. This is not only indicative for their interpretative adaptive capacity to serve for various missions, but raises alarm related to questions of control and power. As experiments have been extended to all spheres of social life, to the cities (e.g. smart city initiatives), streets (e.g. Tesla or Uber field trials), the workplace (e.g. living labs for the future of work) and even homes (e.g. smart meter roll-out), the entry points for particular, technology-centered interests are manifold and far-reaching. Studies have shown that the entanglements of the state and the market through experimental practices have given rise to neoliberal concerns and discussions on the processes of marketization and the creation of state-backed nascent markets for new products and services (Birch and Siemiatycki, 2016). The Toronto case study will serve to exemplify these points of critique. Through its engagement in Quayside Toronto, Sidewalk Labs, an offshoot of the Alphabet family to which also Google belongs, enters new shores, which have traditionally been in the hands of public authorities. Taking the city of Toronto as its test bed, Sidewalk Labs means to build an electric micro grid, mobility infrastructures like bike paths, to employ sensor-enabled waste separation to aid recycling, to design public spaces and utilities like water pipes, or to use a range of data to improve public services more generally, among other services. Municipal tasks, services, utilities, and infrastructures are effectively carried out, i.e. envisioned, designed, implemented and operated, by one of the biggest data collecting and processing companies of the world.

Sidewalk Labs' ambitions to process in effect governmental tasks and their self-conception to act on behalf of Toronto's citizens is further mirrored in its organizational structure, which shows departmental similarities to a typical city administration. For example, they announced job openings for positions in "Resident Experience", Health and Human Services, Education, Economic Development, and other city functions (Pape, 2018)[25].

This adds to an overall picture, as if efforts to turn Toronto into a future smart city only are manageable and realizable through solutions offered by a private company. This observation underpins the general neoliberal critique that the public body is commonly seen as unable to deal with Grand Challenges as being to inefficient, slow, and badly equipped with skills, knowledge and financial means (Kitchin et al., 2019), and that solutions to societal, environmental, or urban challenges should rely on private, market-based approaches (Birch, 2019; Grimsey and Lewis, 2004). In line with that argumentation, smart city advocates promote their intentions to implement and test technologies to offer solutions, which presumably serve the public and provide society with the tools to work "better" – i.e. more efficient, faster, equipped with expertise, cutting-edge technology and sufficient business capital. "We aim to develop a groundbreaking plan to improve the lives of people living in Toronto and cities like it around the world," head of development, Josh Sirefman, stated the company's ambition to improve the quality of life in cities generally, taking the Quayside project as a pilot (Business Insider Deutschland, 2018). However, offering solutions to make products or services more efficient, carbon-neutral, or smart is yet quite an instrumental approach to todays societal challenges (such as energy transition) and sidelines questions that deal e.g. with the distribution and access to these products and services, which might exclude older people or less technically experienced groups of society. While several studies have discussed how the private sector increasingly interferes and performs a range of services that have traditionally been governmental tasks (Cohen, 2001; Lawrence, 1986), scholars have also pointed to its limitations in terms of public responsibility and accountability (Stewart, 1993).

If innovation automatically means privatization, then projects like Quayside Toronto become playgrounds and gateways for economic interests. Even more, these interests will shape the cities for centuries, when the intentions and goals of the architects of the future social arrangement are realized. This puts test beds into the larger circuits of techno-economic imaginaries and makes future visions drivers of market-based decision making

[25] Marc de Pape reported from his interview experiences with the company. He applied for the "Director Resident Experience Position", yet, withdrew his candidacy later as a reaction to the interview experience and observations of the first public roundtable.

(Birch, 2019) – yet, on the basis of trials and testing hypotheses instead of norms and constitutional procedure. That means it is subject to economic decision-making and market logics to decide about which and how technologies are experimented with in test beds. This form of speculation contributes to a shaping of larger patterns of economic development, in that it makes decisions about e.g. of how to deal with natural ressources (which location is deemed useful for experimentation) or in which technologies and industries to invest as a nation-state. However, these processes are largely detached from moral concerns or procedures of public participation, such as bottom-up approaches to incorporate the needs of civil society, in order of technological introductions.

Giving companies access to state-owned services and public data may further support the creation of monopolies. For companies test beds offer a unique opportunity to experiment with new ways of technology use and to collect data from these real-time tests: “This is not some random activity from our perspective. This is the culmination of almost 10 years of thinking about how technology could improve people’s lives,” the executive chair of Alphabet, Eric Schmidt, reveals long-term strategic interests in the Toronto project (Business Insider Deutschland, 2018). Through its engagement in Quayside Toronto, Google will access and own massive amounts of real time data. The data processing company will learn e.g. about the energy use, air quality, and mobility patterns of Toronto’s citizens, which will help the company to adapt its own products and services according to these valuable urban insights, or, it will decide to sell the data to other cities which aim for similar developing plans. Anyway, turning data into a competitive advantage will assure Google’s leading and monopolistic position (Coletta and Kitchin, 2017), what makes critics to predict that there might be, someday, “an enormous blowback from citizens, about these giant tech company deals” (Wired, 2018a).

Interestingly to note, tech companies only have the chance to exploy citizen’s data by partnering with local governments on a large scale. The board of Waterfront Toronto, whose members are appointed by the Government (of Canada, the Province of Ontario and the City of Toronto), unanimously agreed to work with the company to re-design the city’s neighborhood and unlocked about 40 million dollar in investment to prioritize "sustainability, affordability, mobility, and economic opportunity” (Business Insider Deutschland, 2018). For the city, the project is a unique opportunity to engage in the development of emerging technologies and to invest in economic development, when Quayside will become an innovation hub. This idea is known from the concept of "entrepreneurial cities" (Hall and Hubbard, 1998), according to which cities nurture innovation capacities with the aim to encourage local growth and competitive advantages. In order to operate as an entrepreneurial city, the public sector is increasingly taking over characteristics, which are traditonally known from the private sector, i.e. being more risk-taking, profit oriented, and competitivly positioned. While the phenomenon of "urban entrepreneurialism" has gained prominence to make sense of how the changing relations between culture and capital shape urban space almost about 30 years ago (Harvey, 1989). It yet helps to understand the distinctive modes of collaboration between public authorities (applying an entrepreneurialmode of governance) and private actors (taking over governmental tasks) that we observe in test beds.

Furthermore, once implemented test beds bear the risk to extent its scope and scale without formal legitimation**.** Only recently, Sidewalk Labs released its master plan, the latest version of its development plan, which turned out to be in effect more ambitious in scope and with significant departures from earlier plans. Original plans to move Google's Canadian headquarters to Quayside – which were accepted as they have raised hopes to revitalize economic activities and to create jobs in the neighbourhood – were significantly modified: "They've now come along and said no, we're no longer going to put the headquarters on Quayside, but we're going to put it on a different piece of land that we want," the chairman of the agency that is overseeing the Quayside Project, Stephen Diamond, stated. Instead of Quayside, the Google headquarters ought to move to Port Lands, an industrial neighbourhood, which is intended to become subject to a $1.2 billion government project. According to Sidewalk CEO Dan Doctoroff, they needed the greater scale of the port lands for their plan in order to meet revitalization, environmental and affordable housing objectives. "Their ambition is greater than a single district. It is the total re-imagining of the city, one district at a time. This is more than district redevelopment. This is product development for scaling and export." Tech entrepreneur and Toronto citizen Marc de Pape describes the purposeful blurring of product development, city development, and economic development – both, for Toronto but equally with the ambition to scale out (Pape, 2018). The relocation of the headquarter and associated development plans are further representative for an approach of piecewise takeover – or "scope creep" (Pape, 2018) – which overrides formal processes of procurement set up by the board to handle such issues. "And by the way, (they) don’t want to have to go through a procurement for that particular piece of land, because (they) want to build the Google headquarters there,” Stephen Diamond criticizes (Financial Post, 2019). What is more, the newly released master plan not only exceeds the originally envisioned territorial scope but also proposes regulatory and organisational changes, e.g. it requires a guarantee for a new light-rail transit. Critics claim that this is characteristic of how tech companies act: “There is a lawlessness to the style, and to the power moves that the tech industry does. They just kind of do stuff and then they say, ‘Oh, regulate us!’”, Bianca Wylie from the Centre for International Governance Innovation criticizes the company’s proceeding (Financial Post, 2019).

This example is illustrative of how private actors try to end-run around deliberative and often lengthy procedures. Although Toronto’s citizens were asked to comment on the master plan, they were only given relatively short time to go through the document that covers around 1.500 pages and four volumes in total (Financial Post, 2019). Ongoing concerns over public consultation processes have provoked strong public reactions and have led to the resignation and withdrawal of several projects members (The Guardian, 2018b). In her resignation letter Saadia Muzaffar criticizes the company’s information policy and the ways it has dealt with the public and the residents’ concerns so far (Muzaffar, 2018). These observations support my empirical findings, which have revealed lacks of public participation and an imbalanced representation of power in test beds. While EUREF purposeful excluded the public from its innovation campus, fenced off from its residential neighbourhood, and delineated a part of the city as experimental grounds for technology testing and demonstration; EAA aimed to integrate the diversity of local inputs by setting up a number of public forums, which however showed poor attendance by the broader public but turned out to be a gathering of stakeholders and experts.

This brings me to the final point of critique. Rather than engaging with the public, test beds interpret and instrumentalize public space and its inhabitants as private ressources and data delivery entities. As corporate interests capture public space, public goods are turned into a resource for business innovation. What I observed in my case studies and in the Toronto example, they interpret public space and public goods as valuable assets that would potentially increase in value and gain a future perspective through innovation. It emphasizes the tacit value extraction from a public that is instrumentalized as an innovation contributor, a strategic asset in a company’s business model, and test population (Birch, 2017; Tyfield et al., 2017). This business-driven approach to deal with “lost regions” (EAA), “idle former industrial areas” (EUREF), “underused resources” (Port Lands at Toronto’s Waterfront), or so called “developing cities” – e.g. in case of Colombian city Medellín becoming a laboratory for the Global South ((Talvard, 2019) – displays broader patterns of an assetization of the public sphere (Birch, 2017) and processes of collective ordering (Jasanoff, 2005; Laurent, 2016). City officials, planners or consultants “throw in” public space as experimental projects for technology development and testing. They do so striving for both, positioning the city or region as an (inter)national model (for others left behind) *and* fighting individual challenges (e.g. high unemployment and poverty rates) in that they hope to attract companies to settle down and to implement their cutting-edge technologies. To put it bluntly, in setting up test beds cities might risk becoming the extended R&D department of a company. Local residents then become part of such endeavors, utilized or monetized e.g. as data-delivering entitites[26] (Halpern et al., 2013; Marres, 2012a). This view echoes criticisms of the instrumental use of public engagement practices and unfulfilled promises of democracy talk raised by some scholars (Delvenne, 2017; Delvenne and Macq, forthcoming; Irwin and Wynne, 2003; Thorpe and Gregory, 2010; Wynne, 2001). Local inhabitants act at once as audiences and ingredients of the introduced and tested technologies and policies in test beds. As test beds are not just experiments in inanimate lab settings but are, in effect, experiments on the public that commit the latter (however tentatively) to new forms of living or working, test bed-type innovation puts democracy itself for experimentation (Laurent, 2011; Lezaun et al., 2017). Models of democracy – of social order – become co-produced and emerge through the performance of collective practices in the name of innovation.

[26] Recently, energy company E.ON has launched pilot projects promoting smart meter rollout in four selected regions all over Germany (on the islands of Fehmarn and Rügen as well as in Saxony-Anhalt and Lower Bavaria). In these designated areas several hundred customers became part of the test run, in which the customer’s energy consumption was relayed every quarter of an hour through smart metering systems E.ON (2017). The data they generate are the most valuable currency for the company. “The experience we are currently gaining as part of these pilot projects and the cooperation with municipality utilities helps us to optimize the technical performance of the devices and thus to better align the technology with the customers’ preferences,” explains Managing Director of E.ON Metering, Paul-Vincent Abs E.ON (2017).

5.2.3 Test Bed Responsibility Challenges

Instead of serving the interests of political and economic elites and experts, the question is how test beds can be re-imagined to be less expert-driven and technology-centered, but rather how they can meet expectations of becoming more inclusive in orientation and more participatory in practice. In this final sub-section of the conclusion, I will think of legal, organizational, and moral ways to render test beds and their innovation practices in a way that has been termed "responsible" (Owen et al., 2012; Schomberg, 2013; Stilgoe et al., 2013). If test beds are indeed models for future societies with reasonable chance for broader rollout, it brings to the fore a number of questions and concerns related to a responsible use of these instruments: Which accountability measures do we as a society have to prevent potentially harmful or wasteful developments of test bed innovation? How do we deal with the collectivization of risks, when private companies turn entire cities into test beds for particular technological visions? What obligations does a city and its public authorities owe its residents in terms of protection, information and participation? Who determines whether technology tests in test beds have been a success or failure; according to which criteria; and with what consequence? If large amounts of data are collected in public spaces, who will own or control these data? Would it be possible to obtain people's consent for data collected in public spaces? Or, generally, can participants, i.e. citizens and populations, even "opt out" of a test bed?

Designing test beds and governing its technologies in the public interest requires critical scholars to constructively engage with such questions that address concerns over data collection and control, privacy, security, infrastructure and economic development. My aim is not to discuss these questions in its full extent here, but to set impulses for future research that will help to better understand the governance implications when technology becomes closely intertwined with its social, cultural, and political environment in test beds. An important entry point for governing these sites is thus to improve the test bed's design and use by constructively engaging with the ways and implications of simultaneously re-configuring technology and society. Research on test beds should therefore not only look at what is tested in test beds, but engage with the "how" and "why" of its technological developments and the instrumentalization of test beds at different scales. While the "why" helps to study test beds against their wider political and economic context (I have laid down the respective challenges in the previous section), learning about "how" test beds approach innovation will qualifiy the various modes of experimentation we found in these embedded and culturally shaped settings. The two here presented case studies are an attempt to enrich discussions with insights about the ways in which test beds come into being and are reworked when they encounter and negotiate the messy realities of culture and politics. Frameworks of responsible research and innovation (RRI) have lately gained prominence (and critique) as they have put into focus such purposes of innovation, recognizing that public concern relates above all to those questions of how and why innovation happens (Stilgoe et al., 2013).

In order to think of test beds in a responsible way, scholars should scrutinize the tacit assumptions about societal needs, solvable problems, and economic opportunities undergirding the emergence of test beds and its technological choices. In case of EUREF, the campus test bed is positioning itself to offer solutions to a number of – what is framed as – societal needs. It introduces emerging technologies, such as smart grid infrastructures, self-driving cars, or energy-efficient buildings, as solutions to deal with the challenges of energy transition, sustainability, or digitalization, and which have allegedly been realized at EUREF: "the EUREF Campus has achieved Germany's climate targets for 2050 already in 2014", and "the smart city of the future – already today," are two of its most prominent slogans. Learning about test beds is thus learning about the hopes and aspirations of society, about the implicit ideas of collective futures that are envisioned to be realized through technological progress (Jasanoff and Kim, 2015). Further, the emergence of test beds constitutes a mode of figuring out for society the terms of responsibility, risk managing, liability, and accountability when bringing these aspirations into being. Jack Stilgoe has described these ways "in which society and its institutions make sense of novelty" as a "test of social learning" (Stilgoe, 2018).

This thesis has shown that test bed are simultaneously driven and challenged by their respective actor constellation and that the distribution and accomplishment of power became decisive moments. Hence, the tension between control and openness makes the question of who precisely is involved – and who decides who should be involved and how – a crucial issue for questions of responsible governance. Yet, empirical data indicates that equal contribution – of experts and "lay people"; of local and national partners; of business representatives and citizen groups – is limited in practice. Participatory formats, designed and set up by experts and dominant actors preconfigure the deliberation process and thus rather create, than consult its publics (Felt and Fochler, 2010). In the Toronto case, Sidewalk Labs has staged and managed the processes for public engagement in a way that the public as well as relevant public officials have been kept out of key consultations (Goodman and Powles, 2019). Further, how the company has (not) informed the public – a "painfully drip-fed process of public engagement" as both the terms of the collaboration between the company and public authority and the terms of the master plan were hidden for months – suggests that the envisioned smart city may be incompatible with democratic processes and sustained public governance, Ellen Goodman and Julia Powles argue (Goodman and Powles, 2019). In their view, the envisioned city of the future poses in particular three major governance challenges, or what they call "pitfalls for the public" (Goodman and Powles, 2019); privatization, platformization, and domination, which create power asymmetries and a centralization of control. These observations are however not specific to the Toronto case, but also showed up in my case study research. Although national EAA actors have set up a number of citizen conferences, this has prevented neither from a deep mistrust between local and national actors, nor from a perceived imbalance of power, as local actors articulated fears of serving as "guinea pigs". What could be possible ways and reasonable measures out of this dilemma?

First, citizens should not be invited for dialoque at occasional times or for particular decisions when needed, but should be involved in test beds on a steady, institutionalized basis from the very beginning. The institutional distribution of power could be realized e.g. through the implementation of citizen advisory boards in order to insert local knowledge and concerns, to watch over planning and decision-making procedures, and to represent the views of often marginalized groups. Second, learning from test beds requires scholars but also policy and economic actors to bear in mind the problems these initiatives are imagined to serve and the contexts they are inevitably embedded in. In contrast of thinking of "The Public" as an entity or static collective, test beds have the quality to form around particular matters of concern and to speak to the needs of various publics, which might be changing and form as, what Sheila Jasanoff has called, "issue-oriented publics" (Jasanoff, 2014). Third, my research has proved evidence that it is worth for social science scholars to look at what happens next to the big stage of organized dialoque processes and to the history of collaborations. For example, in case of EAA some actors hold strong ties to local green movements and initiatives with which they have already collaborated before the test bed has been offically set up (in form of research projects, single events or business initiatives). In order to increase trust and responsiveness, engaging in test beds should therefore build on these (more or less strong) ties and continue what has already been achieved. Collaboration in test beds should base on a mutual unterstanding and appreciation to recalibrate the relations between experts and citizens, but also between experts from different disciplines and training backgrounds. This implicates that meaningful engagement exercises might open up further areas of dissensus and that they can even generate questions about trust (Stilgoe et al., 2014) – which should yet be put on the table. Fourth, the tools and instruments that are envisaged to inform and engage citizens are to be chosen thoughtfully. For example, national EAA actors have set up a Twitter account that informs about the test bed's activities, what some local actors have condemned as superficial and inappropriate to engage with the region's "real people" (quoted from my interviews) – and which was, in effect, rather used to link local test bed activities with the macropolitics and its advocates at the level of national policy-making.

Exclusion may not only be caused by the choices of selective information technologies, but from actual physical borders. Test bed innovation risks to create new forms of exclusion if (physical) barriers are drawn based on particular imaginations of what should be a critical, representative set-up in order to test technologies. In case of EUREF and EAA, public space is demarcated contingent on its objects of research and testing (a campus within an urban distcrict; a regional territory) which creates sub-populations of vanguards for a presumably "better" way of living on the one side, and with others left behind on the other.

This brings us to critically consider the creation and exploitation of "test populations". As some test beds are experimenting not just in public with the public, but *on* the public as subjects of research within new sociotechnical arrangements, in the end, a responsible use of test bed-type innovation might require new consent procedures. Otherwise, applying the dominant mantra of co-creation, interpretations of what an active partner and what an object of investigation is, might vanish. Obtaining consent from those who are affected (because they are residents in the neighbourhood, customers of the particular service or users of the technology under test) would then be a way to acknowledge the legal and moral differences between experimenters, test-subjects, consumers, and citizens. Furthermore, a consent procedure would not only acknowledge differences but would also allow setting rights and obligations for the different groups. Clear rules could e.g. define which data to collect and how to prevent a misuse of individual data, or they could set common procedures of how to collectively decide upon important questions (such as which technologies to implement, at which scale, and according to which criteria assesing its performance). They could also formulate the possibility or the conditions for opting out of the test bed. However, it remains a question of legal examination and research if there are in fact reasonable ways to "opt out" of using public spaces – or, if people who decline to be part of a test bed have to consider certain public spaces off limits.

This latter aspect becomes very concrete when we think of common procedures of data collection in public spaces. Taking again Toronto's Quayside as an example, Sidewalk Labs proposes to make available much of the data collected in parks and streets, as well as data from publicly accessible private spaces like building courtyards and stores (Sidewalk Labs, 2019; The Conversation, 2019) – information that might relate to an identifiable individual. If data is made publicly accessible to everyone, it however privileges companies that have the tools to store, analyze and use the data, and disadvantages those who do not. Associated visions of the "city as a plattform" for digital applications and services enact forms of intellectual property ownership and data control. Those are in the responsibility of the designers and coders who then become the architects of future societies, as the "digital layer runs through, under, and around the 'physical layer' of the built environment" (Buocz et al., 2019; Goodman and Powles, 2019). That means, whoever controls the city's "digital layer" has also control over the activities – i.e. everyday life activities – which are encoded in that layer (Goodman and Powles, 2019). As long as private companies take over this role, control is exerted according to commercial interest and without public legitimation. Therefore, in order to enhance a responsible use, public data should be, first, collected according principles of necessity and reasonableness. Second, it should be controlled and harnessed by the public (or it representatives) and in public interest, defying market logics of efficiency, optimization or commercialization.

Expectations of scalability raise another challenge of a responsible use of test beds. If test beds serve less as tests than as demonstrators of successful political action and social transformation, it is crucial to ask whether test beds can indeed fail, and what could be appropriate criteria to determine success or failure. If taken seriously, test beds performances would have critical implications for political accountability, further business investments, and scientific rigor alike. My research suggests that definitions of success/failure differ as much as expectations and visions do. More likely than a collective admission of failure, initiatives find ways of justifications and may simply morph into new initiatives or be re-interpreted according to new criteria. In case of EAA, actors repeatedly stressed that each outcome counts as success as it has contributed to learn about bugs and shortcomings – not only technically but also in regard of collaboration experiences. This is a popular strategy of justification not only towards the test bed's consortium, but also towards the funding foundation and policy representatives. In none of my case studies, actors have discussed (not even theoretically) the option to roll-back technology if it has not performed as expected. I suggest that a resonsible use of test beds inevitably requires to take failure, i.e. not passing the test, as a serious option. Then, consequences must include the modification or even roll-back of particular technologies or services, if these did not comply with rules and standards that have been collectively negotiated and defined.

Finally, test beds could also facilitate a more experimental and responsive approach to the regulation of emerging technologies. Speaking to the STS insight that the law is always imminent in innovation decisions and at the same time co-produced (Jasanoff, 2004), in test beds this co-productionist relation between innovation and regulation may come to the fore. This would allow to overcome the common perception that regulation is slow-moving and tends to follow market developments instead of shaping them. The widespread understanding of regulation as a tool for damage control to technology's unintended side effects or unforseen upheavals might be shifting towards a more active role of government regulation in shaping technological systems and the social environments hand in hand. There is a potential of test beds to develop regulatory frameworks in tandem with technology and policy frameworks and along collectively deliberated new rules and regulation. That means, existing regulation in test beds should neither be put on hold nor be excluded seen as a barrier to innovation (what is kind of the idea of special economic zones or experimental clauses). Rather, an optimistic understanding and use of test beds should emphasize regulation as a social shaping of innovation instead of managing potential harmful technologies (Jasanoff, 2007) in that it accomodates public interests, ethical standards and responsive flexibility, e.g. through the implementation of smaller governance forums in which local participants can engage in setting rules and regulations.

6 EPILOGUE

Test beds have become an emerging instrument of innovation policy and governance in contemporary innovation-driven societies – and a matter for democracy. How public authorities and private companies engage in making future(s) through the articulation and exploitation of experimental practices reveals common patterns of the political and economic reordering of society. Through their approach of testing new technologies and its undergirding visions of future societies surrounding such technologies, test beds deliberately intervene into social order. Society becomes the object of active reconfiguration and control for the sake of testing prototypical miniature societies that may or may not serve as truthful representations of a future society-at-large, while stabilizing the very innovations-in-use that ought to bring about this envisioned society.

These sites thus tell us about our world and the choices we make for our future, what we as a society envision to be desirable, possible, and viable – and what is not. We can learn about the motives why and in which ways societies want to know about certain dimensions of sociotechnical changes and not about others. These choices touch not only the ways we understand and see new and emerging technologies, but further, the aesthetics of our living environment, meanings of citizenship, the role of the state vis-à-vis private actors, or cultures of knowledge making (Halpern et al., 2013; Jasanoff, 2004). In how these sites co-produce innovation and its social, cultural, and political environment, they are at the same time a "rehearsal of our future and an archive of our past" (Halpern et al., 2013).

Empirical studies make us aware that these localized experiments are above all contested, situated, and culturally shaped. The observation that idealized visions and practical implementation may clash when entering cultural grounds speaks to the necessity of research that looks exactly at the processes of translation and (re-)alignment between the local and the global, between vanguard visions and sociotechnical imaginaries, and between the past and the future in societal transitions. Assuming that the objective of test beds is to release and scale innovation from a local version onto society at large inevitably requires us further to think about the scalability of this co-productionist relation.

My research strongly supports the core STS insight that what is at stake in innovation is in fact social order. These experiments are the playgrounds on which democratic orders are stretched, scrutinized, risked and potentially reinforced – and social scientists are (or should be) in the position to expose, question and discuss these processes and the role of knowledge, power, and politics in it. We need to unravel the norms, values, methods, cultures and logics that give rise to these future-oriented practices (Selin and Guimaraes Pereira, 2013), and which are eventually shaping our future. This is even more important if these processes go unacknowledged and offside a broader public debate and accountability. Experimental sites bear the risk to become new political spaces for unregulated power play when decisions about collective order are to be displaced from public to more or less confined arenas in which experts and stakeholders negotiate the future (Bulkeley and Castán Broto, 2013; Voß and Schroth, 2018).

Finally, smart city test beds such as Quayside Toronto give us a taste that, in future, it will be the rationalities of digitalization and algorithms that further challenge the relation between science, technology, and society as they will redefine our identity, ways of knowing, and rights by using large sets of data. In a digitalized world, which is yet to come in full swing, control over data may lead to privatization of policy- and lawmaking, rendering citizens as valuable data sources and monitored objects under constant surveillance[27]. Governance by experiments and by algorithms hold potentials not yet exploited – for good or ill – and not yet fully understood. China's social credit system[28], a national reputation scoring system for Chinese citizens with several pilots currently under experimentation, states an example of what is possible if technological opportunities fall onto fertile ground. Issues

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[27] Following a global logic of data and technology driven innovation, Korean city Songdo, the smart city built from scratch and designated by the Korean government to create an international business center and to attract foreign investments, serves as another prominent example of a purposeful created, replicable city, which is a "protocol of a global infrastructure of information and economy" (Halpern et al. (2013). Coined as the "ubiquitous city" Songdo stands for a new era of cities in which computers are physically integrated into built infrastructure like buildings or streets. This smart infrastructure is expected to tell citizens about real-time traffic flows and expected times of bus arrivals, but may also inform public authorities about a crime taking place. The city is thus envisioned as a "physical incarnation of an immense cloud of big data" Halpern et al. (2013), in which data is massively generated, interconnected, circulated and analyzed according to a wide range of uses and interests.

[28] In fact, China's social credit system is not a single system nationally coordinated. Instead local governments have different social credit systems in which they collaborate and exchange data with private companies. It was launched in 2014 and is supposed to be rolled out nationwide by 2020. Technologies like facial recognition, video surveillance, drones and apps deliver data to rate citizens and, depending on the performance lead to benefits (like no-deposit bike rental) or punishments (like being banned from buying a train ticket). The goal is to create a searchable file of every Chinese citizen of amalgamated data from public and private sources tracking their social credit. As well as tracking and rating individuals, it also encompasses businesses and government officials (Wired (2018b).

such as technology-enabled datafication of citizenship, social sorting, or surveillance (Greenfield, 2013; Isin and Ruppert, 2015; Kitchin, 2015) once more disclose ethical dilemmas of what is possible and what is desirable. Over both the possibilities and desirabilities, it is for us as individuals and as society to decide and to set the rules and boundaries for collective experimentations.

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ANNEX

SUMMARIES OF THE ARTICLES AND INDIVIDUAL CONTRIBUTION

ARTICLE 1

Franziska Engels, Sebastian Pfotenhauer & Alexander Wentland: "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.

Contribution Franziska Engels: I have contributed to this article by co-conceptualizing its idea and design, being in close and permanent contact with my supervisor Sebastian Pfotenhauer and my colleague Alexander Wentland, who are both co-authoring this paper. I was further responsible for conducting and analyzing the empirical data of the two case studies. Being closely engaged with the data, I have substantially contributed to the paper's overall framework and its line of argumentation.

ARTICLE 2

Franziska Engels, Anna Verena Münch & Dagmar Simon: "One site – multiple visions. Visioneering between contrasting actors´ perspectives"

Publication: Engels, F./Münch, AV/Simon, D. (2017): One site – multiple visions. Visioneering between contrasting actors´ perspectives, *NanoEthics,* Special Issue "Visioneering sociotechnical innovations: The making of visions", 11(1), 59-74. DOI 10.1007/s11569-017-0290-9

ABSTRACT

Visions of and narratives about the future energy system influence the actual creation of innovations and are thus accompanying the current energy transition. Particularly in times of change and uncertainty, visions gain crucial relevance: imagining possible futures impacts the current social reality by both creating certain spaces of action and shaping technical artifacts. However, different actors may express divergent visions of the future energy system and its implementation. Looking at a particular innovation site involving multiple stakeholders over an eight-year period, we empirically analyze the collective negotiation process of vision making, its shifting over time, and how visions eventually unfold performativity. Adopting a process perspective, we identify four different phases and the respective functions of visions and visioneering related to the site's development by exploring the question: Why do certain visions gain importance and eventually lead to substantial changes of the project in process? Qualitative data from documents and interviews analyzed with reference to science and technology studies show the interweaving conditions that influence the visioneering and the linkage to the actual development of material artifacts. Against the backdrop of innovation projects, this paper explores visioneering as an ongoing, transformative and collective process and reveals its moments of (de)stabilization.

Contribution Franziska Engels: As the main author, I substantially contributed to this article by conceiving its outline and design. I have co-written several parts of it, in particular the introduction, theoretical discussion and conclusion section. I further designed the methodological approach of the case study and conducted the empirical data with my colleague Anna Verena Münch. Together with my co-authors, we analyzed the set of qualitative data, including interviews, observations and documents.

ARTICLE 3

Franziska Engels & Anna Verena Münch: The smart grid as a materialized imaginary

Publication: Engels, F./Münch, A. V. (2015): The smart grid as a materialized imaginary, *Energy Research & Social Science*, Special Issue "Smart Grid and Social Sciences", 9, 35-42. Doi 10.1016/j.erss.2015.08.024.

ABSTRACT

In technical terms, a micro smart grid is one solution for future energy supply from renewable energy sources with the aid of information technology. However, it also symbolises the idea of a transformation into a low-carbon, non-fossil-fuel society. This paper analyses that the micro smart grid works as a sociotechnical imaginary and boundary object across a specific actor constellation with plural backgrounds, interests and perspectives. Empirical data has been gathered for this study from an urban innovation campus in Germany, an ascribed living lab for innovation and research that represents an especially designated place combined with spatially embedded visions of the future city and energy system. Here the micro smart grid imaginary is closely interlinked with the place and becomes materialised: It is argued that despite the micro smart grid's incomplete status in terms of technical advancement and reliability, the imaginary already generates cooperation and commitment across actor groups and sectors. The place provides a shared, protected experimental space as well as boundary objects, thus, first, enabling the actors to cope with the perceived uncertainty in the transition process. Second, it fosters innovation, new business models and forms of cooperation, and thereby, third, contributes to the energy system transformation.

Contribution Franziska Engels: I significantly contributed to the production of this article by conceiving its idea and structure. In collaboration with my colleague and project partner Anna Verena Münch, I organized and managed the interview study and also conceptualized its analysis. As the corresponding author, I was also the main contact to take care of the review process and to revise the paper according to the received feedback.

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