Conclusion

I have become a ‘Scientist for Future’ myself in explicit and implicit ways during the last few years. I signed and supported the birth-giving statement of the ‘Scientists for Future’ movement declaring that *The concerns of the young protesters are justified. A statement by Scientists for Future concerning the protests for more climate protection* (Hagedorn et al. 2019). I have also acted as a mediator, putting proponents of the Scientists for Future movement together with scientists from the Potsdam Institute. During an Open Science fellowship at the Wikimedia Foundation, I collaborated with the library of the Telegrafenberg and with computer scientists to translate the entire publication database of the Potsdam Institute to the open knowledge base Wikidata. In one of the preliminary steps of this translation, we visualized the co-author networks of the PIK scientists, as shown in Figure 55. After a while, I discovered myself as a (very small) node within the network, co-author of the PIK publication *Climate Impacts for German Schools – An Educational Web Portal Solution* (Blumenthal et al. 2016). It was the realization that I had equally become an element of my field and part of my own research data.

It would be wrong to characterize this situation as a mimesis but rather as a shifting of positions of the field and the researcher. ‘The field,’ as I have described it within this book, had not existed four years ago. While such processes may have started before in other locations, the last four years have been a crucial period in the mutual construction of infrastructures, the mobilization of artifacts and the establishment of practices for (what is increasingly labeled as) ‘open science.’ I have tried to describe this shift within this book and to reflect on some of the consequences for scientific practice. Equally, I have been a (very marginal) contributor in the construction of this field, experimenting with new ways to 'open' science and to feed in the perspective of STS and ethnography to such processes. The following paragraphs provide a more condensed view of the shift from traditional practices in climate impact modeling to the quest for digital openness.

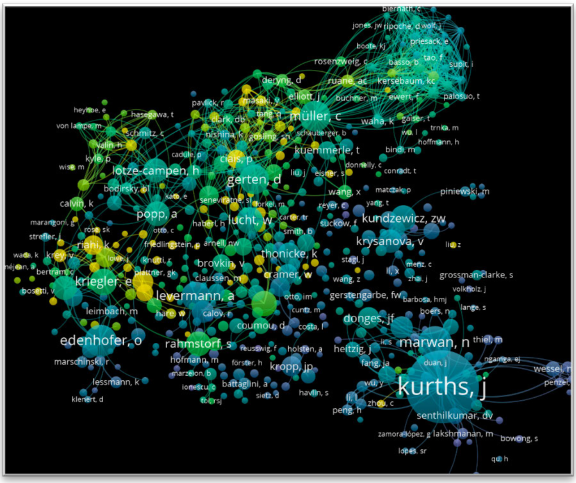

Figure 55: Co-author network of the PIK publication database, visualized with the software VOSViewer.[137] Source: My own visualization

Shifting temporalities in scientific modeling

The reconfigurations documented within this study represent a temporal restructuring of the moments of opening and closure within scientific modeling work. These altered temporal orderings are both

137 VOSViewer: https://www.vosviewer.com/, retrieved on June 14, 2019.

triggered by the mainstreaming of digitally networked infrastructures and socio-political expectations for open science.

Impermeable modeling

Locating moments of openness and closure in traditional climate modeling processes is relatively simple. We can illustrate this by adding to Latour's visualization of the cascade of inscriptions discussed earlier.

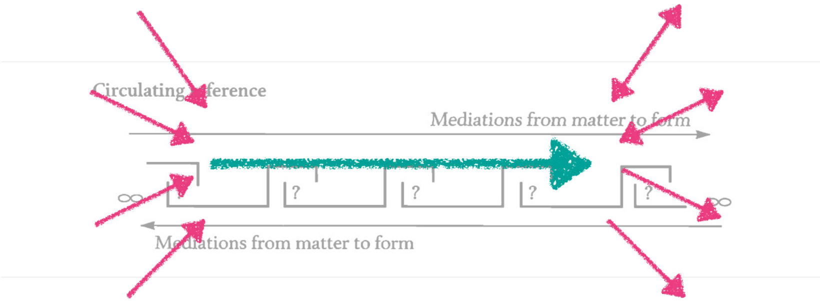

Figure 56: Moments of opening and closure in impermeable modeling.
Source: Latour 1999a supplemented by additional elements

The green arrow represents the transformation of information within the process and time span of a modeling enterprise. Research endeavors in applied research, such as climate impact modeling, are typically triggered by tenders of founding institutions. Scientists try to align their skills and research interests to the demands of the research institutions and frame their proposals as solutions to the problems referred to in the call for projects. Scientists (mostly in teams or consortia) apply for the grants and some of them are funded. Sometimes, new people are hired; more often, existing ones are rededicated to the new project. Scientists gather existing theory, models and data to build upon. Put otherwise, the scientists breath in and seek inspiration from outside of their project team. In Figure 56, this incorporation of information at the beginning of the research process is represented by the one-directional arrows in magenta on the left. After an initial phase of conceptual and organizational reshuffling, the dynamics of scientific processes become more stabilized. The incorporation of outside knowledge is heavily narrowed down to a level perceived as manageable for the researchers, which is represented by the green arrow in Figure 60. This strategy allows for the scientific analysis and knowledge production within the conceptual and methodological boundary conditions of computer modeling. Considering the way in which simulation modeling processes are temporally structured, it is difficult for scientists to incorporate new elements before the simulation rounds are through and the results formally evaluated. Small conceptual changes may have great and unforeseeable consequences for the entire behavior and performance of the model due to the complex mathematical logic and computational architecture of simulation models. Making statements about ongoing modeling processes prior to the formal evaluation is often difficult. Modelers, therefore, often refrain from communicating ongoing research and save representational activities for the final period of the research process. This also prevents them from becoming victims of political attacks from climate skeptic forces who defame climate research as 'fake science.' In Figure 56, this opening up to outsiders at the end of the research process is represented by the magenta arrows on the right. The arrows go both ways, as they include mediation from the inside to the outside but also from the outside to the inside. These interactions between scientists and publics take various forms and include developing scientific papers, producing visualizations, giving interviews to journalists and producing popular science books. On the other hand, the feedback received at the end of the research process may lead to alterations of the models applied, the integration of additional aspects or an alteration of priorities. I call this *impermeable modeling.* The scientific process is sealed within the core period of research. It is only at the end of the epistemic and organizational process that the seal is opened and the newly created knowledge is set free for communication and social negotiation.

Permeability and digital openness

As I have shown in the chapters of this book, the temporalities of interaction within scientific modeling are currently changing. Moments of opening, interaction and feedback with outsiders do not only occur at the end of a modeling process but from the very beginning and throughout projects. As discussed in chapters III – VII, researchers contribute to Github repositories and software libraries, they upload and document vast digital datasets and produce images for their engagement with various stakeholders. Along with these activities, they receive feedback, which explicitly and implicitly informs their work in progress. In other words, modeling becomes more and more *permeable.* The interaction with others within permeable modeling is sometimes happening face-to-face – scientists increasingly speak to social actors, such as journalists, policy makers, teachers and pupils, or more fuzzy categories of 'the general public' or 'non-experts.' In some cases, scientists are comfortable with this new evocation of representation, in other cases, they instead feel overwhelmed by these new expectations. These transformations in the practices of science communication have been widely reflected within the academic literature as conceptual shifts from characterizations of science as an ivory tower, through the public understanding of science, toward public engagement with science and technology (Schäfer et al. 2015).

In this book, I have focused on another transformational shift in scientific practice and communication driven by the rise of digitally networked infrastructures. Nowadays, the mediation of scientific knowledge is increasingly organized through the production, dissemination and negotiation of dedicated artefacts. The artefacts may have different shapes: They may come as interactive visualizations, open datasets or open-source computer models. Nevertheless, they have conceptual similarities. All artefacts produced should potentially be accessible and usable by others without the need to consult the researchers who produced them. The operationalization of this objective strongly preferentiates certain characteristics: Artefacts should be digital, mobile, documented, addressable and accessible across the networked infrastructures of the internet. Put differently, openness is equated with *digital openness.* Referring to historian Theodore Porter (1996), this can be characterized as a strategy of impersonality in science favoring explicit quantified information over embodied expert knowledge. Building on his historical study of accounting practices in the 19th and 20th century, Porter has shown how quantification and statistics emerged as technologies of trust constructing new kinds of legitimacy for economic and political actors through distancing and objectivation (ibid.: 87ff). Echoing Porter, Matthias Heymann, Gabriele Gramelsberger and Martin Mahony have argued that computer modeling and simulation have to be understood as a more recent toolbox of objectivation to exercise epistemic and political power. Their most consequential promise is to provide an objective means to make claims about the future (Heymann et al. 2017). In the present book, I show how the practices, artefacts and digital openness[138] have to be considered as another push towards the depersonalization of scientific knowledge. Of course, science has always worked at making scientific knowledge independent from the researcher and to translate it into a standardized written form that can be shared within communities. The academic paper is the ultimate example of such an immutable mobile for scientific knowledge (Latour 1988). The mobility of the scientific paper, however, appears to be highly limited. Typically, such artefacts only travel between fellow researchers of the same scientific community that shares a common esoteric language. They rarely move across disciplinary borders and beyond the scientific community. For such translation of scientific knowledge across social worlds, the researcher represents a preferential

138 I became aware just before publishing this book that Maximilian Heimstädt had already developed scientific contributions characterizing the term of *digital openness* (e.g. Heimstädt 2014). For production-related timelines, it was not possible to discuss this valuable content further in this text.

passage point to go through. Researchers, therefore, maintain considerable control over the dissemination of the scientific knowledge produced in their own research projects. In the context of environmental science, the PIK and its long-time director John Schellnhuber have perfected the role of scientists as passage points for future knowledge on climate change. Empowered through computer technology, they act as exclusive (human) translators of the phenomena and trends described within their simulations. Within this function, they are consulted by politicians, technocrats, teachers, journalists and company leaders. The flip side of the coin is that they frequently become the victims of 'shoot the messenger' maneuvers by climate skeptics and deniers. A shift of power is taking place in the course of the reconfiguration of scientific practice towards digital openness. Scientific knowledge is not primarily embodied by the researcher nor by artefacts (publications, scientific models). Instead, it is embodied by distributed, networked infrastructures, which often comprise scientific, commercial and media-public spheres. The scientist is one of the nodes of these novel actor-networks, but only one of them. Equally important are novel elements that enable forms of stabilization in increasingly fluid environments. It is not only a matter of standardizing data and programming code but also of a situated publication of the constituted knowledge within certain infrastructures and communities. Depending on the analytical perspective, these elements can be described as *anchoring devices* of knowledge organization or as *viscous elements* within the fluid socio-technical networks of digital technology. Constructing and managing both mobile artefacts and anchoring devices entails strong characteristics of futurework.

New kinds of futurework

Climate impact researchers are accustomed to taking the future into account. Their daily work involves practices of future imagination, the formalization of these imaginations in computer models and simulations, and the representation of insights from such formalized prophecy in worlds outside science. The reconfigurations of scientific practice described in this book, however, add novel features to climate impact research as futurework. The new 'Scientists for Future' should not only make scientifically sound projections of the risky developments ahead. They are also expected to empower others to make such claims about the future. Everything – data, models, visualizations, guidelines – should be made prospectively accessible, comprehensible and reusable for others as early as possible. The prime example of an operationalization of this practice is the work around CLIMADA (Chapter IV and V). Here, models, datasets and documentations are optimized to help others, namely, risk modelers in the insurance industry, to take climate change into account within their own calculation work.

These new configurations in modeling practice hailing permeability and digital openness are illustrated in Figure 57. The vertical blue lines and bullets designate the multiple digital artefacts produced, mediated and disseminated throughout the modeling process. The thinner lines represent the embedding of the artefacts within digital, distributed and networked infrastructures and their blue arrows the prospective outlook for future use.

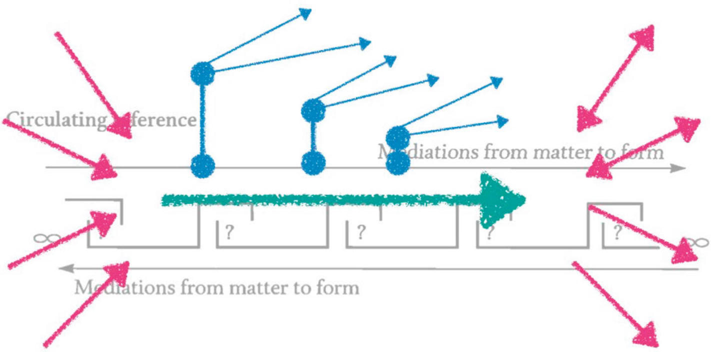

Figure 57: Permeability and digital openness.
Source: Latour 1999a supplemented by additional elements

Investigating achievements and frictions around digital openness

On the one hand, by investing in permeability and digital openness, climate impact modelers influence the way modelers from other fields (reinsurance companies, banks, state authorities) calculate the future. They have their say regarding what scenarios are computationally imaginable. On the other hand, this new kind of futurework takes time and resources. Researchers spend fewer of their working hours thinking about the inner logic and performance of their simulations and more designing explainable and interpretable tools and resources for future use. More than before, scientists have to acquire new professional skills and become veritable designers producing digital artefacts for future use by prospective audiences.

Similar to other major disruptions of scientific practice, the transformation of modeling towards permeability and digital openness does not always happen smoothly and often creates frictions between expectations and actual practice. I have addressed such frictions within Chapter III to VI. While online platforms providing datasets, mobile models and visualizations operate with strategies of impersonality, they tend to obscure the extensive translation work undertaken by multiple human mediators. Neither open data, models nor visualizations should be taken as given; they have to be explained, curated and made relevant by dedicated people. Despite the promises of digital openness to make knowledge accessible everywhere for anyone at all times, knowledge-storing artefacts have to be constantly maintained and actively mediated in order to remain open. I have tried to value this invisible work enabling and powering digital openness in science throughout this book. As such, I have highlighted the work of science communicators, data storytellers and scientific programmers, as well as maintenance workers of data centers. Moreover, I also argued that digital openness can be interpreted as a transitional phase preparing the age of linked data and learning machines. Different than official discourse suggests, digital openness is not primarily fit to make knowledge accessible for humans but for machines. Agency may, therefore, gradually shift to new kinds of collectives (intelligent systems) gathering human (data scientists) and nonhuman actors (algorithms, data, digital infrastructure). While this development is currently only in its infancy, digital openness can be seen as the future imaginary preparing this new generation of cybernetic practice.