CHAPTER 5

A Sociology of Interdisciplinarity

Abstract In building upon the cases presented in Chaps. 2, 3, and 4, we develop a *Sociology of Interdisciplinarity* that draws our empirical insights together with resources from Science and Technology Studies (STS), in addition to Sociology of Scientific Knowledge, Research Policy, Infrastructure Studies, Anthropology, and Philosophy of Science. The key novelty of this framework is using STS insights to unpick the dynamics and consequences of interdisciplinary science, which distinguishes us from decades of earlier interdisciplinarity studies and gaps in understanding. Moreover, we not only focus on individual scholars and their experiences but pay careful attention to the wider contexts of interdisciplinary research, such as the impacts of funding structures, different access to resources, and power relations. We are careful in our approach so that our units of analyses—which vary from research groups and projects to whole epistemic communities and research policies—are most appropriate for the problem definitions that we put forward. The framework rests on a set of six dimensions, which we discuss in relation to current debates in the literature and our empirical analyses.

Keywords Funding structures • Epistemic cultures • Boundary objects • Disciplinary appropriation • Interpretative flexibility • Interdisciplinary energy research

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https://doi.org/10.1007/978-3-030-88455-0_5

5.1 Introducing a Sociology of Interdisciplinarity

We have examined the dynamics of large-scale energy research projects in three different cases: one on holistic interdisciplinary systems thinking in UK energy research (Chap. 2); another on interdisciplinary environmental energy research in Norway (Chap. 3); and a third case of a more conventional, albeit cross-professional, monodisciplinary energy research project in Finland (Chap. 4). Through these dedicated chapters, we have made clear the cases have been fundamentally shaped by the traits of the energy systems and policies in their respective countries, as well as also consequently reflected upon the various different configurations of (interdisciplinary) research practice in play.

In this concluding chapter, we now draw our key lessons together through synthesising a new framework, a *Sociology of Interdisciplinarity*. Our intention in presenting this framework is to put the analytical spotlight firmly on the social dynamics of (doing) interdisciplinarity, in a bid to spark further inspiration for scholars and practitioners in their future work. We would also hope, despite much of this book being built on a bedrock of interdisciplinarity in energy research, that this framework is of direct use and interest to all those interested in well-functioning interdisciplinary research systems. This could include, but not be limited to, managers of funding programmes, research evaluators, administrators, policy officers, and the like.

Our core argument in this book is that interdisciplinary research should be studied as social activity and the scientific ideas that it generates explained by sociological dynamics. This general interest is not novel: it has been the ground for decades of Social Sciences and Humanities (SSH) research programmes. Indeed, an interest in 'interdisciplines', which integrate conventional academic disciplines, and 'problem-based science', which cross disciplinary boundaries, dates back several decades in research and higher education policies (e.g. Barry et al. 2008; Gibbons 2000; Nowotny et al. 2001; Klein 2010). These themes have remained important in current discussions about interdisciplinary collaborative teamwork (Balmer et al. 2015).

A large literature on this topic has generated important insights—such as the differences between *interdisciplinary*, *multidisciplinary*, and *transdisciplinary* research and their approaches and methods (Klein 2010). We visited these approaches when introducing our position on key debates in the literature, in Chap. 1 (Sect. 1.2.1), but it bears repeating that interdisciplinarity is a complex concept and does not have a single definition. Nevertheless, certain taxonomies pertain to it, for example, between theories and methods that are interdisciplinary (i.e. integrating different academic disciplines in knowledge production), multidisciplinary (i.e. juxtaposing disciplines but keeping their original identities), and transdisciplinary (i.e. transcending disciplinary-based knowledge altogether).

The discourse on interdisciplinarity and multidisciplinarity is not merely of theoretical, academic debate, but is also based around real ground-level experiences of doing funded research. Indeed, it forms an increasing part of how energy researchers now work. In 2009, for example, the UK's network of academics UK Energy Research Centre (UKERC) produced an overview of the interdisciplinary research centres in the country (Wang 2009). At this point, the number of new energy centres and networks that cut across standard university departmental and faculty structures was already increasing visibly. The report found nearly 40 cross-departmental networks, interdisciplinary centres, and cross-institutional collaborations across the country. When this document was updated in 2019 (Silvast 2020), the activity around interdisciplinary energy centres and networks in the UK had grown so large that it would no longer meaningfully fit into one review. A response in this updated review was therefore to no longer represent all interdisciplinary initiatives and networks, but instead pragmatically detail research projects that were performing interdisciplinary agendas.

Relatedly, Mark Winskel (2018) has brought together a conceptual interest in interdisciplinarity with the pursuit of energy research in the UK, through various activities under the UKERC banner. He highlights several main choices and trade-offs in interdisciplinary energy research, including disciplinary diversity, integrated knowledge production, and how much non-academics (e.g. industries, publics, and policymakers) participate in the co-design of research (which Winskel names as *transdisciplinarity*, rather than mere *interdisciplinarity*). Our book builds on similar insights considering how interdisciplinarity is being configured in particular energy projects. It builds from Science and Technology Studies (STS)—an underutilised perspective in the study of interdisciplinarity in energy research.

Working from these perspectives, this book has provided a detailed examination of how interdisciplinary energy research has been conceived, and what consequences and dynamics it has had especially to those involved in interdisciplinary research projects themselves. It produced fresh insights into the lived experiences and actual processes underlying interdisciplinarity, rather than how it is being merely explicitly advocated. To accomplish this goal, we presented empirical studies on large-scale energy research projects set between academia, public policymakers, and industries, using mixed SSH methods ranging from ethnographic fieldwork and qualitative interviews to desk-based research and literature reviews. These accounts recounted how interdisciplinarity works in practice, from the perspective of those carrying it out—what works, what does not work, what are the challenges, and so on—which are increasingly relevant given the prevalence of and very real steer for most energy scholarship to be interdisciplinary. We provided ground-level experiences of how interdisciplinarity is done, from an empirical perspective: providing interesting stories and experiences that energy research(ers) can relate to.

Our particular aim has been to move between different scales of interdisciplinarity and explain how these scales are interconnected: from the experiences of scholars, on the one hand, to the impacts of funding structures, the epistemic cultures that produce knowledge on energy issues, and the social dynamics of research projects on the other hand. This book's key contribution is in designing and presenting a new framework, a *Sociology of Interdisciplinarity*, which combines our results and draws insights from various literatures to unpack interdisciplinary research in practice.

The framework rests on six dimensions (Table 5.1), each of which is discussed in turn in the following sections, in relation to the literature and this book's empirics: the impacts of funding (Sect. 5.2), epistemic cultures (Sect. 5.3), boundary objects (Sect. 5.4), appropriating disciplines (Sect. 5.5), interpretative flexibility (Sect. 5.6), and the importance of disciplines (Sect. 5.7).

Before an explanation of each dimension, we believe it useful and instructive to offer some supporting advice on our proposed use of this framework:

- The dimensions are not intended to be comprehensive, but instead represent some of the main issues that spoke to us through the studies in this book. There are inevitably other dimensions, and we are eager to be pointed towards them. We have selected six sets of issues that we think do not get the attention that they deserve, despite STS literature indicating their potential fruitfulness.

Table 5.1 A Sociology of Interdisciplinarity and its six dimensions

Dimension	*Explanation*
1. The impacts of funding	Research funding has effects in bringing about certain kinds of working practices, research teams, and research outputs.
2. Epistemic cultures	Interdisciplinary projects produce knowledge in specific epistemic cultures—knowledge-oriented groups of scholars—that cut across broad academic disciplines (e.g. Engineering, Physics, various SSH).
3. Boundary objects	Knowledge moves between the epistemic cultures in interdisciplinary projects via special boundary objects (e.g. computer models, calculations of risk).
4. Appropriating disciplines	Interdisciplinary projects can involve the more powerful disciplines appropriating the tools and methods of other disciplines.
5. Interpretative flexibility	Interdisciplinary projects create a ground for more disputes about how 'facts' and technologies should be interpreted. While interdisciplinarity is often favoured by funding bodies and researchers as a label, this also conceals the considerable interpretative flexibility of the concept itself.
6. The importance of disciplines	Continued importance of conventional academic disciplines in interdisciplinary contexts.

- One is free to use this framework in any way that they see fit: we envision that uses range from zooming in on one particular dimension, to covering some or all of them in parallel to understand a specific research programme or project.
- The framework was clearly built for critical-SSH analyses, but we are fully committed to them enhancing reflexivity in practical decision-making situations. This could involve, for example, designing a new funding instrument, interdisciplinary evaluation, starting an interdisciplinary programme in a university, or many other uses.
- Lastly, we emphasise this as one Sociology among others—*a* Sociology of Interdisciplinarity and not *the* definitive Sociology. We very much hope that colleagues will offer critique on these dimensions, drill deeper through further empirical contexts, and offer evidence to these dimensions. What follows is therefore a starting point to stimulate reflections on working in an interdisciplinary manner.

5.2 The Impacts of Funding

The first dimension of our framework provides viewpoints for examining university research funding and how the source of funding affects scientific activities, in this case, interdisciplinary research projects. Previous scholarship addresses this issue as the structuring impact of funding (Salmenkaita and Salo 2002). The key arguments about the (un)intended consequences of competitive research funding (Geuna 2001) and the underlying funding negotiations processes (Davenport et al. 2003) are now several decades old. That increased reliance on external funding and competing for it affects research output is—or has now also become—common sense among academic scholars. Yet, empirical research has demonstrated that the outputs of researchers reliant on applied and externally-funded projects do shift in the longer term (Goldfarb 2008). Comparative studies show this especially between scholars mainly working in university-funded projects versus externally-funded projects. The general observation is that if projects require a large degree of support from non-academic sponsors and partners, this impacts upon the outputs that researchers prepare, especially journal articles (Manjarrés-Henríquez et al. 2008).

Such arguments certainly fit with well-established ideas in STS around how documents carry agency—in this case, how funding documents (call texts, proposal templates, etc.) are actively scripting responses from those applying for said funding, and thereby also directly shaping its subsequent outcomes and recommendations. As Royston and Foulds (2021, p. 3) put it, such "documents contextualise the goals that frame energy research, and simultaneously enact and embed—albeit through complex, political and negotiated processes—the knowledges produced by research". Indeed, this has been the rationale behind a number of recent studies that have called for greater diversity in energy research and innovation funding, with a particular emphasis on moving away from natural/technical science-based or techno-economic solutions (e.g. Foulds and Christensen 2016; Genus et al. 2021; Overland and Sovacool 2020).

In general, though, the points that past scientometric and research policy studies make, however, are still focused on disciplinary-based research systems (c.f. Winskel 2018), just with a marked and increasing reliance on competitive external funding—which many argue is only becoming more uncertain and fickle, as a result of its increasing normativity (c.f. Foulds et al. 2021). Furthermore, it is indeed true that many interdisciplinary energy projects are reliant on major and long-term external grants. These kinds of large grants correspond with a pertinent requirement of interdisciplinary projects, as recognised in the UK: the need to learn between disciplines and coordination/maintenance of interdisciplinary collaboration (Hargreaves and Burgess 2009; Longhurst and Chilvers 2012). But these kinds of grants also have specific values and priorities attached to them. During the past years, interdisciplinary grants have been especially linked to delivering fresh insights on grand societal challenges, notably energy and climate issues. Examples are easily available for all to see, such as the European Commission's mainstreaming commitment to SSH (Kania and Bucksch 2020), which has often led to the deployment of forms of SSH that are "minimal, disciplinarily-narrow, overly-instrumental and lacking [of] critical perspectives" (Foulds et al. 2020, p. 5) within large-scale interdisciplinary energy projects.

The Norwegian Centres for Environment-Friendly Energy Research (FMEs) (examined in Chap. 3) were evaluated by a strategic and finance consultancy (Impello 2018), highlighting important findings on the instrumental outcomes that they were meant to achieve. The main research question of the evaluation report was whether public research funding to energy research has been worth it in monetary terms. While it acknowledges research results (e.g. knowledge, concepts, and systems), the report's main conclusions are about impacts that are quantifiable: that is, calculations on the future impacts of energy research to emissions, energy use, economically, and for innovativeness. Here, large grants were expected to generate measurable effects to energy provision and the economy (while the report includes a category of other qualitative effects, which includes impacts on society, these are only assessed as binary—i.e. as detected or not detected).

The evaluation does not explicitly talk about the effects of interdisciplinary collaboration and explicitly leaves the social scientific FMEs outside of the evaluation (Impello 2018, p. 22). Our literature reviews in Chap. 3 point to the prevalence of social scientific and sociotechnical publications on FMEs appearing as grey literature (e.g. reports, evaluations, and student theses), taking precedence over peer-reviewed articles on this topic. Resembling the scientometric studies that observe support duties externally funded projects (Manjarrés-Henríquez et al. 2008), the interviews with FME members recognised Social Scientists as often becoming their administrative coordinators, communication experts, or supporters studying, for example, innovation or consumer acceptance. Complementing this focus, the Finnish case in Chap. 4 points to how scholars working for external funders became the producers of policy-relevant costs and figures, where the academic methodological considerations on these figures (and the social scientific qualitative valuations related to them) were often difficult to translate to direct policy and regulatory relevance. All of this suggests that the projects with large grants configure particular roles for SSH research—also recognised in the UK whole systems research (Mallaband et al. 2017).

Concurrently to large grants, however, some funding agencies have encouraged interdisciplinarity in almost diametrically the opposite way. Some of them engage in short-term, facilitated projects to encourage interdisciplinary research. An example from the UK is the Sandpit funding model, developed a decade ago by the Engineering and Physical Sciences Research Council (EPSRC) in the context of whole systems research. In the sandpits, which lasted only a few days, invited academics held workshops and engaged in brainstorming with the eventual aim of generating competitive bids for large-scale grants. This short-term model was said "to bring individual academics together who would not, under normal circumstances, be likely to meet and share ideas" (Hargreaves and Burgess 2009, p. 8). Here, the idea is that unconventional ideas will be encouraged by transgressing normal ways of working within academic disciplines.

This general model of short-term sandpits can also be observed within large granted research projects. One possible manifestation of it is the recurrent reliance on workshopping and project meetings to come to more relevant interdisciplinary themes for research. Notably, nearly all of the findings of interdisciplinary working in the CESI project in Chap. 2 were drawn from various kinds of project meetings: events where academics from different disciplines were required to come together and share their ideas on a set common theme, such as energy demand research, future energy scenarios, or policy relevance of energy modelling tools. The ideal seems to have been that interdisciplinary knowledge production happens in encounters during the meeting, and that one crucial output of it is an organised dialogue in itself. Workshop notes were collected and shared as one relevant material outcome of these encounters. Conversations and presentations held at workshops also sometimes became the resource for further project work, as earlier workshop conversations would affect future workshops or concrete decisions being made on the direction of the modelling tools.

Another, and a third, potential way that funding may affect interdisciplinary working is the need to frame disciplinary differences in ways that are recognised by grant funding agencies. Interdisciplinary research is, by definition, unconventional. However, as two scholars in the Social Studies of Science note, "to gain funding for such research, scientists are forced to outline unconventional ideas in ways that still relate to recognised concepts and findings, as well as adhering to the conventional requirements of relevant fields of research" (Philipps and Weißenborn 2019, p. 884). Indeed, from our own proposal-writing experiences, we can certainly point to numerous examples of colleagues creatively relabelling themselves along disciplinary lines, in a bid to align with funder expectations.

Furthermore, STS scholars have also collaborated with Julia Thompson Klein—the noted interdisciplinary studies scholar—to examine how interdisciplinary research was carried out in project proposals funded by the Academy of Finland (Huutoniemi et al. 2010). They noticed that ideal types and conceptual categories of interdisciplinarity were common, as was reliance on names of disciplines in grant applications. Instead of these explicit labels, the study scrutinised interdisciplinary research content—focusing on how research had crossed conventional bodies of knowledge, concepts, methods, and research practices. This study came to constructive conclusions on genuine interdisciplinary work rather than mere teams of interdisciplinary scholars. Interactions between research fields happened frequently and were substantial for the examined projects. But to discover this, the scholars had to look at research content itself, thereby going beyond how disciplinary and interdisciplinary labels were explicitly articulated.

This finding directly brings us to the next dimension and the need to study how interdisciplinary research is being carried out in project work, more than the labels given to it.

5.3 Epistemic Cultures

The concept of epistemic cultures was popularised by anthropologist Karin Knorr Cetina (1999), who developed the concept in her detailed ethnographic study of two fields of science: that of High-Energy Physics and Molecular Biology. Epistemic cultures can be defined as units that "produce and maintain specific understandings of what valid knowledge is and how it should be produced and understood" (Kruse 2021, p. 3). Knorr Cetina based her study of knowledge production on ethnography of scientific laboratories and their working practices and cultures, but the concept has been since applied to a variety of problems in STS, ranging from citizen science projects (Kasperowski and Hillman 2018) to forensic evidence

(Kruse 2021). The underpinning issue with such studies is that they have been developed through using epistemic cultures to investigate scientific disciplines, which aligns with the agendas of this book.

Knorr Cetina's (1999) approach to disciplines is constructive: disciplines are apt for addressing how science is organised. Yet, they offer less cogent descriptions of expert practice, which is why she coined these practices as 'epistemic cultures':

> In the past, terms such as discipline or scientific speciality seemed to capture the differentiation of knowledge. The notion of a discipline and its cognates are indeed important ones in spelling out the organising principles that assign science and technology to subunits and sub-subunits. But these concepts proved less felicitous in capturing the strategies and policies of knowing that are not codified in textbooks but inform expert practice. The differentiating terms we have used in the past were not designed to make visible the complex texture of knowledge as practiced in the deep social spaces of modern institutions. To bring out this texture, one needs to magnify the space of knowledge-in-action, rather than simply observe disciplines or specialties as organising structures. (Knorr Cetina 1999, pp. 2–3)

This stream of research on epistemic cultures connects well with our findings from our three cases on interdisciplinary energy research. Indeed, the interdisciplinary energy agendas that we have observed were not directed towards disciplinary (sub)units that are contained in textbooks and should still inform the strategic discourses of interdisciplinary researchers. Instead—as we explain further in Sect. 5.7—the agendas focused on how researchers work, using various methods and tools, reasoning, and other elements in their "machineries of knowledge construction" (Knorr Cetina 1999, p. 3). This focus includes how such knowledge practices are assigned with cultural significance in different contexts.

To be clear, Knorr Cetina's work on epistemic cultures examined the diversity of scientific laboratories and, in doing so, deep-dived into the detailed ways of working, attributing of scientific authorship, and collective structures in these normally restricted field sites. This book has also used ethnography to study the inner life of collaborative interdisciplinary teams—especially in Chap. 2—but applied it more strategically, complementing it with other data sources (e.g. written documents, researcher interviews, and literature reviews) especially in Chap. 3, and drew on data gathered whilst working in a conventional applied project in Chap. 4.

With these clarifications in view, we strongly advocate the concept of epistemic cultures as a means by which to explain the dynamics of interdisciplinary research in these three settings.

To us, epistemic cultures offer an appropriate description of the differences that arise when various teams come together to solve problems in large interdisciplinary energy projects. In Chap. 2, it helped point out that the science of energy modelling, now widely applied in interdisciplinary projects, is in itself disunified, divided into subcommunities of scholars that model a particular subsystem of the whole energy system, and attribute meanings differently to their findings. The point is not that they are different subunits of one discipline—such as subdisciplines of the Physical Sciences and Engineering—but that their knowledge about the energy system is made in a widely different manner, giving rise to different epistemic cultures (Silvast et al. 2020).

We saw these epistemic differences manifest between so-called energy demand modellers on the one hand, who are attuned to the intricacies of energy use in everyday life and the uncertainties of measuring it, and more conventional energy supply modellers on the other hand, for whom energy demands of everyday people appear as statistical properties to be fed into the energy computer models and solved as part of flow equations. We would argue that the salient difference was in their machineries of producing knowledge: in this case, what the model knew of the target system.

Chapter 4 showed similar epistemic differences among the scholars who all work in power systems technology. At least three epistemic cultures had influenced the practice of producing more scientific costs for the reliability of electricity infrastructure: one focused on statistical methods; another on economic modelling; and a third took an empirical, mainly pragmatic, approach to these costs. Each of these cultures found it challenging to work with another culture to solve problems, hence highlighting similar problems between knowledge production within one and the same discipline that would be normally addressed as problems in working between academic disciplines.

The differences observed in this book between Energy Social Scientists and Engineers, such as modellers, can be also explained by their different epistemic cultures: concerning not only the obviously different ways in which these scholars produce knowledge, but also differences in attributing authorship and working collectively (i.e. epistemic cultures). There is a distinct contrast between the more collectively focused, collaborative-modelling communities and the Social Scientists and Humanities scholars that often work in a solitary way or as part of small dynamic groups of colleagues (Beaulieu 2010). These differences manifest, for example, when both epistemic cultures are asked to come to solutions to future energy issues, and the steps taken may be entirely different across them.

Different epistemic cultures may also go some way to explain disciplinary balances in interdisciplinary energy projects. In Chap. 3, we saw that Social Scientists had constituted the minority in some of the early Norwegian Centres for Environment-Friendly Research (FMEs). While various reasons may be behind this resource distribution, one possible explanation can once again be offered by epistemic cultures. Namely, the culture of some Engineers may be based on the assumption of large teams needed to work collectively to run models and to experiment with technologies, whereas Social Scientists are expected to work in relative isolation. The solution to change these disciplinary balances within interdisciplinary projects is therefore not only a simple matter of redistributing resources, but it also requires acknowledging the different cultures of knowledge production, and how those differences can be understood and appreciated.

But if epistemic cultures successfully highlight the inner life of particular scientific knowledge production within a bounded working culture, there is one key limitation that pertains to the concept. This, as Kruse (2015, p. 110) remarks, is that the concept "does not address the question of how knowledge might travel between epistemic cultures". This critique is highly pertinent to our cases, as most interdisciplinary energy projects are exactly about the exchange of knowledge between different knowledge-oriented cultures, or whole disciplines. We need more and different conceptual resources from STS to more fully address this issue, which takes us to our next dimension: boundary objects.

5.4 Boundary Objects

In Chap. 2, we visited the field of UK energy modelling and learnt about some of the models used and being developed, especially by the EPSRC-funded Centre for Energy Systems Integration. Another known modelling example in the country, though now superseded, is the MARKAL,[1] which was also reviewed in the same chapter. The MARKAL model was advanced by academics but applied in energy and climate policy at large. It was also

[1] MARKAL: MARKet and ALlocation.

in use for a remarkably long period of time; starting from early developments in the 1970s, to it still being used in the late 2010s. UK government policies and priorities changed markedly during this time: from energy systems analysis and strategy development during the 1970s oil crises, for example, all the way to energy market liberalisation in the 1980s, and then current decarbonisation goals.

What made this energy computer model successful for so many stakeholders and in a rapidly changing policy environment? One possible explanation could be its sheer complexity and wide scope. The University College London (UCL) Energy Systems Team has claimed rigour and credibility because of the model boasting half a million data elements, and because of the wide-ranging extent of the energy system that it models, from production resources to fuel processing, infrastructures, conversion, end-use, and service demands (UCL 2021).

This complexity of the model is impressive in itself considering that all energy models are necessary simplifications of the system that they represent. Yet, and intriguingly, four UK scholars, one of them based at the UCL, have offered a somewhat different interpretation of the 35 years of history of the MARKAL model (Taylor et al. 2014). They argue that MARKAL was successful mainly because it functioned as a 'boundary object' (Star 2010). This means that MARKAL facilitated dialogue—in practice, bringing together communities of practice with various institutional and professional logics. The examples that the authors use are academics and policy practitioners. While arguably sharing the same overarching goal of decarbonisation, these communities can differ in respects to the rationales of how this goal should be reached: where academics want to introduce more debate, for example, policy practitioners may need to close the debate to make decisions. Nevertheless, as a boundary object, the model can fulfil both these goals at the same time as well as allowing knowledge integration across the boundary.

Boundary objects are artefacts, concepts, or methods that lie at the interface of different social worlds, such as politics and the economy. They are also potentially at the interface of different epistemic cultures that are special kinds of social worlds, which are made coherent by their members working with the same specialised tools and technologies (Clarke and Star 2007). Boundary objects facilitate co-operation and coordination between such social worlds because the identity of these objects—even if not all their details and intricate functioning—is understood across these worlds. In addition to computer models, earlier literature in energy research cites databases, standardised methods, and forms as examples of boundary objects (Taylor et al. 2014). The cases in this book offer several similar and other further examples.

For example, in Chap. 2, we presented computer models that are functioning, or are at least expected to function, in very similar manners to MARKAL in the UK. In fact, these models (as boundary objects to policy decision-making) received specific and explicit attention among the project members, even if not in the same terminology. The concept of boundary objects introduces a novel interpretation of how this policy relevance was happening. We could, rightly, critique the energy systems modellers for not developing a deeper understanding of how policy processes and governance work and the manifold cycles involved in them. Yet, we could also argue that the very point of models as boundary objects is that they act as intermediaries between these social worlds. Neither the policy community needs to understand the intricacies of academic energy modelling, nor can the modelling community understand the details of policy processes, but the boundary object fulfils both logics and rationales. In Chap. 2, the same could be said about the concept of energy demand and future energy scenarios: objects and methods whose identity was understood across different parts of a large project, and that actually facilitated the project's co-operation and coordination, even if there were many implicitly different interpretations of what these concepts could mean. That is to say, there are simplifying, reductive steps involved in interdisciplinary exchange that allow knowledge trading to happen.

In Chap. 4, the calculations of reliability costs for infrastructure, and the very concept of there being such costs, resemble boundary objects (see Silvast and Virtanen 2019). Market regulators interpret the costs to be about meeting the expectations of consumers with their 'willingness to pay' for electricity reliability. This cost is 'performative' as its main purpose is for the energy distributors to internalise the need to be reliable: it does not have to be an 'actual cost', although that is obviously of value. The researchers studying these costs interpret them to be an empirical phenomenon that exists among real consumers out there, or an object to be examined by statistical methodologies. The notion of there being costs for breakdowns of a ubiquitous critical infrastructure service is shared by all the involved professional communities, yet the rationales for using and examining these costs differ. Nevertheless, not one of them would claim that there are no reasonable costs to be found, although this would be a typical social scientific critique of the rational costs of energy use in everyday life (e.g. Christensen et al. 2020). In other words, a shared level of credibility is required for working across social worlds in projects.

In the Norwegian case in Chap. 3, the concept of environmental innovation was also similar to a boundary object, especially during the early days of the large centres studied. Even if innovation initially had no single interpretation, its identity was understood in a somewhat coordinated (yet flexible way) that could be yielded by the knowledge production tools of the respective epistemic cultures. In this setting, as shown by the evaluation (Impello 2018), innovations could indeed mean commercialised inventions as is traditionally the case (Schot and Steinmueller 2018), but they could also encompass new tools and methods such as energy systems analysis, optimisation and simulation, definition guidelines, and even handbooks for environmental design. We could critique the innovation term for lacking conceptual depth, but boundary objects take the argument in a different direction: namely that as boundary objects, these innovations were likely able to coordinate the group activities and generate coherence among them. As Taylor et al. (2014) showed with the MARKAL, boundary objects can function to connect professional communities even when they do not have a necessary disagreement, but simply have to operate in different institutional and professional contexts.

In the next section (Sect. 5.5), we study further the moving of methods and approaches between different social worlds and epistemic cultures, especially relating to Social Sciences and other disciplines. This qualifies how, in contrast to boundary objects that mediate between social worlds, translating scientific methods between the confines of disciplinary identities is not always frictionless and unproblematic. In building on this still further, Sect. 5.6 then discusses how scientific and technological disputes may relate to interdisciplinary projects.

5.5 Appropriating Other Disciplines

Diane Forsythe's famous research in STS was situated at the intersection of Medical Informatics, Computer Sciences, Ethnography, and Anthropology—hence why she operated at the interstices of the Natural Sciences and Social Sciences, leading to her research being fundamentally interdisciplinary by design. In describing these interdisciplinary collaborations, which tended to centre on user studies, she coined the term 'appropriation'.

In contrast to its current use in 'cultural appropriation', Social Scientists have traditionally used the term in a more neutral manner. It refers simply to people acquiring new things, such as consumer products. In this sense, for example, it can be said that fitting new Information and Communication Technologies to people's lives is 'appropriation', where the main reference is to the negotiations and considerations that led to acquiring these technologies (Haddon 2011). This more neutral meaning of the term also characterises how we use it in this book, since we want to avoid claiming that there are some actors appropriating the property of others in collaborative projects.

Forsythe (1999, 2002) made an intriguing discovery in her work with Medical Informatics, working in these fields herself in the role of an Anthropologist. She noted the increasing prevalence of anthropological ethnographic methods that supported software design since the 1970s. While this led to an increase of trained Anthropologists employed by research laboratories and companies, it also had another unforeseen consequence: non-Anthropologists, such as Physicians and Computer Scientists, started to borrow ethnographic techniques in their own work. That is to say, the dynamics of appropriation emerged. While such borrowing is not inherently problematic, she argues that ethnographic expertise was lost during translation, meaning that social scientific methods became misunderstood at large as a result. Building on experiences from such collaborations, Forsythe (1999, p. 130) summarised what she called "six misconceptions about the use of ethnography in design":

1. Anyone can do ethnography—it's just a matter of common sense.
2. Being insiders qualifies people to do ethnography in their own work setting.
3. Since ethnography does not involve preformulated study designs, it involves no systematic method at all—"anything goes" (p. 130).
4. Doing fieldwork is just chatting with people and reporting what they say.
5. To find out what people do, just ask them!
6. Behavioural and organisational patterns exist "out there" (p. 130) in the world; observational research is just a matter of looking and listening to detect these patterns.

Forsythe (1999) proceeds by correcting and qualifying these misconceptions, and we draw from some of that now, but the discussion on the 'proper' use of social scientific methods is not in the direct agenda of this book. What is more interesting here is asking why appropriation had happened in these collaborations, given that they had also typically perceived the Social Sciences as 'new' and 'soft' disciplines in the very same settings (Forsythe 2002). There were myriad reasons for the appropriation, some of them to do with intellectual curiosity and some with the increasing awareness about the Social Sciences as such. Firstly, Medical Informatics involved Physicians, Nurses, Medical Librarians, Computer Scientists, and Information Scientists, hence being at the interstices of Medicine and Computer Science. These were, for a key part, influential and highly educated experts, themselves knowledge workers, some of them with doctorates both in Computer Science and in Medical Science, and already working in interdisciplinary manners. Secondly, many of them had been routinely exposed to the Social Sciences: namely, having had "some acquaintance with ethnography from reading publications that draw on ethnographic research, hearing talks at professional meetings, working with social scientists on research teams, and/or being subjects of ethnographic inquiry themselves" (Forsythe 2002, p. 145).

In other words, more generally, it is the exposure to social scientific ways of working that enabled the influential and interested knowledge workers from other disciplines to appropriate the social scientific method to their own work. This explanation also clearly seems relevant to the interdisciplinary energy research collaborations we have been studying in this book. It was especially pertinent to Chap. 2's CESI 'demand modellers' project—modellers dealing with everyday energy demands—who had branched over to the Social Sciences. We could argue that being an insider in studying energy demand also gave confidence for a participant to label their work as 'sociotechnical'. This confirms our observations more generally: technical experts that are insiders to the study of domestic consumers, household technologies, and related subjects, often turn implicitly like Social Scientists, advocating the same applied methods, research questions, and even critiques. This might suggest, as Forsythe (1999) outlined in her misconceptions, that anyone can learn to be a Social Scientist over time as it is mainly common sense. But the assumption is also problematic because social scientific methods are not meant to be common sense, but to run counter to it: that is to say, they are meant to "problematize things that insiders take for granted" (Forsythe 1999, p. 130) towards which an insider is not in a privileged position.

Several other scientists in the CESI project took more distance from calling their work Social Science, but the dynamics of appropriation were still apparent: mainly in the ways of labelling what the Anthropologists and other Social Scientists in the project were expected to be doing, most typically named as, for example, 'consumer research', 'policy studies', or 'qualitative methods'. In this, what appeared was Forsythe's (1999) one key misconception that social scientific method is just about studying what people do—essentially by talking with them, whether they be consumers or policymakers—and descriptively reporting it as a result. In the Norwegian case in Chap. 3, a common expression in these large-scale collaborations was that Social Scientists are addressed in them as 'the people experts'. These kinds of labels set between disciplines may be relatively well-meaning and simply call for inclusion of other perspectives, but they can have severe consequences if we draw from Forsythe's (1999) critique of the expertise implied by them. Ethnography and other qualitative methodologies involve considerable discipline and rigour, and much of the involved expertise is highly technical, as anyone that has taken a methods class in the Social Sciences will doubtlessly know (Robison and Foulds 2019). Thus, when this expertise is underappreciated—that is to say, if the Social Sciences are just seen as a matter of common sense and talking to people—that may encourage short-term studies whose value and rigour may be questionable for the Social Scientists, but also for the research projects at large.

Finally, in the Finnish case in Chap. 4, we saw perhaps the closest expression of what Forsythe (2002, p. 133) calls "deleting" the field of the Social Sciences. In this project that studied the perceptions of laypeople on electricity reliability, qualitative accounts on this reliability were routinely described as 'subjective' and by implication as 'non-objective', 'soft', or even 'unscientific'. However, this assumption is highly dubious, once we consider the histories of the fields that study similar issues. The examination of the costs of electricity reliability is a relatively novel topic. The earliest source that our report on this topic (Silvast et al. 2006) cites was published in 1989 (Wacker and Billinton 1989), and the oldest sources cited in that early paper are in turn from 1972. It is plain that the disciplines of Anthropology, Sociology, and Social Psychology are much older than Customer Cost Studies, and that these disciplines have been routinely applied historically to the study of risk perception (e.g. Douglas and Wildavsky 1983) and to the disruption of normal routines as an impact of different disasters (e.g. Quarantelli 1954, 1960), which could also involve infrastructure disruptions. This accrued knowledge, which would have been directly relevant for examining the costs of electricity interruptions as risks or as disruptive events sociologically, was therefore not utilised because of the hierarchies and divisions of knowledge implied in this project setting.

That said, the first author in this project also experienced other kinds of appropriation, once again resembling what Forsythe (1999, 2002) outlines in her critique. While seen as 'subjective', the qualitative accounts of customer costs were clearly also relevant, and the author was routinely invited to project meetings and later, to talk in industry training events and even write a series of columns to a Finnish trade journal on these issues. These communications were never about the costs or other statistical knowledge, but mainly about how customers 'experience' power failures. Hence, while Social Science–generated evidence was almost entirely 'deleted' from the scientific report and the regulatory model that it informed, it seemed to have found another use in this context. Social Sciences became the servant of Customer Experience Studies, as it was assumed that qualitative accounts from everyday life would discover what the customers actually think and do, and this could be relevant for power companies, for example, in dealing with customer complaints or corporate communications. Such a role can have policy impact in its own right, but it may not speak to an increasing amount of interdisciplinarity assumed to be taking place.

5.6 Interpretative Flexibility

Do commentators agree on what interdisciplinarity means? This section discusses the issue and moves to a commonplace tool from STS: the idea that technologies and concepts have interpretative flexibility. Interpretative flexibility has started to refer to any flexible meanings in general, but the concept has more particular roots, which we visit briefly now to qualify how the concept has been used and informs our own interpretations herein.

The idea of interpretative flexibility has two closely related origins in the history of STS (see summary in Pinch and Bijker 1984). Firstly, within the Empirical Programme of Relativism—a branch of Science Studies—which has focused on disputed knowledge and scientific controversies. Science Studies scholars used these controversies methodologically to examine how social negotiations explain the status of some, especially disputed scientific findings. Namely, when scientists conduct experiments and discover new data, and when these cannot be explained by the established knowledge, the findings acquire interpretative flexibility: what is their correct explanation? Because the scientific findings may have more than one interpretation, social negotiations are drawn upon to close these debates, although the closure may only last for a time. It should be stressed though that the links between scientific facts and external social forces are complex and notoriously difficult to show, and the authors of this theory were not advocating the view that scientific knowledge is a simple result of social agreement. Instead, they simply argued that social processes can play a role in scientific processes, especially when disputed findings are at stake.

Secondly, STS scholars Pinch and Bijker (1984) took the idea of interpretative flexibility and applied it anew in the case of technological development. Their methodological strategy was to study controversies about technology to highlight, again, how social negotiations play into resolving them. The interpretative flexibility in this case refers not to scientific findings but to technologies as such: different social groups have different ideas about what technologies mean, how they should be designed, and how they work. These groups—called relevant social groups when they share the same interpretation of a studied technology—seek to establish their view and eventually the technological controversy is closed and stabilised. Once again, this closing of the debate may be influenced by social processes that are not necessarily scientific or technological, although how that happens is an empirical problem and not straightforward. The pertinent conclusion is that any technology—such as the oft-used example, bicycle—has no single interpretation during its inception and development, but multiple groups interpret the uses, designs, risks of technology, and so forth, differently. This then has an impact on what that technology becomes like.

In this book, we can draw on all the meanings of interpretative flexibility introduced here: the two meanings in classic STS; and the one general meaning, which simply states that concepts have flexibility when they are interpreted differently. Firstly, the Science Studies meaning introduces an intriguing angle to interpretations that happen within interdisciplinary projects. While the classic works talked about a core set of scientists that close controversial debates, in interdisciplinary projects the main actors offer a much wider scope of different kinds of expertise and perspectives. We argue that our cases—such as the energy computer models in Chap. 2, the innovative energy collaborations in Chap. 3, and the cost calculations in Chap. 4—could become more mired in controversy as more epistemic cultures begin interpreting their results. The opening to greater epistemological variety makes integrative interdisciplinary research difficult as a practical matter.

Indeed, it could be said that interdisciplinary projects even explicitly set the stage for the kinds of scientific controversies examined in Science Studies. For an energy computer modeller, for example, a modelling result may be undisputed enough (although we do not want to underestimate the complexity of the interpretation of what constitutes a 'valid' finding from computer models, see Silvast et al. 2020). Yet, Economists, Sociologists, Legal scholars, or Ethicists might have entirely different interpretations of the implications of the same results. Especially theories and methods that lie at the intersection of different disciplines—such as Engineering methods that seek to synthesise expert opinions or the cost calculations of complex risks in Chap. 4—contain potential for causing disputes when their inner logics and functioning are exposed to interpretation by multiple academic disciplines. These kinds of controversies can be generative for new ideas as such, but clearly also slow down the pursuit of science.

The technological meaning of interpretative flexibility from Pinch and Bijker (1984) also finds it corollary in interdisciplinary working. Here, the matter is not so much that findings are disputed, but that different stakeholders will have various interpretations of how energy technologies should be designed and used. A typical example is offered by wind power. Place attachment and concerns about landscape and fairness are among the many factors that are known to affect the interpretation of wind installation. Discussions and opposition have been afloat in many countries that have installed large-scale wind power (see Delicado et al. 2014).

The wind power controversy is outside of our scope, but we draw on it to highlight that interdisciplinary projects, and especially transdisciplinary projects that transcend to non-academics as co-designers of researchers, could increase the number of such disputes that need to be tended to by research. This happens mainly because more and different flexible interpretations will be made effective in these projects. For instance, we would argue that the future energy scenarios examined in Chap. 2 have been shaped by this process: because the future energy technologies that they include, or exclude, are so readily disputed by different stakeholders, it has been relatively slow to produce the scenarios. In other words, interdisciplinary methods that promise to cover a considerable amount of ground also expose a space for controversies considering the flexible interpretations about technology. As Pinch and Bijker (1984) explained, many controversies and disputes are eventually resolved, but sometimes this does not happen by consensus; at times, it can require re-interpreting what the problem was in the first place. Undoubtedly, interdisciplinary projects will need a toolbox of such strategies available if they are to succeed.

Lastly, we can draw on the more generous meaning of interpretative flexibility and note that it has resonance to interdisciplinary working. It is by now well established that the concept of interdisciplinarity has no single meaning and cannot be defined in any exactitude (Huutoniemi et al. 2010; Klein 2010). It is thus obviously clear that interdisciplinarity, multidisciplinarity, transdisciplinarity, and crossdisciplinarity are often used interchangeably, since they have interpretative flexibility. For example, while interdisciplinary and multidisciplinary are sometimes simply exchangeable, at other times, a difference is made between them that suggests academic interdisciplinarity literature was drawn upon. The flexible use of these terms is not to be dismissed as such (there are no clear alternatives that would offer a deeply anchored designation, so any conceptual taxonomies that work should be seen as adequate for their purpose). But it is still worth reminding ourselves that the term 'interdisciplinarity' conceals a considerable amount of flexible possibilities for research designs, approaches, methods, and theories that are not always explicated when the term is used.

Another relatively common and established conclusion is that interdisciplinary projects give rise to different interpretations of the core concepts that they use. As we have seen in Chap. 2, these flexible concepts include energy demand, energy scenarios, and even the very concept of what is an energy model. These terms might be understood differently in various energy-related sectors and epistemic cultures, and the same could be said of the key terms drawn upon in Chap. 3 (e.g. environmental innovation) and Chap. 4 (e.g. energy costs). Here we visit this theme only relatively briefly because there are good lexicons available that precisely address the diverse interpretations of energy-related language and what uses these concepts could imply (e.g. Foulds and Robison 2017).

Huutoniemi et al. (2010) come to other interesting conclusions when they study how interdisciplinarity manifests in research proposal writing in Finland. Here, the interpretative flexibility of interdisciplinarity is not merely an abstract observation. It is genuinely difficult to find out when interdisciplinarity is more of a rhetoric and when it concerns work that explicitly integrates academic disciplines. As we argued in Sect. 5.2 on epistemic cultures, aligning with what Huutoniemi et al. (2010) propose, the working practices of scientists offer one route to observe this integration empirically. Related to this, the degree of interdisciplinarity is often difficult to value in exactitude. As Chap. 1 outlined, interdisciplinarity simply means that more than one discipline is brought together. But then the question becomes, which disciplines should these be? When Power Systems Engineering is brought together with High Voltage Technology approaches, is this interdisciplinary? Or is it only when Sociologists are working with Power Systems Engineers? While there seemingly is no privileged answer, and both are true by strict definition of interdisciplinarity, some such as Winskel (2018) suggest distinctive forms of interdisciplinarity—called whole systems research—which work across a wide disciplinary range. Thus, there is more research that needs to be done on overcoming the interpretative flexibility of interdisciplinarity and making distinctions that scholars and practitioners can use, such as between more radical and less radical versions of interdisciplinarity. Another potential route, which will we end with, is to ask once again: why are academic disciplines important, even in highly interdisciplinary circles?

5.7 The Importance of Disciplines

This book has examined the social activities that surround interdisciplinary energy research. It has highlighted lessons, strategies, stories, and what works and does not work. While we have been highly focused on these sociological dynamics in this book, these lessons are obviously not meant to claim that interdisciplinarity does not work, whether in theory or in practice. It should be clear that we are both vocal supporters of more interdisciplinarity in energy systems and have spent most of our scholarly careers in advocating these kinds of research and study programmes.

We want to end, though, on a slightly more ambivalent note as concerns the academic literature on interdisciplinarity. Before we start this, we want to stress the value of these new concepts and their extensive discussion over the past decades. This has not only generated academic impact that has lasted for decades, but deeply affected how scholars addressing grand societal challenges now work. A good example is given by the UK, where the amount of interdisciplinary and cross-institute energy networks has grown too extensive to fit it into one review, as was mentioned in Sect. 5.1.

Yet, we must also admit to certain conceptual ambivalence about the discourse of interdisciplinarity. It is clearly the case that interdisciplinarity, transdisciplinarity, and multidisciplinarity have received numerous designations and detailed discussions both in academic works and in official documents (see Klein 2010 for a review). That said, many whole volumes and books published on interdisciplinarity contain no attempt to define what is being integrated by being interdisciplinary—namely, what is an academic discipline? To use the terms of this chapter, 'discipline' appears to have become a kind of a boundary object (Star 2010) that integrates various social worlds that talk to the increasing importance of interdisciplinarity, yet very few try to designate what exactly disciplines are.

However, there are important pockets to look for in STS for understanding disciplines, the most famous of which is physicist Thomas Kuhn's (1962) foundational work on *scientific paradigms*. STS scholar, Mike Michael (2017), has also characterised what a paradigm implies: that traditions of scientific research cohere because of a combination of techniques and theories that scientists immerse in. Paradigms grant scientists presupposed ideas and background assumptions, and grounds for training students into the scientific community via specific instruments, ideas, and practices. While paradigms are not the same as disciplines—instead, one discipline has multiple paradigms, as one is superseded by others during scientific revolutions—the important point is that interdisciplinary scholars (including those in our studies in this book) do draw on a large set of assumed instruments and practices, and often explicitly name them as disciplines.

Therefore, the interdisciplinary grey papers in Chap. 2 talk to the importance of Statistics and Mathematics, and discipline-crossing computer models are frequently rooted in the discipline of Physics; the FMEs in Chap. 3 are divided into 'technological' and 'social scientific' centres; and the cost assessors in Chap. 4 still identify themselves as Power Systems researchers. Meanwhile, the existence of energy-related SSH has become an almost universally accepted idea in Europe, not only among research funders (e.g. the Norwegian Research Council, as examined in Chap. 3), but also among interdisciplinary academics many of whom would contest the idea of a single discipline of Social Science (e.g. Foulds and Robison 2018; Royston and Foulds 2019). This is not contradictory. Even without claiming that disciplines are like monoliths that mostly exist in distant university faculty structures, there are grounds to defend the rigour of possessing certain traditions of thought and presupposed ideas that give scholars their standards of objectivity, forms of proof, and conditions for understanding quality. Without possessing any backgrounded ideas and ways of attributing meaning to findings, knowledge production would become practically impossible, perhaps a kind of never-ending controversy that STS scholars describe in the context of interpretative flexibility; a dispute without a closure (Pinch and Bijker 1984). Therefore, we argue, scholars should still call themselves Anthropologists, Sociologists, Geographers, or any other disciplinary identities they resonate with, even amid the influential discourse on increasing interdisciplinarity.

We discussed in Chap. 1 that Jacobs (2013, p. 29) likened disciplines to professions as both involve scholarly associations, conference meetings, and publication in specific peer-reviewed journals. Of course, these definitions are up for debate and we, like many other interdisciplinary Social Scientists that we know, remain ambivalent about the importance of disciplines and interdisciplines. One could certainly and easily show that various interdisciplines—such as our own STS—now host their own journals, conferences, associations, and avenues for receiving doctoral degrees, and have set up such arrangements with great efforts whilst remaining rigorously interdisciplinary by identity. The same is true for several other established, new, and emerging fields: from Gender Studies to European Studies, Transport Studies, and much else.

Therefore, both disciplines and interdisciplinarity matter: this much is clear to decades of interdisciplinarity literature. The journey that this book has taken has tried to stress the importance of reflexivity and the situated nature of disciplinary resources and constraints. All those interested in well-functioning interdisciplinary systems should remain aware of the different degrees of recognition and influence that the new interdisciplines have. There is much dynamism and breadth in new interdisciplines—although the same has been said of disciplines—but scholars and students have to confront the confines of the funding structures, publishing practices, and academic positions when pursuing interdisciplinarity in practice. The opportunities for interdisciplinary collaboration can bear fruit only when paired with recognition of academic disciplines to do this work successfully and with rigour. For all those practising interdisciplinary energy research—SSH researchers included—both ambivalences and opportunities are inescapable.

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