II. Future work

After entering the *Albert Einstein Science Park*, I pass by several buildings of the GFZ, the canteen and kindergarten shared by all institutes. On the top of the hill, I walk by the imposing main building of the Potsdam Institute and step into the woods again. After about 50 meters, one can differentiate between the fabric of the forest and another structure built by humans – the newest building on the Telegrafenberg, adequately referred to as the *House in the Woods.*

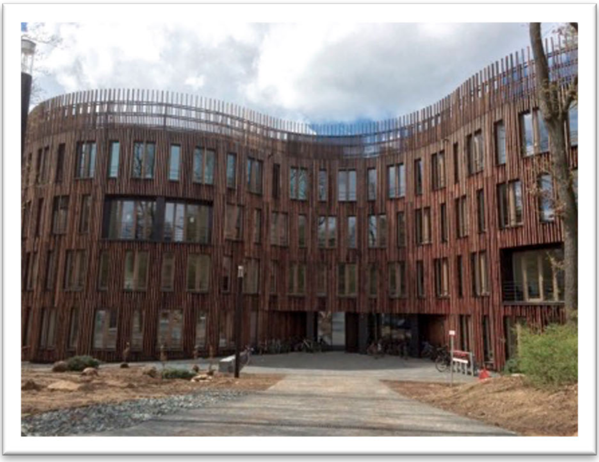

Figure 10: The House in the Woods. Source: Own photo

At the time of my first arrival, the building was in its last stage of finalization and the smell of the recently painted walls was still filling the air. Considering that the house was not completely occupied by PIK staff, I generously received my own office on the second floor of the 'Earth Wing.' The cloverleaf form, the wooden façade, the tortuous inside and the illustrious designations (e.g. 'Heaven Wing,' meeting room 'Africa') evoke a spiritual feeling between anthroposophist and Silicon Valley aesthetics. The building does not only fit well into its environment – it is a materialized model for the way we ought to build, work and live in the future. This representation of a sustainable future becomes visible prior to entering the building or even looking at the façade. The front yard of A56 is marked by an immense bicycle parking space and construction, complemented by a small parking lot for electric vehicles.

Figure 11: The front of A56 with the parking area for bikes (left) and electric cars (right). Source: Own photo

On my first day at the PIK, scientist Tim Neitzel kindly welcomed me at the House in the Woods. The PIK scientists had just moved from one of the remaining constructions of the GDR era to their brand-new office building, the latest architectural addition to the science park. I received my own office, which happened to be the 'model office.' Furnished by an architectural agency, it simulates the typical equipment of a scientist. Accordingly, I found myself in the strange position of a model researcher in a model office investigating the culture of modeling work.

About climate change/research

Characterizations of climate change fill countless books and take many forms. Climate scientists usually understand climate as 'averaged weather,' as can be illustrated by the following definition by the World Meteorological Organization:

> Climate in a narrow sense is usually defined as the 'average weather,' or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. [16]

Such averaged weather patterns may change due to natural variability ("climate variability") or – increasingly the case – because of human activities ("climate change"):

> 'Climate change' means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. (United Nations 1992)

16 WMO website: http://www.wmo.int/pages/prog/wcp/ccl/faq/faq_doc_en.html, retrieved on April 23, 2019.

This characterization by the United Nations Framework Convention on Climate Change (UNFCCC) from the year 1992 points us to another aspect of climate change as a concept – its intrinsically political nature. This consideration of the political consequences of human-made climate change (a pleonasm, so to say) had already been established as early as 1979, when the Charney report (Charney et al. 1979) provided the first comprehensive assessment of global climate change triggered by increasing carbon dioxide (CO_2) emissions. As Gabriele Gramelsberger and Johann Feichter have shown, the report transformed climate change into a public policy issue, “interlinking climate science and politics by establishing a growing number of international research programs, conferences, WGs, intergovernmental panels, and committees” (2011: 2). Since then, a multitude of activities have been conducted and various institutional organisms established to smoothen the interface between science and policy, most prominently represented by the establishment of the IPCC in 1988. The dominant way conceptualizing science-policy-society interfaces through the vehicle of the IPCC has been described and criticized by a variety of actors, including authors in science and technology studies (Hulme/Mahony 2010; Shackley/Skodvin 1995; Yearley 2009). Among other things, these authors called attention to the strong disciplinary bias of the IPCC towards the natural sciences,[17] and the virtual absence of accounts from interpretative social sciences. Accordingly, Steven Yearley has argued that

> […] the focus of analyses of the debate over climate change has – understandably– been fixed on the natural scientific aspects of the issue as represented in models of the climate, oceans and atmosphere operated by scientists associated with the IPCC (Intergovernmental Panel on Climate Change) and others. […] This orientation has led to a neglect of the importance of the ways that economic and social scientific aspects of global warming have

17 The only social science discipline marginally represented within IPCC reports has long been (macro-)economics.

> entered into the business of forecasting, understanding and trying to manage the changing climate. I thus propose to set out and exemplify the case for refocusing attention on to the social science aspects of climate change. (Yearley 2009: 390)

This critique widely shared within the social sciences gave way to numerous studies on the social and cultural aspects of climate change within the last dozen years. These studies explored how people locally make sense of global climate change (Barnes/Dove 2015; Hulme 2016; Jasanoff 2010; Krauss/von Storch 2012), mapped the controversies, inactions and opportunities linked to global warming (Hulme 2009; Storch/Krauß 2013), and specifically focused on the aspects of futurity and invisibility (Doyle 2009; Nicholson-Cole 2005). Building on such new, more culturally grounded understandings of climate change, communication and media studies have established 'climate change communication' as a new distinctive field, taking into account the particularities of climate change for human cognition and sense-making (Moser/Dilling 2007; Neverla 2012; Schneider/Nocke 2014; Sheppard 2012). The *Anthropocene* is a concept which enabled the interment of some of the disciplinary science wars fought around climate change (Crutzen 2006; Steffen et al. 2011):

> The term Anthropocene suggests: (i) that the Earth is now moving out of its current geological epoch, called the Holocene and (ii) that human activity is largely responsible for this exit from the Holocene, that is, that humankind has become a global geological force in its own right. Since its introduction, the term Anthropocene has become widely accepted in the global change research community, and is now occasionally mentioned in articles in popular media on climate change or other global environmental issues. (Steffen et al. 2011: 843)

The Anthropocene concept, since its evocation by climate scientist Paul Crutzen and others, has been key to establishing a new thinking about climate change, enabling more holistic views of human-environment relationships and climate change in particular.[18] Recent achievements incorporating such broader perspectives are reflected in the idea of *planetary boundaries*:

> Since the Industrial Revolution, a new era has arisen, the Anthropocene, in which human actions have become the main driver of global environmental change. This could see human activities push the Earth system outside the stable environmental state of the Holocene, with consequences that are detrimental or even catastrophic for large parts of the world. […] To meet the challenge of maintaining the Holocene state, we propose a framework based on 'planetary boundaries.' These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. (Rockström et al. 2009: 472)

The planetary boundaries concept has been developed by a group of interdisciplinary scientists, which include several leading figures of the PIK, such as Hans Joachim Schellnhuber (former director) and Johan Rockström (acting director). The aim of the concept is to 'close the loop' between human and environmental dynamics and integrate all relevant relationships into the methodological framework of Earth System Science (Donges et al. 2017; Schellnhuber/Wenzel 1998). The way to handle such cybernetic integration is to formalize, represent and operationalize them in simulation models. Such dynamic simulations can then be used to 'run into the future,'[19] enabling statements about future risks and to propose modes of steering into more sustainable ways of living.

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18 While the Anthropocene concept has been able to assemble researchers from the natural sciences, the social sciences and the humanities, it has also fueled new controversies. Among other things, it has been argued that the Anthropocene as a cybernetic concept helped to break the taboo of climate engineering as a solution to the climate crisis (Asayama et al. 2019).

19 A figure of speech in the community of simulation modelers. See, for example, https://bonnsustainabilityportal.de/de/2019/06/fona-erwarmung-der-arktis-fuhrt-zu-wetterextremen-in-unseren-breiten-awi-forscher-entwickeln-

Climate modeling and simulation

Simulation modeling has long been established and represented as the fundamental organizing principle for the global epistemic community that surrounds the climate change issue (Edwards 2001: 34; Sundberg 2007: 473). Accordingly, computer models, simulations and the scientific practices around them have been a recurrent theme in academic fields, such as science studies, STS, and the philosophy, sociology and anthropology of science. A rich literature in STS and the philosophy of science is available addressing epistemic and representational issues regarding climate models and simulations (Gramelsberger 2008a; Pias 2008; Winsberg 2010) and to computer models in general (Sismondo 1999). Along this thread, Gabriele Gramelsberger characterizes the relationship between fish in the ocean and simulated fish in a simulated ocean concisely as follows:

> But these fishes are to be enjoyed with caution, they cannot be angled. You would not even see them if you were diving in the simulated ocean, because neither the ocean nor the shrimp exist in the form we know. Rather, they are semiotic objects, all of which are mathematical in nature and subject to an unimaginable logic and purely functional point of view. (Gramelsberger 2008b: 84, translated by the author)

Gramelsberger and others have aptly characterized the way scientists have translated the world into mathematical models and simulations. Equally, a number of authors have characterized the way computer modelers understand and deal with these complex relationships between models and realities; in climate research (Lahsen 2005; Sundberg 2008) and beyond (Leonardi 2012; Turkle 2009). Many of these accounts have observed a "lure of the virtual" (Bailey et al. 2012) in simulation work – the situation when actors become immersed in their

klimamodell-das-den-schwachelnden-jetstream-erklart/, retrieved on May 3, 2019.

virtual worlds and have trouble to distance themselves from their mathematical representations of reality. Myanna Lahsen, for example, contends that "Critical distance is […] difficult to maintain when scientists spend the vast majority of their time producing and studying simulations, rather than less mediated empirical representations" (Lahsen 2005: 908), and a modeler "explained the difficulty of distinguishing a model from nature […]" (ibid.: 909).

While I have personally witnessed several such situations of the "lure of the virtual," the relationship between modelers and their simulations at Potsdam Institute differs to some extent from Gramelsberger's and Lahsen's observations. As a matter of fact, I found the scientists surprisingly conscious and reflective about the limits of models in representing phenomena. This difference between my observations and those described in existing literature may be explained by different circumstances: The 2000s was the time when STS scholars and philosophers of science became particularly interested in climate simulation. Climate science had been characterized as the new lead discipline for the dawning age of simulation-driven science (Gramelsberger 2008a: 105). Climate modeling became a focus of newly established research programs in the social sciences and humanities: In Germany, for example, the scientific network *Atmosphere & Algorithms*[20] and the Institute for Advanced Study in *Media Cultures of Computer Simulation.*[21] One reason for this interest in the 'social' and the 'cultural' in climate simulation was that these models became literally overwhelming. The spatial resolutions of the models improved significantly, the phenomena represented became ever more diverse and universal, and its political anchoring and backing increasingly powerful. The 4th assessment report

20 https://www.geisteswissenschaften.fu-berlin.de/en/v/atmosphere-algorithms/index.html, retrieved on April 3, 2019.

21 https://www.leuphana.de/en/dfg-programme/mecs/about-mecs.html, retrieved on April 3, 2019.

of the IPCC published in 2007 introduced the visual representations of climate simulations into mainstream media (Mahony/Hulme 2014; Schneider 2012; Schneider/Nocke 2014; Walsh 2014). This body of literature mostly investigated the making of global models, which then became a matter of collective work distributed between countless scientists and infrastructures. These models were all-embracing. Many scientific careers were built and maintained accompanying the life of these models. Scientists spent many years with one global climate model, or rather the representation of a particular aspect within one model. This overlap of a model with one's daily practice and reputation produced risks of immersion into one's own virtual creation.

In fact, this differs considerably from the scientific practice witnessed during my fieldwork at the Potsdam Institute. On the one hand, its scientists work mostly on different models and projects simultaneously. Impact models are relatively small and simple compared to global climate models. As a result, the possibilities and dangers of immersion seem relatively small. On the other hand, the scientists at PIK spend a considerable time with representational work, rather than just writing computer code. Given the increasing social, economic and political relevance attributed to climate research, the scientists have become professional mediators of their work. They have become open scientists, in the sense of a professionalization of representational practice. Regarding the analysis of work at the boundaries of traditional science, it is not useful to treat discretized computer worlds as isolated from the everyday scientific practice of their producers, users and stakeholders. As Cornelius Schubert has argued,

> social performativity might actually have a larger impact on the creation of societal futures than epistemic performativity itself, because it is the social processes of legitimation and justification in which – in a pragmatist sense – the predictions are *'made true.'* (Schubert 2015: 5)

As will be shown throughout this study, it seems convenient to investigate the social performativity of climate impact predictions as a mutual configuration of analog and digital practices within an entanglement of sociotechnical infrastructures. At times, everything seemed permeable and fluid in this world – the facts and artifacts, the communities and social worlds, and the technologies and infrastructures. However, this perceived fluidity may be more of a consequence of our human sensorium and our investigative practices as researchers than of the phenomena themselves. Perhaps, we just need different eyes to look at things.

Simulating climate futures in Germany

I had the status of a visiting scientist at research domain (RD) IV addressing '*Transdisciplinary Concepts and Methods'* in my one-year fieldwork at the PIK. At the time, the domain was an assemblage for researchers and research subjects that did not fit into the other three research domains. This included fundamental research on nonlinear physics, cross-sector activities, such as visualization methods and tools, sociological research and transfer projects developed together with external partners. Accordingly, the annual meeting of the research domain was referred to as 'chaos days,'[22] which has been an apt characterization for the event. The research domain and its annual meeting have now been rebranded as 'complexity science' and 'complexity days.' It seems that researchers have found a way to achieve a disciplined lack of clarity, as John Law put it: "Clarity doesn't help. Disciplined lack of clarity, this may be what we need" (Law 2007: 2). As a matter of fact, this might be an apt description for all endeavors of interdisciplinary and transdisciplinary research, including Earth System Analysis (ESA) and media ethnography. Against this background, the present chapter is a dialogue between climate impact research (research object) and ethnography (method, theory) on tactics aiming at such a disciplined

22 'Chaos days' is the name of an annual punk gathering in Germany.

lack of clarity. It discusses ways of gaining access to, producing data about, and being able to analyze and describe a field of interest. In the case of the PIK, this field of interest is the future with climate change. Within my own research, it is the practice of describing such futures. In both cases, it should be highlighted that the description of the field is a matter of co-construction. In the case of research at the PIK, this translates to a cautious consideration of the epistemic status of models and simulations, which are not to be confused with true representations of a (future) reality. As Sergio Sismondo has rightly put it:

> Whereas theories, like local claims, can be true or false, models and simulations are typically seen in more pragmatic terms, being more or less useful, rather than more or less true. (1999: 247)

This reservation regarding the status of truth in computer simulations is well established at the PIK. The cautious characterization of predictive statements can be illustrated by a seminal scientific paper co-authored by the PIK researchers which describes future scenarios as follows:

> Socio-economic and emission scenarios are used in climate research to provide plausible descriptions of how the future may evolve with respect to a range of variables including socio-economic change, technological change, energy and land use, and emissions of greenhouse gases and air pollutants. (van Vuuren et al. 2011: 6)

Quantitative scenarios have been the primary vehicle for climate research since the 1990s to describe such plausible descriptions of futures.

Regarding the case of contemporary ethnography, the anthropologists Akhil Gupta and James Ferguson have highlighted that its purpose is not to describe the characteristics of a *bounded field* as a representation of a certain reality but rather to investigate *shifting locations* by means of observation, reflexivity and intervention (1997: 138). These shifting locations equally include those of the elements identified within the fieldwork and the position of the researcher (Haraway 1988; Rose 1997). Accordingly, the aim here is not to draw a complete image of the predictive practices at the PIK but to discuss a collage of selected impressions and highlight possible methodological access points for media ethnography. In so doing, the characterization aims at grasping crucial aspects of futurework (Fine 2007: 102) at the PIK: Its heterogeneity and constant alteration, paralleled with a quest for stabilization and harmonious representation.

An idioculture of futurework

Based at RD IV, I had an opportunity to move freely between different research groups and to be fairly independent of the more disciplined agendas and working routines at the rest of the institute. When I entered the PIK, I was particularly interested in figuring out how researchers at this specific location are able to produce scenarios about the future with climate change. While such knowledge about the future is not the only matter of concern for the institute, it is certainly its specialty and the origin of its reputation. The PIK's idioculture is one of futurework. The sociologist Gary Alan Fine has coined the term "idioculture" for the way a setting of cultural elements defines how members of a community interact with each other at work or generally in life:

> Idioculture consists of a system of knowledge, beliefs, behaviors, and customs shared by members of an interacting group to which members can refer and employ as the basis of further interaction. (1979: 734)

Fine has conducted a number of fascinating studies of idiocultures, including those in little league baseball teams (ibid.), fantasy role-playing communities (Fine 2002), meteorologists (Fine 2007) and restaurant workers (Fine 2008). The study on Chicago-based meteorologists, *Authors of the Storm: Meteorologists and the Culture of Prediction* (Fine 2007), is especially relevant in the context of this study on climate modelers. As Fine argues, different idiocultures of work are occupied with different temporalities. Some jobs are dealing with the temporalities of the past (e.g. librarians, historians, archeologists), many have a strong connection to the present (care workers, news journalists) and some have a deeper relationship with the future.

> […] a few are given the assignment of looking forward, such as physicians, financial planners, fortune-tellers, pollsters, and, here, meteorologists. They engage in futurework. (ibid.: 102)

This does not mean that futurework can discard the past and present, only that these temporalities are interpreted towards a definition of the future:

> These boundaries are not hard and fast, but a matter of emphasis. A police detective might be charged with determining the location at which an arrest can be made or may be asked whether a criminal is likely to strike again; the car salesman, about a repair history of a vehicle or the likelihood of a car needing repairs in the future; the internist may be asked about the meanings of past symptoms, current medical interventions, as well as the patient's prognosis. (ibid.: 102)

Fine's analysis inspired an international network of interdisciplinary researchers[23] to think about distinct cultures of prediction in climate modeling. The anthology *Cultures of Prediction in Atmospheric and Climate Science,* the principal outcome of the research network, aims at offering a "broadened framework of cultures of prediction to describe and better understand postwar predictive efforts based on computer simulation" (Heymann et al. 2017: 19) The articles cover topics such

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23 Atmosphere & algorithms, a scientific network funded by the DFG German Research Community (2010–2012). https://www.geisteswissenschaften.fu-berlin.de/en/v/atmosphere-algorithms/index.html, retrieved on April 19, 2019.

as the transformation of climate models from heuristic to political instruments (Heymann/Hundebøl 2017), the downscaling of global climate models to the local level (Mahony 2017) and the visual semantics of the future in climate change imagery (Schneider 2017). Building on these case studies, the editors of the anthology highlight a number of key characteristics that drive predictive practice in climate research more generally. These include the important social role of the predictions, the character and significance of computational practices, the domestication of uncertainty, the degree of institutionalization and professionalization of predictive expertise, and the cultural impact of predictive practices and claims (Heymann et al. 2017: 20). However, the case studies of the anthology also show how idiocultures of prediction differ from place to place and from situation to situation. In the following, I will discuss some aspects that differentiate the predictive culture and practice at the PIK from those of other places and actors in the field of climate research.

Towards Earth System Analysis

In the case of the Potsdam Institute, the specialization in futurework has been an essential component of its institutional design. We can identify some of the characteristics of this 'futurework by design' by going through a conceptual anthology *Earth System Analysis: Integrating Science for Sustainability* published by PIK director Hans Joachim Schellnhuber and others in 1998. In the introduction to the anthology, the editors Hans Joachim Schellnhuber and Volker Wenzel outline the ingredients of ESA, as a "science *in statu nascendi*," having

> 1. a genuine subject, namely the total Earth in the sense of a fragile and "gullible" dynamic system,
>
> 2. a genuine methodology, namely transdisciplinary systems analysis based on, i.a., planetary monitoring, global modelling and simulation,

> 3. a genuine purpose, namely the satisfactory (or at least tolerable) coevolution of the ecosphere and the anthroposphere (vulgo: Sustainable Development) in the times of Global Change and beyond. (Schellnhuber/Wenzel 1998: vii)

The editors also reflected on the process of scientific innovation in a broader sense, including the obligatory reference to Thomas Kuhn and his paradigm shifts:

> Employing T. Kuhn's all too popular epistemological theory, we have to search for a generating paradigm shift as triggered by some "experimentis crucis", a major historical event, certain revolutionary technological developments, or the like. (ibid.: viii)

The rhetoric artfully plays with temporalities, considering the paradigm shift towards ESA as a realized event in the past, thereby confirming its existence and relevance. For the authors, the birth of ESA is triggered by the "co-operation" of three crucial factors: Firstly, "the race for the Moon created the opportunity to observe planet Earth from space with sophisticated equipment" (ibid.), which made ESA "conceivable." Secondly, ESA became "feasible" through

> the advent of electronic super-computers established the technological platform for sufficiently fast and comprehensive global simulation modelling based on adequate management of the plethora of now available monitoring data. (ibid.)

Thirdly, the discovery of the ozone hole confronted the international community "with the evidence that humanity can and, in fact, is about to transform the character of the global environment," (ibid.) thereby, making ESA "mandatory." The main part of Schellnhubers conceptualization focuses on the element of technical 'feasibility,' emphasizing the role of computers and simulation experiments in ESA:

> the advent of sophisticated parallel computer hard- and software [...] in combination with recent progress made in scientific modelling of complex systems might allow the establishment of *virtual impact laboratories.* Renewable artificial Earth systems could be exposed there to various simulated crash scenarios in order to study the potential consequences. As a matter of fact, these cyberspace experiments should be the most powerful tool for generating entire ensembles of assessments within a reasonable stretch of time. (Schellnhuber 1998: 8, emphasis in original)

Schellnhuber acknowledges the origin of computer simulation in military contexts and advocates for further repurposing of these technologies for the social good: "Why shouldn't we make full use of the knowledge and methods involved for less destructive purposes like the preservation of our environment?" (ibid.: 133) The text particularly demonstrates Schellnhuber's focus on what-if thought experiments and engagements with the future. Accordingly, he describes the challenge of climatic change with an analogy of a predicted meteor collision and its impacts on Earth:

> Imagine ... that astronomers were warning us of a huge asteroid heading towards our planet. The collision was supposed to occur in some twenty years from now, but neither the date of the impact nor its site could be predicted with satisfactory precision at this point in time. From the already available approximate knowledge of the celestial maverick's mass and orbital parameters it could be inferred, however, that the collision energy would correspond to an explosion of at least 10 gigatons of TNT. (ibid.: 5)

Schellnhuber elaborates on questions regarding the probability of such an event and then goes further, asking – what would mankind do? According to him, humankind would come together and ask the scientific community to work out a comprehensive impact analysis assessing aspects such as collision probability distribution, identification of consequences, options for protection, adaptation or rehabilitation and options for mitigating or even preventing the collision (ibid.: 6) Adapted to the issue of climate change, this is a fairly detailed description of the challenges scientists at the PIK have been dealing with since the establishment of the institute in 1992 – the translation of human-environment relationships into discrete classes and mechanisms, the calculation of probabilities of future impacts of climate change, and the proposition of ways to deal with these consequences by mitigating GHGs and adapting to the unavoidable.

Earth System Analysis highlights the quality of control through all-compassing information well beyond the scope of traditional climate science. Schellnhuber was explicitly influenced by the idea of cybernetics and suggested an operationalization of sustainability management as *geocybernetics,* described in an article as "the art of adequately controlling the complex dynamic Earth system under uncertainties of all kinds" (Schellnhuber/Kropp 1998: 411). The issues at stake for the PIK director require a radical rethinking of traditional methods used in the sciences, challenging Karl Poppers principles of hypothesis testing and falsification: "[...] We are not willing or allowed to sacrifice the integrity of the one and only planetary specimen we have got for the sake of scientific progress" (Schellnhuber 1998: 131). Against this background, he proposes simulation modeling as a tool for virtual experimentation, a generation of future projections and a proposition of management options:

> There is one way out of this dilemma, however, namely virtual falsification or verification of Global Change hypotheses with the help of artificial copies of the Earth System or of crucial parts of the latter. [...] a runaway greenhouse event, e.g., in virtual computer reality may cost us one CPU year on the most advanced CRAY machine, but not our lives! In such a case, we simply restart the digital game and try to employ a more careful strategy. In this way we may eventually be able to explore the plume of potential coevolutionary futures as generated from the present state of the Earth System by the management options contained in $\mathfrak{R}$. (ibid.: 133)

Keeping the origins in cybernetic thinking in mind, it becomes clear that work carried out at PIK has always been more than traditional science. Andrew Pickering has described the relationship between traditional science and cybernetics very adequately as follows:

> While classical science has thus been an epistemological project aimed explicitly at knowledge production, cybernetics is an ontological project, aimed variously at displaying, grasping, controlling, exploiting and exploring the liveliness of the world. (2002: 430f)

The geocybernetic concept for ESA is also reflected in the original logo of the Potsdam Institute, depicting a tree (Earth system), a troubled sky (climate change), and a human hand (human agency), (en)framed in a purple triangle (ESA) (see Fig. 11).

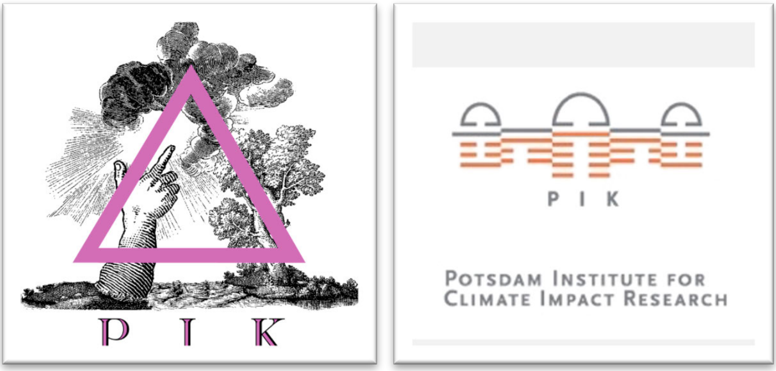

Figure 12: Old (left) and new (right) logo of the Potsdam Institute. Source: PIK

As we will see later on, computer modeling and simulation may be characterized as the framework (cf. Heidegger 1954) stabilizing the Pandora's Box of transdisciplinary sustainability research. The emblem was later replaced with a logo depicting the PIK headquarters and Spieker architecture formerly hosting the astrophysicists of AOP. One may read this as a sign of institutional maturation and subordination to the traditions of the Science Park Albert Einstein.

Disciplining transdisciplinarity through technology

One of the features of work at PIK is its truly transdisciplinary nature. As Andrew Barry, Geogina Born and Gisa Weszkalnys have shown,

> ideas of interdisciplinarity and transdisciplinarity imply a variety of boundary transgressions, in which the disciplinary and disciplining rules, trainings and subjectivities given by existing knowledge corpuses are put aside or superseded. (2008: 21)

Despite the instability resulting from inter- and transdisciplinary settings of scientific work, such a practice has been hailed as a solution to a variety of perceived contemporary problems for many years. This includes the relationships between science and society, the development of accountability and the need to foster innovation in the knowledge economy (ibid.: 21). Accordingly, interdisciplinary work may be focused on very diverse issues and manifest itself in a variety of ways. Interdisciplinary researchers may gather around so-called grand challenges of humanity (sustainability studies, climate research), around new sociotechnical configurations,[24] or around methodological devices (ethnography, artistic research). Referring to Nigel Thrifts *Re-inventing Invention* (2006), they invoke the example of ethnography in the IT industry, which

> offers a set of techniques through which businesses are expected to be able to transform their knowledge of and engagement with those micro-spaces of

24 E.g. computer-supported cooperative work.

> social life, replete with social and cultural difference, to which they previously did not have access […]. (Barry et al. 2008: 32)

These techniques may then create new forms of technical objects that are recognized as, at once, socially and culturally embedded (ibid.: 25). Regarding disciplinary composition, a common constellation is a collaboration between natural sciences or engineering, on the one hand, and the social sciences, humanities or arts, on the other (ibid.: 228). The power, relationships and roles of the different disciplines involved is often a matter of fierce debate in the conceptualization and practice within interdisciplinary settings. Barry and colleagues characterize these different modes of interdisciplinary engagement as follows: (1) The integrative-synthesis mode, where two or more disciplines essentially merge together. Examples for this constellation are biochemistry and astrophysics. (2) The subordination-service mode. Here, disciplines are organized according to a clear hierarchical division of labour, with one or several disciplines providing services or complementing the work of others. An example of such collaborations are ELSA-arrangements, where social scientists are invited into projects within the natural sciences to comment and critique on ethical, legal and social aspects (i.e. 'ELSA') (see Hullmann 2008). Similarly, settings in the Digital Humanities often employ scientific programmers (computer scientists), who provide technical services to the project-leading humanities researchers. In both cases, these disciplinary roles may be seen as problematic (see for example Balmer et al. 2016 for a problematization of ELSA/ELSI). (3) The agonistic–antagonistic mode, where "interdisciplinarity springs from a self-conscious dialogue with, criticism of or opposition to the intellectual, ethical or political limits of established disciplines or the status of academic research in general. (ibid.: 29)

Depending on the level of dissolution of disciplinary boundaries and the integration towards the new subject, the cooperative settings may be framed as 'interdisciplinary' (agonistic–antagonistic, subordination-service) or 'transdisciplinary' (integrative–synthesis). In other cases, collaboration may go well beyond the boundaries of scientific fields, therefore, evoking characterizations of post- and a-disciplinarity (Krishnan 2009; Sayer 2000).

As we have seen concerning the example of the AOP, different aspects are conducive for the establishment of innovative scientific work beyond established disciplines. Obviously, the creation of a formal institution enables the mobilization and reception of financial funds, mostly emanating from fiscal resources in our case. The foundation of AOP as a formal institution in 1874 was followed by an allocation of financial funds to be spent for construction materials, wages and technology on Potsdam Telegrafenberg. The institutionalization was also necessary as a means of national recognition and admission into the international networks of astronomy. However, institutionalization alone does not explain how astronomers, physicists, mathematicians, and technologists were able to collaborate and steadily develop a routine later becoming recognizable as astrophysical practice. Rather, it was precisely the decision to establish a new, particular and independent place *to do astrophysics* that enabled the development of this new practice. As highlighted before, it would have been logical to base the new institution and initiate astrophysical work in the center, Berlin. However, drawing together people, technologies and infrastructures on this formerly blank sheet of Potsdam Telegrafenberg facilitated a new perspective on the night sky, the Earth, science and the use of technological instrumentation. By shifting locations (Gupta/Ferguson 1997) from Berlin to Potsdam, one might forget existing mental maps and unlearn established routines that prevent such new views. On the other hand, unlearning may not only have taken place but also taken time. It was helpful that the AOP scientists and technical personnel were not only closely working together but also living there together at

Telegrafenberg. Spending time together enabled them to tinker with new kinds of observatory technology and methods. These experiments then finally stabilized around the method of spectral analysis, which has guided astrophysical research practice until today.

Similarly, transdisciplinary work at the PIK is primarily structured around computer modeling and the digital infrastructures of computational science. This aspect of the scientific method as a stabilizing element for work at the PIK is echoed by the mission statement on its institutional website:

> PIK addresses crucial scientific questions in the fields of global change, climate impacts and sustainable development.
> Researchers from the natural and social sciences work together to generate interdisciplinary insights and to provide society with sound information for decision making.
> The main methodologies are systems and scenarios analysis, modelling, computer simulation, and data integration.[25]

While paragraph one opens up a Pandora's Box of heterogeneous challenges and fields and paragraph two gathers the skills of heterogeneous actors to address these challenges, paragraph three stabilizes this work by means of a limited methodological toolbox: "[S]ystems and scenarios analysis, modelling, computer simulation, and data integration."

Programming the future

The expertise of the PIK researchers in computer modeling, simulation and digital analysis is the most notable common denominator at the PIK. Digital calculation does not only structure the scientific working practices at the institute, it is a genuine element of its idioculture. This omnipresence of computer code at the PIK can be illustrated by a note

25 https://www.pik-potsdam.de/institute/mission/mission?set_language=en, retrieved on April 2, 2019.

hanging in the shared kitchen of the House of the Woods. The note urges colleagues to keep the kitchen clean and to wash dishes by hand if the dishwasher is out of service. The note is written as computer code in the programming language Python, which proposes a way to 'run' the kitchen (see Fig. 13).

Very broadly, scientific practice at the PIK has been interwoven with the development and mainstreaming of computational sciences in the last few decades. Gabriele Gramelsberger traced the role of computers for scientific practice historically in her book *Computerexperimente*.

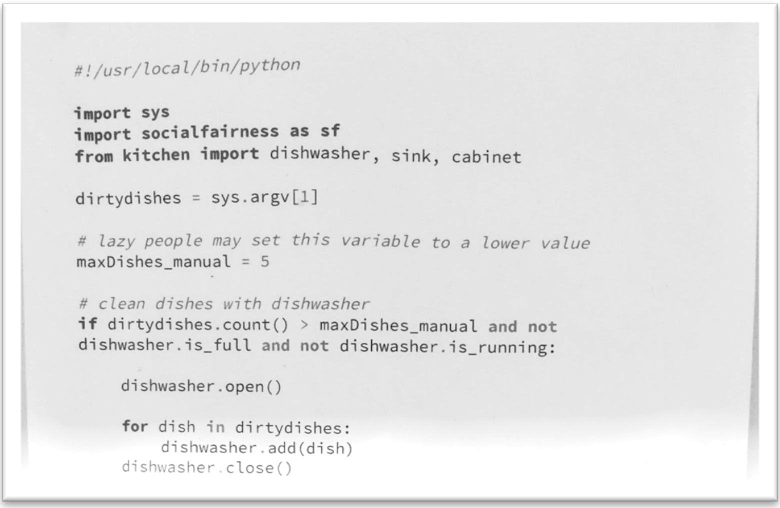

Figure 13: Dishwasher Python note in kitchen.
Source: unkown, picture taken by the author at PIK kitchen

She describes how the appearance of electronic computers and their worldwide distribution changed the practice of and environment for scientific knowledge production massively: "No discipline and no scientific method remain unaffected by the use of computers"

(Gramelsberger 2008a: 85, translated by the author). For her, the advent of computers in science marks "the second half of the scientific revolution in modern times" (ibid.: 85). Computational departments have emerged in almost all scientific disciplines in the last fifty years. In addition to theory, expertise, observation and measurement, simulation was added as a new epistemological instrument in the 1950s, and has been used more intensively since the 1970s.

> The newly established computational departments follow their own research logic, which is characterized by the numerical analysis of complex systems, application- and problem-oriented research questions, a high degree of interdisciplinary cooperation and international networking as well as the dependence of knowledge progress on the performance of computers. (ibid.: 96)

The significance of the computer as an instrument for research, experimentation and forecasting is particularly evident for climate research:

> While the astronomy was the leading discipline in the transition from medieval to modern science, climate research is the leading discipline in the currently developing simulation sciences. (ibid.: 105)

Daily practice in computational science only marginally intersects with the 'BC' (before computers) practices of the originating disciplines. This discrepancy between the daily work at the PIK and the scientific traditions at university was a salient issue in my interviews with scientists at the PIK. As researcher Jeremias Scholz explained to me, he originally studied physics but says that he learned most of his professional skills during his PhD studies at the PIK. When I asked him what he referred to, he mentioned computer programming in particular. He had only taken one single course in C++ at university. He then did his PhD at the Potsdam Institute, acquiring more comprehensive skills in C++, C and FORTRAN. As Gabriele Gramelsberger argues, these computer languages and their codification of mathematical formula can be described as a *lingua franca*, without which the interdisciplinary collaboration in computational science would be inconceivable (Gramelsberger 2008a: 144). As a matter of fact, many mathematical equations, models and program parts can be found in different disciplines. The Navier-Stokes equations of fluid dynamics, for example, are equally used in atmospheric and ocean models, as well as in medical and technical fluid simulations (ibid.). Scientific programming uses theory in a modular way fit for experimentation. It comes in the form of a construction kit composed of programmed theoretical building blocks (ibid.).

According to Jeremias, many modelers work with the Network Common Data Form[26] (NetCDF) infrastructure, a set of software libraries and self-describing, machine-independent data formats that support the creation, access and sharing of array-oriented scientific data. Younger researchers especially also use the programming language Python, which essentially builds on open-source codes and communities (see Chapter IV).

> Once, I had a database in Excel with information on city names and I wanted to plot that on a map. So, I looked for a library for Python to do this. And I found a free library to do this on the web. The place to look for these things is Github. There are some researchers who often publish on Github and there are automatic programs that create a documentation for your code to publish it on the Github website. (Discussion with Jeremias Scholz during lunch at Telegrafenberg Cafeteria)

I asked Jeremias if the PIK modelers also use cloud services. He told me that many modelers work with data on the Earth System Grid,[27]

26 On NetCDF: http://www.unidata.ucar.edu/software/netcdf/, retrieved on July 14, 2019.

27 On Earth System Grid: https://www.earthsystemgrid.org/home.html, retrieved on July 14, 2019.

which is stored by the Deutsches Klimarechenzentrum[28] in Hamburg. The Earth System Grid is an international data distribution portal that dispenses information for the IPCC Assessment Reports, the most important international publication format for policy-oriented climate research. Otherwise, the PIK has a very strict data policy and does not allow scientists to use commercial cloud services (e.g. Amazon Web Services, Google Cloud, IBM Cloud) for computing and storage. As a matter of fact, my interviews with US researchers also suggest that this is a German (and European) cultural specificity. United States scientists are generally more open to using services from private companies, be it software tools (e.g. Esri's ArcGIS) or cloud services (e.g. AWS). Permeability between scientific and commercial worlds is also facilitated by cultural and geographic proximity, given all of the relevant services are provided by US companies. We can give the example of the 2016 annual meeting of the American Association of Geographers, where the author and colleagues from Locating Media participated with presentations. The gigantic conference featured the company Esri as prominent main sponsor, a situation unimaginable in Europe.

Working in technology

The reliance on digital infrastructure at the PIK is reflected by the interior design of the offices at the House in the Woods. My furniture included a desk, a Dell desktop computer, a telephone, a plastic daisy flower, a bookshelf, and a number of empty book spines made of

28 On Deutsches Klimarechenzentrum: https://www.dkrz.de/, retrieved on July 14, 2019.

cardboard. Tim Neitzel commented sarcastically on the impertinence of installing a humanities scholar in an office with fake books.

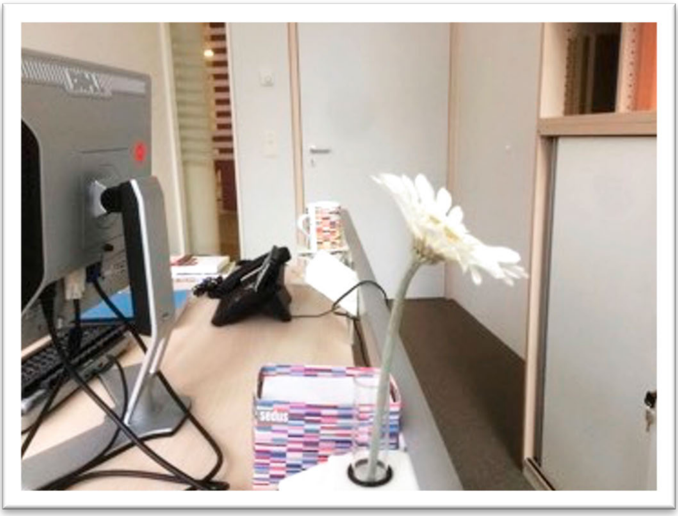

Figure 14: Model office in the Earth wing
of the House in the Woods. Source: Own photo

Books seem to vanish from the office spaces at the PIK. Some senior scientists still host entire personal libraries in their rooms, but the equipment and furniture of younger scientists is mostly limited to a laptop and one or two monitors. Computers are omnipresent at the PIK. Knowing how to use the digital infrastructure is key to become part of the PIK ecosystem, as the following episode illustrates. Just after entering my new office, I started the desktop computer whose system was under my table. After an hour, it became clear to me that I had dropped a brick. The supposed PC had not been a PC. Instead, it was a remote visualization server, which had been stored in the formerly empty office. Someone later put warning signs on the servers as I had not been the first to make the mistake (Fig. 15).

Star and Ruhleder reminded me that infrastructure is always learned as part of membership to a community of practice: "Strangers and outsiders encounter infrastructure as a target object to be learned about. New participants acquire a naturalized familiarity with its objects as they become members" (1996: 113). And as I could learn during the first two hours at the PIK, infrastructure becomes visible upon breakdown:

> The normally invisible quality of working infrastructure becomes visible when it breaks; the server is down, the bridge washes out, there is a power blackout. Even when there are back-up mechanisms or procedures, their existence further highlights the now-visible infrastructure. (ibid.)

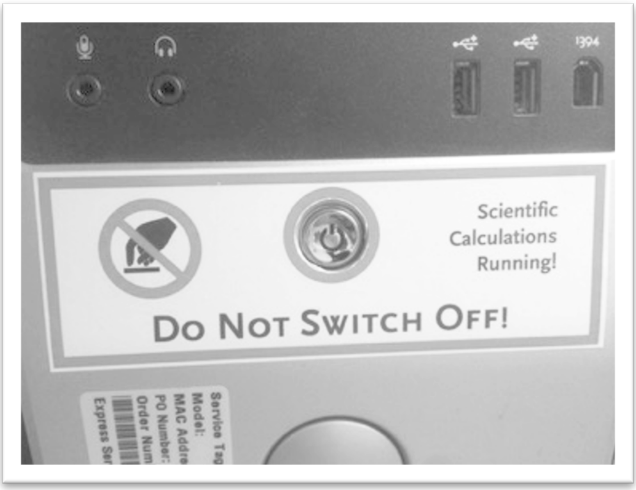

Figure 15: Do not switch off! Scientific Calculations Running! Source: Own photo

The beating heart of the digital infrastructure at the House of the Woods is the supercomputer living in the basement of the building. The 'cluster,' as such high-level performance computers are referred to by actors in the community, had been installed as an integral part of the architecture finalized in late 2015. Such supercomputers are prestige objects that are gladly financed by governments, in this case by the

German Federal Government, the Federal State Government of Brandenburg and the European Union. Tragically, they have a rather short life and are typically outdated after five years. At the time of acquisition (2015), the computer featured ranked 353 of the world list of the fastest computers.

Characterizing the supercomputer as the 'beating heart' is more than a metaphor. The House in the Woods is a materialization of the 'organic architecture' imaginary, promised (but not realized) by the Einstein Tower. The shell of the building is made of wood paneling, which allows for a perfect embedding into the forested environment of Telegrafenberg. Looking outside the window of the office, one can observe deer and rabbits on a daily basis. The form of the House in the Woods is also 'organic,' representing a three-leafed clover, which can be spotted from space. Similar to the Einstein Tower, the outer and inner design of the House in the Woods avoids right angles and has the feel of a fluid sculpture rather than solid, stable architecture. Entering the building, one stands in an atrium flooded in light. Offices and meeting spaces are distributed on three floors and the three wings (cloverleaves), which are designated as the Earth, the sky and the sun.

Figure 16: View from my office into the woods (left) and inner atrium (right).
Source: Own photos

The meeting rooms bear the names of geographic continents, highlighting the global dimension of climate impact research. Given the omnipresence of computers in the work of the PIK scientists, it may be surprising that digital infrastructure is virtually invisible to the human eye. The only visible trace of digital infrastructure for the outsider is the signpost (Fig. 17) next to the elevator, featuring the supercomputer in the basement. One seems to gain direct access to the cluster by pressing the button for level -1, which is, of course, an illusion. The server room is well locked and can only opened by a few dedicated employees who have been on board the PIK since its beginning.

In fact, we should consider the 'black boxing' of technology and infrastructure as a conscious design choice. We will see later that the PIK's work is not just about calculation, but a lot about accountability and representation. Technology is understood as the primary working tool enabling statements about climate change and the future. By contrast, the obligatory passage point (Callon 1984) to mediate the insight of these technological experiments to outsiders is the PIK scientist, possibly without the consideration of help from nonhuman elements. It is telling that the supercomputer (calculation) and the conference room (accountability) share the same floor in the House in the Woods.

Figure 17: Floor plan of the House in the Woods. Source: Own photo

The supercomputer is connected via sophisticated network structures and can technically be accessed from all the offices at the House in the Woods. In this sense, the House in the Woods resembles a cybernetic organism, consisting of material (machines, cables), human (scientists) and symbolic (distributed network software) elements. In this context, we can again refer to Thomas Gieryn's article "What buildings do," in which he proposes analyzing buildings as "walk-through machines":

> A different sense of buildings comes from seeing them as 'walk-through' machines. Buildings are technological artifacts, made material objects, and humanly constructed physical things. To see them this way brings buildings within the compass of a promising theoretical orientation developed initially for the study of machines. (2002: 41)

Having the example of the PIK building in mind, this methodological approach gains another quality and significance. Buildings in the age of smart architecture actually *are* machines, in the common sense of the word. Equally so, computers become walk-through architectures again, as in the early days of the technology. The machinist nature of the architecture is encompassing but can be described specifically by the following conjunction of elements. As a matter of fact, the supercomputer is not only a conditional element for the scientific experiments carried out at the PIK but also provides all the heating energy in winter. The entanglement of different energetic circuits (information, heating, cooling) and media (electric energy, water) creates opportunities but also new risks. As Klaus König, the PIK's head of IT systems highlights:

> There is one disadvantage of this direct cooling. If there is a breakdown in the water circuit, I also have to switch off the cluster to be able to repair it. (Interview with König)

The only incident when Klaus König had to shut down the supercomputer since its installment was triggered by such a problem in the cooling system. One of the filters in the water circuit had been clogged by bacteria in the water, thus, needing replacement.

Figure 18: Fluid elements running through the system. Vertical tubes for water, black cables for electricity and blue for information. Source: Own photo

As a consequence, all scientific simulation had to be stopped and the CPUs turned off until the congestion was eliminated. Apart from this onetime exception, the supercomputer has been a valuable and essential companion for the scientists. Nevertheless, the episode shows that the technical integration of several vital functions into one system comes with a considerable increase of complexity, risks of infrastructural breakdown, the need for new control mechanisms and irreplaceable human expertise. One has to gain considerable situated knowledge to understand the behavior of these multiple fluidities running through the computer (see Fig. 18).

Calculation and accountability

It seems obvious to characterize the Potsdam Institute as a center of digital calculation. Bruno Latour has used this term in his book *Science in Action* for sites,

> where inscriptions are combined and make possible a type of calculation. It can be a laboratory, a statistical institution, the files of a geographer, a data bank, and so forth. (1999b: 304)

If we use Latour's term here, it must be added that inscriptions entering the PIK are different from the ones discussed by Latour, being specimens, probes, paper maps and tables. Inscriptions reaching the Potsdam Institute take the form more of standardized, digital datasets. This may entail, for example, a numerical time series projecting a spatiotemporal change of temperatures within the 21st century. They are equally an element and a late product of what Paul Edwards refers to as the "vast machine," a globally distributed climate knowledge infrastructure (2010: 432). As a result, the data have already passed through numerous rounds of refinement and standardization within other centers of calculation. Considering its holistic claim to take into account all dimensions of sustainable development, The PIK is not only processing weather- and climate-related data but also socioeconomic indicators from statistical agencies, natural disaster damage data from reinsurance companies, risk assessment data linked to armed conflicts, and so on. In this sense, the PIK is not only a part of the vast machine described by Paul Edwards but a globally distributed climate knowledge infrastructure (ibid.: 432). It is also an element of a macroeconomic, commercial and international security machine. Or rather, this attribution of infrastructures with occupational fields and social worlds may also have to be reconsidered and reviewed in a world marked by dissolving boundaries between occupational fields, multipurposed technologies and infrastructures and a deep permeability of data (see Chapter V). *Inter alia*, this means that scientists working at the PIK have no control over and fairly limited knowledge about the making of the data in the first place. This situation creates challenges of trust, which are countered by a number of practices, including the standardization of model components, simulation procedures, data formats, and extensive obligations for documentation and reproducibility. Regarding global climate data, Edwards contends:

> To make data global scientists developed suites of intermediate computer models that converted heterogeneous, irregularly spaced instrument readings into complete, consistent, gridded global data sets. They also literally created data for areas of the world where no actual observations existed. […] As time went on, these techniques became so tightly intertwined that they transformed the very meaning of the term data. Today, the processes atmospheric scientists invented are ubiquitous not only in geophysics but throughout the sciences. Virtually everything we now call "global data" is not simply collected; it is checked, filtered, interpreted, and integrated by computer models. (ibid.: 188)

These standards are required for every scientifically relevant element that enters the institute. Just as well, the PIK ensures that everything leaving the institute meets the same requirements, which is operationalized by internal and external audit and review mechanisms, and through informal peer pressure. As Edwards has argued, scientists themselves are constantly engaging in practices of infrastructural inversion: "The climate knowledge infrastructure never disappears from view, because it functions by *infrastructural inversion*: Continual self-interrogation, examining and reexamining its own past" (ibid.: 432). Such activities of infrastructural inversion are undertaken within the many nodes of distributed networks, such as the vast climate machine. However, what distinguishes centers of calculation from other individual nodes is their ability to co-create the procedural rules for the game. Accordingly, anthropologist Richard Rottenburg has argued in *Far-Fetched Facts*, his parable of development aid:

> The translation chain selected here is connected with many other chains in a worldwide network. Not all of the individual nodes in this network have the same meaning or significance, even if locally appropriate translations exist everywhere. Some nodes are able to define the procedural rules of the technical game in such a way that others are forced to follow them. (2009: 87)

The Potsdam Institute clearly represents such a central node, wielding considerable power within its networks. In so doing, it is not only able to co-create the rules of the game but to redefine who is playing it. This parallelism between calculation and accountability can be illustrated by the making of Shared Socioeconomic Pathways (SSPs) at the PIK. The Potsdam Institute is involved in the process of generating globally agreed quantitative scenarios for GHGs and socioeconomic development in the 21^{st} century. As mentioned before, scenarios have long played an important role in simulation-driven climate research. An increasingly broad array of scenarios had been developed over time. On the one hand, this was due to the fact that more and more issues became the object of scientific scrutiny in climate-related research. Moss and colleagues (2010: 748f) introduce a typology of prominent scenarios used in climate-related research, which can be summarized as follows:

Socio-economic scenarios describe the evolution of the society and ecosystems, in the absence of climate change or climate policies. For example, such scenarios can represent future conditions of economic growth, GDP [Gross Domestic Product] and population size.

Emissions and radiative forcing scenarios. Emission scenarios describe potential future discharges to the atmosphere of substances that affect the Earth's radiation balance, such as greenhouse gases and aerosols. Accordingly, they focus on long-term trends in energy and land-use patterns. Radiative forcing scenarios in contrast express radiative forcing, i.e. potential future changes in energy in the atmosphere due to GHG emissions.[29] According to the nature article, "it is important to differentiate between emissions and RF scenarios, because radiative forcing takes place after a certain time lag following the discharge of GHGs" (ibid.).

Climate scenarios are representations of future climate conditions such as temperature, precipitation and other climatological phenomena.

Impact, vulnerability and adaptation scenarios focus on changes in environmental conditions. While such changes may occur regardless of climate change, the latter often influences them. For example, such scenarios can represent future water availability and quality at basin levels, sea level rise, and characteristics of land cover and use. As such factors often affect the vulnerability of natural and social systems, they can be described and measured by vulnerability studies and scenarios. In the end, such studies can also serve as input for impact scenarios analyzing possible coping mechanisms with the changes ahead. (ibid.: 749)

However, the multiplication of application contexts of scenarios was only one reason for the mushrooming of scenarios in climate research. A second factor was the need to improve existing scenarios by considering new research insights. A third reason to trigger the development of new scenarios was linked to organizational concerns within the community of climate researchers: Namely, the community realized that working on climate issues would only be effective if researchers adhere to a shared set of scenarios. Such harmonization, standardization and disciplining work was understood to increase the consistency and collaboration of climate research and policy. All these factors led to a

29 Radiative forcing (RF) is the measurement of the capacity of a gas or other forcing agents to affect that energy balance, thereby, contributing to climate change.

number of scenario generations that were broadly shared within the climate community: Namely SA90, IS92, SRES (Girod et al. 2009) and the Representative Concentration Pathways (RCPs) and SSPs used currently. The Potsdam Institute is one of the research institutes in this globally distributed effort of developing global community scenarios. In so doing, it co-creates the "scenario matrix architecture" (van Vuuren et al. 2014) that serves as an underlying infrastructure and obligatory passage point (Callon 1984) for all prospective futurework within the community of climate researchers.

Scientists at the PIK are not only contributing to the organization of the climate research community, but they also constantly mediate between the social worlds of climate science and policy. John Schellnhuber was involved in the conceptualization of the IPCC,[30] the United Nations body for assessing the science related to climate change, from early on. This proximity to the world climate council was formative for the PIK and explains the strong influence that the climate modelers on Telegrafenberg exert on international scientific and political processes regarding climate change. The alignment with the IPCC is not only reflected in the thematic focus and personal ties but has been imprinted in its institutional structure. In addition to domain IV (my affiliation), research domains mirror the WGs of the IPCC:

PIK	**IPCC**
Earth System Analysis (RD I)	The Physical Science Basis (WG I)
Climate Impacts and Vulnerabilities (RD II)	Impacts, Adaptation and Vulnerability (WG II)
Sustainable Solutions (RD III)	Mitigation of Climate Change (WG III)

Table 1: Comparison of the PIK's research domains (RDs; left) and the IPCC's working groups (WGs; right). Source: Own table

30 https://www.ipcc.ch/, retrieved on February 3, 2019.

This strategy to focus on the IPCC paid off for the institute in the sense that several PIK researchers have acted as lead authors of the influential assessment reports of the climate council. The IPCC's WG III on *Mitigation of climate change*, for instance, is currently coordinated by PIK researchers.

Investigating the boundaries of openness

The PIK scientists have become equally cautious and professional in the representation and mediation of their scientific work because of the centrality of the PIK in public debates regarding the climate crisis. They became not only experts on calculation but also the accountabilization of their calculations. This professionalization constituted a challenge but also an opportunity for my ethnographic research. I observed and participated in my fieldwork in many of these activities aiming at 'communicating' climate research to outsiders. More than that, I have been heavily dependent on such practices of mediation in order to gain access to information. As ethnographic researchers, we should not take this provision of access for granted but consider our own shifting position towards or within our field. Why have I been given access to an institution or how did I have to position myself in order to gain access to informants, information and infrastructure? As the sociologists Hirschauer and Amman have argued, a certain mimesis of the person, a fit into the milieu, is necessary for the design of the copresence as a 'disturbance' introduced into the field of investigation (1997: 25). In my opinion, this does not only mean that the ethnographic researcher is increasingly able to adapt to his/her 'field.' Rather, the personal biographies and attitudes of researchers towards the field already enable certain access points and prevent others. In my case, I could contribute some insights from past work as a policy consultant for climate policy, I had an interest and some knowhow about map design, and had already cooperated with PIK scientists in a project with the University of Potsdam (Schneider/Nocke 2014). Without this preliminary work,

access to the field (in this case, the institution of the PIK) would probably have been impossible.
The identifications, roles and functions ascribed to me in the diverse situations of contact with interlocutors differed considerably. Depending on the context, I was perceived as a visualization designer, knowledge sociologist, media or communication scientist, anthropologist or cultural scientist.

> Search ambivalent identifications, or perceived identifications, immediately locate the ethnographer within the terrain being mapped and reconfigure any kind of methodological discussion that presumes a perspective from above or 'nowhere.' (Marcus 1995: 112)

My investigation during my field research was not limited to observation but increasingly included interventions. I became a mediator of climate change impacts within my role as a visiting researcher at Potsdam Institute; I commented on the graphics and presentations of scientists, created a series of workshops around the 'visualization of climate change' and worked on a publication together with climate scientists. As Marc-Anthony Falzon has pointed out, "[…] ethnographers typically think of data as a gift from their informants, with all the implications of reciprocity that gift exchange implies" (2016: 1).

George Marcus pointed out that the 'mimesis' between the ethnographic researcher and his/her field often entails professional and private spheres:

> In contemporary multi-sited research projects moving between public and private spheres of activity, from official to subaltern contexts, the ethnographer is bound to encounter discourses that overlap with his or her own. (1995: 112)

I became very sensible to the climate debate and how it was conducted within the public sphere during my fieldwork at the PIK. It became apparent to me that it is virtually impossible to separate 'the science' and 'the politics' of climate change. Accordingly, it has to be considered as a political statement and positioning to work at the Potsdam Institute and not at another institute of the Earth Sciences. As a matter of fact, this political demarcation of the PIK and its researchers became especially apparent when I was in contact with researchers of the second geoscientific institute on Telegrafenberg, the GFZ. The relationship between the two institutes (PIK and GFZ) has always been marked by strong competition, sometimes latent resentment and mistrust. On the part of the PIK researchers, GFZ is seen as a scientific contributor to the climate crisis, with its strong (though decreasing) focus on natural resource extraction methods and technology (e.g. oil, minerals). On the other hand, PIK researchers were sometimes depicted as arrogant and excessively focused on the political positioning and public placement of its research insights. The cultural difference between the two institutes is driven more generally by a different focus regarding temporalities of the Earth System.

Figure 19: Guided tour in the Long Night of the Sciences in front of a PIK building on June 15, 2018. Source: Own photo

As a GFZ scientist declared during a guided tour (see Fig. 19) across Telegrafenberg, "we at GFZ are focusing on the past of the Earth. By contrast, the PIK is focusing on the future. Based on our findings about the past, they are developing computer models making statements about the future"[31]. While researchers from both institutes are using similar methods, GFZ is occupied much more with generating and analyzing empirical data, while the PIK uses these data in their models and simulations.

In fact, there have long been virtually no contact points between the researchers of the PIK and GFZ, despite of their physical proximity on Telegrafenberg and similar research objects. However, this situation is currently changing with the establishment of shared open data infrastructures (see Chapter V) concentrated at the science park library, which is establishing new points of contact between the four scientific institutes on the hill. Moreover, common challenges related to datafication and machine learning have also given rise to a shared new research network labelled *Geo.X Data Science*.[32]

Using open and closed doors

"It can be considered a paradigm of ethnography that failures in field access, averaging resistance and failure of attempts at understanding can also be used diagnostically, namely, as a method of relevance detection" (Hirschauer/Amann 1997: 19f) Even though my interlocutors were always interested in the concepts and activities of mediation, I was often confronted with boundary work (Gieryn 1983) between the world of scientific knowledge production and science communication. I noticed during my workshops and interviews that scientists are very sensitive and often disapprove certain boundary crossings between these alleged worlds of science (content) and communication (form). It is generally assumed that climate knowledge about the future is created within computer simulations; it is then carried to the public domain by

31 Guided tour in the Long Night of the Sciences 2018 on June 15, 2019.

32 https://www.geo-x.net/en/, retrieved on April 2, 2019.

project managers, visualizers and PR people. This way of maneuvering was especially apparent and routinized within the institute's so-called 'flagship projects,' which were accompanied by professionalized representation machinery.

It became apparent while doing my ethnographic research of scientific work at the PIK that scientists nowadays invest a lot of energy thinking about the representation and communication of their work outside scientific circles. Climate impact researchers are very concerned about the positioning of their knowledge outside their field. The very fact that I was invited as a visiting scientist at the PIK bares evidence of this. When I presented myself as a media scholar, I once received the answer: "Ah yes, we should do much more to communicate our knowledge to the media and the public."[33] The same researcher also told me that they integrated this module on communication and visualization into a project proposal for the *Joint Programme Initiative*[34] of the European Union, "because donors always want to have this now." Scientists generally rather feel obliged to fulfill this task to communicate with outsiders and see this as a priority of their work. They often seem to feel uncomfortable with this obligation as, for them, this is not their expertise. Having lunch with Jeremias Scholz and another young postdoc at the institute,[35] the former asked me what I think about such expectations about scientists communicating directly with the public. He mentioned that he was quite conservative in this regard. He sees the need to translate knowledge to broader audiences, but he also thinks that he and his colleagues do not dispose the necessary skills to do so.

33 E.g. discussion with Jeremias Scholz on September 9, 2019.

34 The Joint Programming Initiative "Connecting Climate Knowledge for Europe" is a pan-European intergovernmental initiative gathering European countries to jointly coordinate climate research and fund new transnational research initiatives that provide useful climate knowledge and services for post-COP21 Climate Action. See http://www.jpi-climate.eu.

35 Lunch with Jeremias Scholz and Layla Winston on September 9, 2019.

Several of my interview partners were overwhelmed by the impact that their excursions into mediation work had had in the public realm.

Compared to their peers in other academic disciplines, climate impact researchers can even be characterized as having been particularly concerned with the representation of their work outside the boundaries of their field due to the characteristics and peculiarities of climate impact research. While being abstract and complex, climate impact research is seen as highly relevant for other societal fields, such as policy, economics, health or security. Climate impact research is a relatively new scientific field. This means that there is a lot of space for experimentation and many aspects of the phenomena researched (climate, climate change and its implications for other systems) are not yet known. This high public exposure coupled with the instability of climate knowledge can be seen as an uncanny combination for the scientists at work. Be that as it may, climate researchers feel a strong need to communicate with the world outside their community of scientists. They do so engaging in multiple activities, depending on their occupational fields, professional skills and personality. These issues of 'communicating' or 'opening up' were often mentioned during my interviews with PIK researchers. At this point, it seems useful to mention a few aspects of my interview methods, as they structured the way in which my informants elaborated on forms of openness in their work.

Diagram elicitation

At the beginning of my fieldwork, I started a series of semi-structured interviews (Kvale 2007; Odendahl/Shaw 2001; Pierce 2008) addressing the issue of knowledge practices. The original idea was to trace the making of a 'prediction' and to investigate how such knowledge is transformed when it crosses boundaries of social worlds. This could, for example, be a prediction developed within a simulation modeling process at the PIK, which is then transformed to make it fit for the world of policy making. I had in mind Bruno Latour's cascade of inscriptions tracing botanic and pedological knowledge practices observed within fieldwork in the Brazilian Amazon (1999a) as an underlying theoretical concept. In contrast to Latour's example, it became apparent that scientific practice in simulation modeling could not be observed 'in action' by just being there with the researchers. This would have meant staring for months at the back of modelers, staring, in turn, into their computer screens. Writing computer code as the primary daily practice in simulation modeling is ungraspable by traditional ethnographic means of observing, describing and/or recording embodied movements and articulation. As a matter of fact, this might be the case for the observation of many other working practices within today's knowledge society. The second problem is the distributiveness of activities in simulation modeling within space and time. Climate impact modelers may work on three or more projects in parallel. Realizations (i.e. calculations) of simulation models take time (days, weeks). Therefore, modelers would start one calculation in the supercomputer, continue to work on the computer code of a second model, go to meetings of yet another project, then check in again on project one and evaluate the results of the simulations. In so doing, they work together with others who may not be present on the same floor, in the same city or country. In order to deal with these methodological issues, I decided to conduct interviews with simulation modelers and trace knowledge practices *ex post*. After some exploratory discussions, it became apparent that it would be impossible to understand and retrace knowledge practices just by letting scientists talk about their work. The only way to stabilize such conversations was to make use of visual artifacts and structure the interviews around these representations of scientific work. Drawing on Douglas Harper's approach of photo elicitation (2002), I asked every interviewee to bring a visualization (mostly diagrams or maps) that could be used to explain some elements of their current or past working activities. I spent a considerable time with some of my interviewees looking at their visualizations. Torsten Casius, for example, could explain to me his work on developing and running the 'SWIM'[36] model simulating European waterways.

As he told me, the most considerable challenge was to find, collect and harmonize the datasets representing spatiotemporal values for hydrological and land use-related information. On the one hand, it would necessitate calling administrators or researchers in the Czech Republic, Poland or the Ukraine and asking them kindly to donate their datasets for the research carried out by the Potsdam Institute. If phone calls do not suffice, he would have to travel there to collect the data for himself. In this sense, 'collecting data' does not mean getting in contact with the simulated phenomenon in question (e.g. the Donau river) but with the actors holding back the datasets on their computers.

Figure 20: The working environment of Torsten Casius (visualized datasets on land use for SWIM simulation in GRASS software). Source: Own photo

36 Soil and Water Integrated Model.

As we can see in this example, climate impact simulation is not only a 'technical' challenge. The international character of the phenomena simulated also poses considerable social and political challenges, drawing together all necessary ingredients. As we will see in Chapter V, the movement around open data aims at reducing the barriers to receive, access and use these ingredients. Torsten Casius also talked about issues of representation in transformative data practices:

> You often have the trouble to transfer the whole thing to SWIM's own data formats. SWIM takes soil profile files according to a completely defined scheme. These are ASCII files. And, of course, this format is not provided with the input data you have. You have some kind of ACCESS database with soil parameters in it, but that's not the format that SWIM needs. So, this transformation creates a lot of work. That's why colleagues developed methods to convert the data from the international world map – very extensive Python or R scripts. [...] Well, I had a bit of a bad feeling when I processed the data with that. [...] The scripts threw out two or three soils without parameterization, which I had to puzzle out by hand [...]. And you never know: If it is so complex; is it correct then? Doing everything by hand, however, is not less error-prone. And it's definitely a lot of work. (Interview Casius, translated by the author)

As we can see, the establishment of circulating references between different inscriptions in a research process is as relevant in 'digital pedology' (i.e. manipulation of land use data) as in its analog version described by Bruno Latour: "The transformation at each step of the reference […] may be pictured as a trade-off between what is gained (amplification) and what is lost (reduction) at each information-producing step" (1999a: 71).

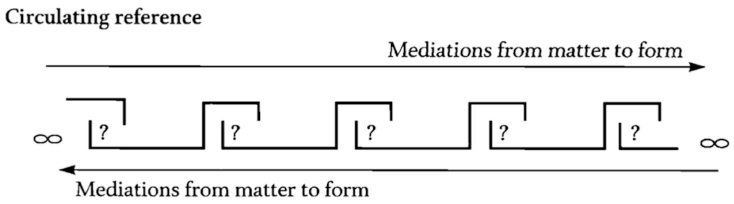

Figure 21: Circulating reference. Source: Latour (1999a: 73)

I started to develop visual guidelines to structure my interviews with informants as a second methodological device (see Fig. 22). In the middle of the map is a square, where my interview partners could describe the project that would be discussed within the interview.

Figure 22: My visual interview guideline. Source: Own visualization and photo

The left side of the map is meant for technical inputs to the computer model, such as algorithmic code and datasets. On the right side, is space for outputs (e.g. data, code, visualizations). However, these elements are complemented by other ingredients, such as human contributors, financial means, essential skills of the actors involved and infrastructure required for the project. In my interviews, I first asked my informants to talk about and fill out the input-output elements in the visual guideline. The aim here was to make them comfortable and speak in their (technical) language about things they know best. Later, I focused more on questions that are normally not covered within the daily in-house discussions at the institute; for example, the description of tacit knowledge (MacKenzie/Spinardi 1995) that make up a good modeler or problems with the 'delivery' of more comprehensive outcomes (e.g. lacking success to sustain project results and make them useful for other scientists). At the bottom of the page, the guideline features a visual representation of Bruno Latour's chain of circulating references (1988). This underlying heuristic of the interviews was rarely addressed explicitly, but sometimes my interviewees would ask about the 'theory' behind my research.

The right timing for openness

In the interviews, researchers would often mention communication activities, such as 'public and press relations,' 'policy advice,' 'stakeholder engagement,' 'outreach,' 'science communication,' 'open sourcing,' 'science education' and "'open science.' At the beginning of my field research, I interpreted the labels of the interaction between science and nonscience as variations or even synonyms of the same practice. The discussions with scientists were mainly driven by the question 'how to communicate information to different audiences,' so-called 'user groups' or 'target audiences.'

I had to reevaluate this interpretation significantly after a year working at the PIK. It became clear that the primary issue of controversy was not how to talk to whom but *when* to talk. All my interview partners were equally interested and ready to pass on their scientific insights to others, including those outside their WGs, their institution and the scientific community. By contrast, there have been very contradictory views among interviewees whether such openness should involve elements other than stabilized scientific evidence and when such elements should be passed on.

What we may call the 'conservative view' of timely openness would suggest that the only task of researchers is to conduct scientific experiments. If these experiments are successful, the scientist may write an academic publication communicating his/her insights. Accordingly, he/she may also engage in other activities of science communication. In the best case, this task of science communication is delegated to professionals, such as the PR department, a media agency or perhaps even another dedicated academic institution. An example of the latter is a collaboration between the Potsdam Institute and the design department of the School for Applied Sciences in Potsdam (FHP). The FHP interaction designers created *A Brief History of CO2 Emissions,* a dynamic animation featuring insights from the PIK's simulation of the SSPs. While the animation was composed using the newest available design components by FHP, it mediated highly stabilized and published scientific knowledge.

On the other hand, we can identify a 'progressive view' of timely openness, which operates with terms such as 'open science,' 'open data,' 'stakeholder involvement,' or 'participatory design.' We may focus on *Open Science* as the most fashionable umbrella term, aiming at the incorporation of all these other approaches. As Benedikt Fecher and Sascha Friesike highlight:

> 'Open Science' is one of the buzzwords of the scientific community. Moreover, it is accompanied by a vivid discourse that apparently encompasses any kind of change in relation to the future of scientific knowledge creation and dissemination; a discourse whose lowest common denominator is perhaps that science in the near future somehow needs to open up more. (2014: 11)

Fecher and Friesike identify a number of different schools of thought in the understanding of open science: The Public School, the Infrastructure School, the Pragmatic School, the Democratic School and the Measurement School.

A lot of scientists believe, for example, that science must be accessible to the public ('Public School'). Consequently, they engage in concrete communicative activities, such as science blogging, science PR and experimentation with citizen science. Other scientists are more concerned with the legal and financial restrictions to knowledge dissemination and believe that knowledge must be freely available ('Democratic School'). The Open Access Publishing movement is a prime example of these concerns. In another reading, Open Science is more about making collaboration within the research community more efficient and effective ('Pragmatist School'). This may embrace a valuation of digital communities and collaboration platforms, and expected network effects. Another variation of open science is concerned mostly about the aspect of evaluation ('Measurement School'). Many researchers consider the current dominant evaluation systems, such as impact factor schemes, as problematic. They propose alternative possibilities of evaluation, such as altmetrics and open peer review. Finally, an Open Science theme of increasing prominence is infrastructure ('Infrastructure School'): "The infrastructure school is concerned with the technical infrastructure that enables emerging research practices on the Internet, for the most part software tools and applications, as well as computing networks" (ibid.: 36).

The proponents of the progressive view of timely openness can be attributed mostly to the infrastructure school of Open Science. These actors experiment with ways to make the scientific process itself open from the beginning. Equally, they engage in futurework, aiming at a design of research elements which enables the reuse by others. In the following chapters, I will address three ways to 'open up' research elements at different points in time of the scientific process: Visualizations (Chapter III), software (Chapter IV) and datasets (Chapter V). In Chapter VI, I will discuss an example beyond science which makes use of multiple 're-usable elements.'