Who gets what, when, and how? An analysis of stakeholder interests and conflicts in and around Big Science
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"The union of the political and scientific estates is not like a partnership, but a marriage.
It will not be improved if the two become like each other, but only if they respect each other's quite different needs and purposes."

Don K. Price (1965)

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List of Abbreviations

AfLS	The African Lightsource
CDR	Conceptual design report
CERN	The European Organization for Nuclear Research
CHF	Swiss franc
DG Connect	Directorate General Communications Networks, Content, and Technology
DST	South African Department for Science and Innovation
D4S	Diplomacy for science
EC	European Commission
EDA	Engineering design activities
ESS	The European Spallation Source
ESRF	The European Synchrotron Radiation Facility
EU	European Union
FET	Future and Emerging Technology
HBP	The Human Brain Project
HEP	High-energy physics
HGP	The Human Genome Project
IfA	Institute for astronomy
IGSO	Intergovernmental science organization
INSCONS	Addressing Global Challenges through International Scientific Consortia
IO	International organization
ITER	The International Thermonuclear Experimental Reactor
LHC	The Large Hadron Collider
LTWG	The Large Telescope Working Group
OECD	The Organization for Economic Co-operation and Development
POT	Political opportunity theory
REP	Renewable energy project
RMT	Resource mobilization theory
SAF	Strategic action field
SARAO	The South African Radio Astronomy Observatory

SD	Science diplomacy
SiD	Science in diplomacy
SKA	The Square Kilometer Array
SKAO	The SKA Observatory
S&T	Science and technology
S4D	Science for diplomacy
TIO	TMT International Observatory
TMT	Thirty Meter Telescope
UH	University of Hawai‘i
UK	The United Kingdom
USD	US dollar
URSI	The International Union of Radio Science
QCA	Qualitative comparative analysis

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1. Introduction

Public attention to and academic interest in Big Science has surged in recent years, among other things because some policymakers and scientists frame this type of science as a way to address some, if not all, of the great challenges of our time (Koch and Jones, 2016). In the pertinent scholarship, Big Science is most commonly defined as conventional science made big in three dimensions, namely organizations, politics, and machines (Hallonsten, 2016: 17). This definition reflects that the organization of large scientific projects requires hierarchical structures and big teams that are typically, but not always, formed and organized around large scientific instruments (Cramer et al., 2020: 10). It also indicates that large-scale research projects need substantial funding, in the multimillion- to billion-dollar class, which usually comes from the highest political level (Hackett et al., 2004: 750).

In the 1960s, when the term Big Science was first coined, it was used in a different sense. The physicist and manager of science Alvin Weinberg, for example, used the term to describe what he perceived to be a worrying development in the organization of research and development. Specifically, he argued that Big Science requires the increasing subordination of scientists at the expense of their academic freedom and individual creativity, especially if large-scale research projects are connected to the military-industrial complex (Cramer et al., 2020: 8). In Weinberg's days, Big Science did indeed have a clear military connection and was attuned to a bipolar geopolitical world order (Ulnicane, 2020: 76; Hallonsten, 2016: 5). Accordingly, "Cold War" Big Science was especially prevalent in disciplines such as physics, astronomy, and space science (Crease and Westfall, 2016).

With the end of the Cold War, however, Big Science "transformed" in two important ways (Hallonsten, 2016). First, it began to more strongly focus on "innovation-based growth, sustainability, and addressing grand challenges" (Ulnicane, 2020: 76) as well as favoring practicality and industrial participation over basic science (Westfall, 2012: 439; Crease and Westfall, 2016: 30-32). Second, Big Science became increasingly common in research fields other than astronomy, physics, and space science (Hallonsten, 2016: 6). It has, for example, found its way into disciplines such as neuroscience, biomedicine, and material science.

Both "Cold War" and "transformed" Big Science bring a plethora of different stakeholders with potentially diverging interests and expectations together for a long period of time (Hackett et al., 2004: 749; Anderson et al., 2012; Börner et al., 2021). This includes policymakers, scientists, (scientific) managers as well as local host communities. Each group has considerable, though sometimes different, stakes in Big Science. For instance, policymakers typically perceive Big Science as a means to accumulate or increase national prestige and prosperity (McCray, 2010; Krige, 2013; Riordan et al., 2015; Williams and Mauduit, 2020). Scientists, in turn, hope to shape research agendas for the coming years or decades through Big Science (Baneke, 2020: 169). Finally, local host communities are typically interested in the local socio-economic investments which Big Science may stimulate (Walker and Chinigò, 2018). These diverging interests require stakeholders to negotiate and to compromise between and among one another. In cases where this is not possible, conflicts are likely to arise in and around Big Science.

This thesis aims to shed light on how different stakeholders pursue as well as negotiate their interests within and in relation to Big Science, and to explain how this may lead to conflicts between and among stakeholders. In doing so, it contributes to a deeper understanding of stakeholder interests and conflicts which is of academic and practical relevance as such an understanding lays the groundwork for effective stakeholder and conflict management.

1.1. Literature Review

The existing scholarship on Big Science is highly heterogenous (Capshew and Rader, 1992: 5) and interdisciplinary (Rüffin, 2020: 27), with contributions coming from disciplines as diverse as science and technology studies (e.g. Mahfoud, 2021; Aicardi and Mahfoud, 2022), history (e.g. Cramer, 2020; Brookhuis, 2022), political science and international relations (e.g. Walker and Chinigò, 2018; Ulnicane, 2020; Robinson, 2020; Kaufmann et al., 2020), management and organization studies (e.g. Lambright, 2002; D'Ippolito and Rüling, 2019) as well as sociology (e.g. Hallonsten, 2016; Gastrow and Oppelt, 2018). Given the interdisciplinary nature of the Big Science literature, it comes as no surprise that not all scholars examining large-scale science projects use the same language and terminology. For example, some scholars refer to what this thesis labels as Big Science as "large-scale science projects" (Shore and Cross, 2005), "megascience" (Jacob and Hallonsten, 2012; Bodnarczuk and Hoddeson, 2008), "large-scale research infrastructures" (D'Ippolito and Rüling, 2019), "international organizations" (Zapp, 2018), or "public research institutes" (Jang and Ko, 2019). The following literature review takes this into account and provides an overview of the literature which explicitly or implicitly deals with science collaboration in the multimillion- to billion-dollar class, with the objective of identifying blind spots in the ramifying literature.

In the literature on Big Science, studies which engage in theory-building are few and far between. Most studies borrow existing mid-range theories or concepts from different disciplines to examine specific phenomena in large science collaborations. Theoretical concepts that feature prominently in the Big Science literature include but are not limited to science diplomacy (Höne and Kurbalija, 2018; Claessens, 2020; Åberg, 2021), trading zones (Lenfle and Söderlund, 2019), pork barrel politics (Hallonsten, 2016), and moral economy (McCray, 2000; Baneke, 2020). Principal–agent theory is one of the few mid-range theories that is used in the Big Science scholarship (Hallonsten, 2016). In addition, systematic comparative analyses of Big Science are hard to come by (Rüffin, 2020: 41-42). Noteworthy exceptions are two studies that look into the different pathways that facilitated the establishment of the European Organization for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor (ITER) and the International Space Station (Robinson, 2019; 2020), Shrum et al.'s (2001) examination of the role of trust in 53 collaborations in physics and related sciences; as well as Traweek's (2009) and Knorr Cetina's (1999) seminal comparative studies of several physics and molecular biology laboratories in the US and Japan. Apart from these exceptions, most scholars working on Big Science have so far largely used single case studies (e.g. Hilgartner, 1995; Lambright, 2002; De Mendoza and Vara, 2006; Bodnarczuk and Hoddeson, 2008; Agrell, 2012; Westfall, 2012; Tuertscher et al., 2014; Cramer, 2017; Walker and Chinigò, 2018; Walker, 2019; Claessens, 2020; Chinigò and Walker, 2020; Aicardi and Mahfoud, 2022), a considerable portion of which are descriptive–historical in nature (e.g. Hermann et al., 1987; Velho and Pessoa Jr, 1998; De Mendoza and Vara, 2006; McCray, 2010; Hallonsten, 2011; Riordan et al., 2015; Heinze et al., 2015a; Heinze et al., 2015b; Cramer, 2017; Åberg, 2021; Brookhuis, 2022). Scholars have, for example, chronicled the (early) history of ITER (McCray, 2010; Åberg, 2021), CERN (Hermann et al., 1987), the German national research laboratory DESY (Heinze et al., 2015a; Heinze et al., 2015b), the European Synchrotron Radiation Facility (ESRF) (Cramer, 2017), the Swedish synchrotron radiation facility MAX-lab (Hallonsten, 2011), the Superconducting Super Collider (SSC) (Riordan, 2001; Riordan et al., 2015), the Laser Interferometer Gravitational-Wave Observatory (LIGO I) (Collins, 2003), the Brookhaven National Laboratory (Crease, 1999) and the US Atomic Energy Commission laboratory system (Seidel, 1986).

Four major themes dominate the literature on Big Science. First, studies on Big Science have investigated how scientists collaborate in large-scale research projects (e.g. Merz and Cetina, 1997; Traweek, 2009; D'Ippolito and Rüling, 2019; Aicardi and Mahfoud, 2022).

Focusing on the Human Brain Project (HBP), Aicardi and Mahfoud (2022), for example, investigate how scientists and science funders navigate the tensions and interactions that arise between formal and informal collaborative infrastructures within the project. They find that the formal infrastructures that were created to facilitate and structure collaboration within HBP sometimes clash with the preferences and everyday routines of researchers. D'Ippolito and Rüling (2019), in turn, examine collaboration types at the Institute Laue-Langevin, a science facility that provides one of the most intense neutron sources in the world. In doing so, they show that instrument scientists and users collaborate more or less intensely depending on, first, their knowledge and experience regarding the use of neutrons and, second, their interest in future developments and deepening the collaboration. Studies focusing on scientific collaboration in Big Science have further demonstrated that resources (e.g. Knorr Cetina, 1999; Bodnarczuk and Hoddeson, 2008; Traweek, 2009; Baneke, 2020), scientific objectives (e.g. Hilgartner, 1995; Mahfoud, 2021), work and task division (e.g. Knorr Cetina, 1999; D'Ippolito and Rüling, 2019), as well as management (e.g. Cook-Deegan, 1994; Hilgartner, 1995; Collins, 2003) are of particular interest to scientific communities and often cause conflict between and among them.

Second, Big Science studies have examined which political and scientific compromises as well as conditions facilitate the establishment of Big Science projects (e.g. Hermann et al., 1987; Wang, 1995; Kevles, 1997; Bodnarczuk and Hoddeson, 2008; McCray, 2010; Riordan et al., 2015; Panese, 2015; Claessens, 2020; Baneke, 2020; Åberg, 2021). Such studies on the politics of Big Science have shown that policymakers and scientists typically are most interested in and fight over issues like site selection, financial contributions, scientific access (on this specific issue, see also Langford and Langford, 2000; Williams and Mauduit, 2020), and procurement of goods (Hallonsten, 2014: 35). Krige (2013), for instance, describes how Germany was so adamant about hosting Europe's 300 GEV super proton synchrotron accelerator in the 1960s that it cancelled a high-level meeting to settle the accelerator's siting question at the last minute because it feared that the meeting's outcome would not be in its favor. Studying the US astronomy community of the late 1990s, McCray (2000), in turn, demonstrates that the question of scientific access can ignite fierce debates between scientists and considerably prolong the genesis of a big telescope project. Like Krige's (2013) and McCray's (2000) analyses, most studies on the politics of Big Science have predominantly focused on actors and countries of the Global North, particularly from the US and Western Europe (Velho and Pessoa Jr, 1998: 195), while neglecting to study those of the Global South.

Notable exceptions are De Mendoza and Vara's (2006; 2007) studies of Brazil's and Argentina's efforts to create Big Science facilities for experimental science between the 1960s and 1980s. In those studies, the authors argue that the process of establishing a Big Science facility is less time-consuming and controversial in authoritarian regimes because there is no need for consensus-making between "the forest of boards and committees" which are typically involved in getting Big Science off the ground in democracies (in: Hevly, 1992: 359). De Mendoza and Vara's studies indicate that in authoritarian settings it is key for scientists to convince a few central policymakers or military figures of a project to get it funded. These findings are supported by Velho and Pessoa Jr.'s (1998) study on the genesis of the synchrotron light national laboratory in Brazil. In their study, Velho and Pessoa Jr. seek to "identify similarities and differences between the experience of developing countries" and Western science nations in establishing Big Science facilities. Analyzing the synchrotron light national laboratory, they conclude that countries of the Global South promote national Big Science on similar grounds as countries of the Global North do. In both cases, Big Science aspirations are driven by a "desire to participate in the [science] game with the best possible resources to guarantee scientific leadership and prestige" (Velho and Pessoa Jr, 1998: 208). Velho and Pessoa Jr. do acknowledge, however, that proponents of the Brazilian laboratory were rather modest in their intent as they refrained from establishing a Big Science facility in a mature and costly research field like particle physics. In line with what de Mendoza and Vara (2006; 2007) argue, Velho and Pessoa Jr. hold that the genesis of the Brazilian laboratory differs in one important aspect from that of similar facilities in countries like the US or Japan. Specifically, they contend that in the latter case, a Big Science facility has to be approved by several political and scientific bodies, while "the entire decision-making process of building" the synchrotron light national laboratory in Brazil was "much less democratic" and largely driven by a few scientific and political individuals (Velho and Pessoa Jr, 1998: 209-210).

Third, studies on Big Science have explored and conceptualized the national and regional socio-economic benefits that may result from Big Science (e.g. Florio and Sirtori, 2016; Beck and Charitos, 2021; Kantor and Whalley, 2022), such as CERN (OECD, 2014), the European Extremely Large Telescope (Cunningham and Dougan, 2009), and the Square Kilometer Array (SKA) (Atkinson et al., 2017), a big astronomy project currently under construction in South Africa and Australia. A majority of studies which focus on the economic impact of Big Science investigate innovation and technology transfer processes in the development of spin-offs through and the effects of technological procurement for Big Science collaborations (e.g. Vuola and Hameri, 2006; Autio et al., 2004; Castelnovo et al., 2018; Scarrà and Piccaluga, 2020; Wareham et al., 2022). Case studies on CERN are particularly prevalent in this context (Rådberg and Löfsten, 2023). Florio et al. (2018), for instance, try to identify mechanisms which explain how Big Science can promote learning and innovation in their industrial partners. They also investigate how the Big Science–supplier relationship influences the performance of industrial contractors. To do so, Florio at al. (2018) analyze data from a survey of 669 CERN suppliers. They find that an industrial partner's performance and development improves because of its association with CERN. Florio and colleagues argue that this is the case because being associated with CERN facilitates the acquisition of technical know-how, provides access to scarce resources, and reduces uncertainties for a supplier (Florio et al., 2018: 932). Autio et al. (2004), in turn, use evidence from three case studies of companies that have collaborated with CERN and key assumptions of social network, social capital, and inter-organizational learning theories to come up with 24 propositions that explain how knowledge may spill over from Big Science to industrial companies. Like Florio at al. (2018), they underline that a company's association with CERN boosts new product and business development (p. 118).

As one of the few, Barandiaran (2015) examines to what extent international Big Science collaborations benefit a nation's scientific community. Investigating astronomy development in Chile, he finds that the country's astronomy community profited from and grew thanks to policies that fostered greater involvement of Chilean astronomers and universities in foreign astronomy projects from the 1990s onward. At the same time, Barandiaran contends that foreign scientists and institutions are the main beneficiaries of astronomy development in Chile, in part because the Chilean state caters to their needs, not to those of its own science community. According to Barandiaran, in the Global South, top-down state support for foreign science projects often directly clashes with the interests and needs of the more disadvantaged local scientific community. Broadly in line with Barandiaran's argument, Jang and Ko (2019) show that Big Science collaborations in the high-energy physics (HEP) field benefit "latecomers" like Mexico or Argentina by increasing their scientific output. At the same time, their bibliometric study of HEP "latecomer" publications indicates that an HEP latecomer's most highly cited publications typically remain the product of international collaborations within established and often Western-dominated Big Science installations.

In comparison to the national and regional impact of Big Science, its local dimension has so far been neglected. This applies to both the socio-economic effects and the perception of Big Science at the local level. Regarding the former, there are some notable exceptions. Peterson and Miller (2019), for example, have investigated the impact of the Fermi National Accelerator Laboratory on the Chicago metropolitan area. In addition, several South African scholars have examined the socio-economic impact of SKA on South Africa's Karoo region and its local host community (Walker and Chinigò, 2018; Walker, 2019; Gastrow and Oppelt, 2019; Chinigò and Walker, 2020). In doing so, they have also studied why parts of the local community resist SKA. In large part, their findings align with those of Hawaiian scholars that have examined the "why" and "how" of local opposition to the Thirty Meter Telescope (TMT) on Hawai'i Island (Salazar, 2014; Casumbal-Salazar, 2017; Goodyear-Ka'ōpua, 2017; Case, 2019; Kuwada and Revilla, 2020). Among other things, both strands of literature find that local opposition to Big Science is likely to emerge if community engagement is considered insufficient; if a Big Science facility is to be built on land with symbolic, ancestral, or spiritual significance; if local socio-economic benefits of a Big Science collaboration are perceived to be lacking; and/or if local communities are concerned about the environmental impact of Big Science. Stenborg and Klintman (2012) as well as Kaijser (2016) show that environmental concerns also triggered local resistance to the European Spallation Source (ESS), a multi-disciplinary research facility worth 1.8 billion euros located in Lund, Sweden.

Fourth, the Big Science literature has examined the organization and management of large science projects (e.g. Chaiy et al., 2009; Hallonsten and Heinze, 2012; Boisot, 2013; Eggleton, 2018; Merz and Sorgner, 2022). With respect to organization, most studies have focused on coordination as a central organizational challenge in Big Science. For instance, in their case study of CERN's ATLAS project, Tuertscher et al. (2014) examine how actors with diverse backgrounds collaborate to develop a complex technological system when coordination through hierarchy is not feasible. They argue that two things were central for effective coordination in ATLAS. First, Tuertscher et al. (2014) contend that a "boundary infrastructure" consisting of texts, tools, and simulation models that were transparent and accessible to all enabled collaborators to interpret and anticipate each other's actions. Second, their analysis shows that processes of contestation and justification within review panels for the respective subsystems of the ATLAS detector allowed collaborators to acquire knowledge that colleagues with a different background possessed. This knowledge, in turn, was ultimately needed to work on different subsystems in a distributed yet parallel fashion. Partly building on insights from Tuertscher et al.'s study, Lenfle and Söderlund (2019) argue that an "interlanguage"—meaning shared concepts, project management tools, and physical objects—likewise facilitates coordination in Big Science. They contend that the development of such an interlanguage is the outcome of a process which consists of five distinct phases. In phase one, the Big Science collaboration is set up, effectively creating a boundary between the organization and its environment. According to Lenfle and Söderlund (2019), this delineation is necessary for focused discussions and interactions to occur and the need for an interlanguage to materialize. Phase two is characterized by disagreements between the collaboration's experts which occur due to the collision of "thought worlds" (Dougherty, 1992: 179) or "creative abrasion" (in: Leonard-Barton and Swap, 1999). In phase three, an interlanguage slowly emerges as members of the collaboration borrow metaphors and concepts from other fields and redevelop them to suit their purposes. This process continues in phase four, during which metaphors, concepts, and artefacts from phase three are tested, revised, and re-tested. According to Lenfle and Söderlund (2019), at this stage, metaphors, concepts, and artefacts have matured to such a degree that they form coherent meaning to collaborating members, which allows them to more easily integrate their knowledge. Finally, in phase five, the interlanguage is institutionalized and "possibly reused in other" collaborations (Lenfle and Söderlund, 2019: 1731).

When it comes to the management of Big Science, studies have paid particular attention to the role of leadership, funding, communication, human resources, and national cultures (e.g. Shore and Cross, 2003; Shore and Cross, 2005). Touching on almost all of these dimensions in his comprehensive study of ITER, Claessens (2020) concludes that the political nature of this particular Big Science project caused many of its governance- and management-related challenges. In particular, he criticizes that ITER's early directors were diplomatic appointees that lacked experience in managing large-scale science collaborations. According to Collin (2003), such experience is crucial for a successful transition from Small to Big Science. In his study of LIGO I's early days, he argues that the project only became viable after an experienced scientific manager cut the size of the project and hired engineers to plan its construction and to provide realistic costing for the project.

As the literature review shows, there are three blind spots in the scholarship on Big Science. First, so far, scholars have sidelined theory-building and -comparison. Instead, they have used existing mid-range theories and concepts from other disciplines to study socio-political phenomena in large science collaborations. Second, the Big Science literature has largely focused on actors and countries of the Global North as Big Science stakeholders and has neglected to study those of the Global South. Finally, it has examined the national and regional impact of large science projects while paying comparatively little attention to the local impact and perception of Big Science.

1.2. Research Objectives

This thesis seeks to help close the blind spots that have been identified in the previous section. It is part of a broader European Research Council-funded project on the subject of "Addressing Global Challenges through International Scientific Consortia" (INSCONS). The INSCONS project aims to study the organizational dynamics of international scientific consortia and their interactions with broader scientific communities, various national stakeholders, and industry (INSCONS, 2021). According to the INSCONS project proposal, the thesis was intended to investigate the politics of international scientific consortia, broadly understood as the "processual" aspects of the formation and development of international scientific consortia in their cultural–political environment (Jong, 2018). This included interactions between consortia and various national entities, the political challenges that promoters of consortia face in reconciling national interests, governance structures, and cultural frames, as well as processes through which stakeholder groups end up on the periphery or outside of consortia. In doing so, the thesis was supposed to use detailed qualitative data that illuminates which coalitions stakeholders forge, which framings they use to promote their agendas and to contest those of others, as well as which interests stakeholders pursue during the creation and development of international scientific consortia (Jong, 2018). Finally, the thesis was intended to study the same three cases that the INSCONS project focuses on. These cases are ITER, the HBP, and an international terrestrial laser scanning group.

In what follows, the thesis remains committed to the objective of studying the politics of international scientific consortia as defined in the INSCONS proposal. Moreover, it does so by using qualitative methods. It also examines most of the case studies that the INSCONS project focuses on. At the same time, the original research subject and objectives of this thesis were slightly reinterpreted. First, international scientific consortia are reframed as Big Science collaborations, a term more commonly used in the social studies of science to refer to large and international science collaborations such as ITER and HBP. Second, the thesis pursues two research objectives that are more narrowly defined than what was initially envisioned in the INSCONS project:

1. The thesis seeks to shed light on how different stakeholders pursue and negotiate their interests within and in relation to Big Science.
2. It aims to explain how this may lead to conflicts between and among stakeholder groups.

In line with these two research objectives, chapters two, three and four, which make up the backbone of this thesis, respond to the following three research questions:

1. Which objectives do emerging powers of the Global South pursue in Big Science and under which conditions are they likely to achieve their objectives?
2. When and why does local opposition to Big Science persist?
3. How can conflict emergence in Big Science be theorized?

Each research question addresses a blind spot that has been identified in the literature review in section 1.2. Research question one, for example, explicitly focuses on emerging powers of the Global South, a stakeholder group that is often neglected but is increasingly important in Big Science due to this group's (geo)political ambition and importance as well as its growing scientific capacity. By focusing on emerging powers of the Global South, the thesis also more broadly advances the relatively recent global and postcolonial turn in disciplines that have contributed to the Big Science literature (e.g. Harding, 2011; Fan, 2012; Robinson et al., 2023). By examining local resistance to Big Science, research question two, in turn, concentrates on the under-researched local dimension and perception of Big Science projects. Research question three, finally, seeks to advance theory-building in the Big Science literature.

1.3. Theoretical Considerations

This thesis draws upon and combines a variety of existing and emerging theories and concepts of different research traditions to generate flexible and rich interpretative frameworks that speak to issues of policy and practice (Katzenstein and Sil, 2008: 110; Sil and Katzenstein, 2010: 411). In this sense, it follows eclectic modes of theorizing which are grounded in a pragmatist view of social knowledge (Friedrichs and Kratochwil, 2009: 701). Such a view contends that expanding the possibilities of dialogue between different—and at times competing—research traditions enhances intellectual progress and versatility (Katzenstein and Sil, 2008: 110). It does so by "selectively drawing upon a variety of research traditions" and "defining and exploring problems in original, new, and creative ways" (Katzenstein and Sil, 2008: 110). According to proponents of eclectic theorizing, it particularly lends itself to research "that engages, but does not fit neatly within, established research traditions" and that bears on "substantive problems of interest to both scholars and practitioners" (Sil and Katzenstein, 2010: 411-412; Sil, 2020: 441). They also argue that eclectic theorizing is a conducive approach whenever researchers aim to address problems "that are wider in scope than the more narrowly delimited problems" (Sil and Katzenstein, 2010) raised in paradigm-driven research.

All of this applies to research on Big Science, which is often policy-oriented as well as problem-driven and does not fit in well with one particular research tradition. This is why chapters two and three of this cumulative thesis engage in eclectic theorizing. Chapter two combines the concept of science diplomacy (SD), which has both material and ideational foundations, with key assumptions of rational choice institutionalism. In the pertinent literature, SD is most commonly defined as a concept that can be applied to the role of science, technology, and innovation in three dimensions of policy:

1. Science in diplomacy (SiD): Informing foreign policy objectives with scientific advice;
2. Diplomacy for science (D4S): Facilitating international science co-operation through diplomacy, and
3. Science for diplomacy (S4D): Using science co-operation to improve international relations between countries (The Royal Society and AAAS, 2010: vi).

Several SD scholars and practitioners have challenged this widely circulated SD taxonomy (e.g. Fähnrich, 2017; Rungius and Flink, 2020; Ito and Rentetzi, 2021) and have suggested alternative SD definitions. Yet most of them share the same material–ideational foundations as the one presented above, as they argue that SD is a means to seize new markets and key technologies as well as attract foreign talent and investment (Flink and Schreiterer, 2010: 669). At the same time, SD is understood to be a form of "soft power" (The Royal Society and AAAS, 2010: 11 ff.), a term that Joseph Nye coined and defined as "getting others to want what you want" through cultural attraction, ideology, and international institutions rather than through coercion (Nye, 1990: 166). In addition to the concept of SD, chapter two builds on key assumptions of rational choice institutionalism, which "seeks to shed light on the role that institutions play in the determination of social and political outcomes" (Hall and Taylor, 1996:

936). Rational choice institutionalism draws on the so-called "new economics of organization," a literature strand which underlines "the importance of property rights, rent-seeking, and transaction costs to the operation and development of institutions" (Hall and Taylor, 1996: 943). It assumes that actors have a fixed set of preferences and behave in a strategic manner to achieve their preferences (Hall and Taylor, 1996: 944-945). Moreover, rational choice institutionalism views politics as a series of collective action dilemmas, which can be defined "as instances when individuals acting to maximize the attainment of their own preferences are likely to produce an outcome that is collectively suboptimal" (Hall and Taylor, 1996: 945).

The analysis in chapter three is guided by a framework which fuses structuralist and cultural approaches to social movement emergence with the ideational concept of place attachment. The chapter specifically builds on resource mobilization, political opportunity, and framing theory. Resource mobilization theory (RMT) stresses the role of organizational structures and processes in social movement emergence and development (Rohlinger and Gentile, 2017: 11). According to this approach, "movements, if they are to be sustained for any length of time, require some form of organization" (McAdam and Scott, 2005: 6). This includes leadership, administrative structures, and resources (Freeman, 1979). Political opportunity theory (POT), in turn, argues that the broader political context, for example state institutions and other organized groups, determines which objectives as well as tactics social movement participants choose and how likely it is for them to succeed (Meyer, 2004: 127).

Both RMT and POT have been criticized for overemphasizing structures and sidelining meaning-making processes in explaining the emergence and development of collective action (Della Porta, 2020). Framing theory and the concept of place attachment, in contrast, emphasize the role of meaning-making processes in the emergence of collective action. Framing "refers to the meaning-making processes associated with the construction and interpretation of grievances, the attribution of blame, and the creation of rationale for participation" in social movements, while frames are the outcome of said meaning-making processes (Rohlinger and Gentile, 2017: 16). They tell the public what is at stake and outline the boundaries of a debate (Rohlinger and Gentile, 2017: 16). Place attachment, in turn, can be defined as the "emotional bonds between people and places" (Cass and Walker, 2009), where "place refers to space that has been given meaning through personal, group, or cultural processes" (Vorkinn and Riese, 2001: 252). The concept stems from the literature on opposition to renewable energy projects (REPs), where it is used to explain why some people object to REPs. It challenges "the notion that the not-in-my-backyard phenomenon adequately explains" opposition to REPs (Sovacool, 2009; Cass and Walker, 2009; Devine-Wright, 2009; Devine-Wright, 2005) by arguing that place-protective attitudes drive opposition to REPs whenever a project is seen as having a negative and direct impact on a place of great emotional, cultural, or symbolic importance (Devine-Wright, 2009: 432).

Bridging diverse strands of theorizing such as the ones outlined above is believed to come with three distinct advantages. First and foremost, it is argued that eclectic theorizing generates richer, fresher, and more flexible interpretative frameworks with broader explanatory scopes (Katzenstein and Sil, 2008: 111; 117). For proponents of eclectic theorizing, this broader explanatory scope compensates for the loss of parsimony that inevitably results from bridging diverse strands of theorizing. Second, proponents of eclectic theorizing contend that by transcending theoretical schools of thought researchers gain a deeper understanding of the research subject under investigation. Eclectic scholarship more generally is further believed to raise critical and socially important problems which have been sidelined by paradigm-driven research (Hemmer and Katzenstein, 2002: 577). Third and finally, due to its practical orientation, eclectic scholarship arguably speaks to both scholarly and policy debates, thus producing value beyond the academe (Katzenstein and Sil, 2008: 111).

At the same time, eclectic theorizing comes with some distinct challenges. For instance, it requires epistemological flexibility (Sil, 2000: 353) and intellectual versatility (Katzenstein and Sil, 2008: 117) to meaningfully translate and recombine theories from separate research traditions. Where such flexibility and versatility are lacking, the translation and integration of schemes and logics devised in separate research traditions may remain superficial at best or may turn out to be unsystematic and patchy at worst.

1.4. Methods and Data

As part of the INSCONS project, this thesis, including its methods of investigation, was approved by an ethics review committee. Because chapters two to four build on data from expert interviews—a form of human subject research—getting such approval was of vital importance.

Expert interviews and small-N case studies, the second main method used in this thesis, feature prominently in chapters two to four because they are generally considered useful for the in-depth investigation of complex and contemporary social phenomena which are either difficult to get access to or are relatively unexplored (Yin, 2003: 16; Gläser and Laudel, 2009: 13; Bogner et al., 2009: 2). This applies to the overarching research objectives of this thesis as stakeholder interests are difficult to uncover without getting access to the stakeholders themselves and stakeholder conflicts are a complex social phenomenon in Big Science which has so far remained relatively unexplored from a theoretical perspective.

In expert interviews, researchers interview individuals with specialized knowledge about a particular social phenomenon of interest. In doing so, they gain an in-depth and multifaceted understanding of said phenomenon. Compared to other qualitative methods, expert interviews are an efficient way to gather rich empirical data (Eisenhardt and Graebner, 2007; Bogner et al., 2009: 2). Because their objective is to collect "factual information" (Kaiser, 2014: 3; own translation), expert interviews are often less time-consuming than oral history interviews or participant observation. This particularly applies when they are semi-structured, meaning that the sequence of questions to be asked is predefined through an interview guideline. Due to their structured, yet sufficiently flexible nature, semi-structured interviews leave researchers more room to explore new themes which may come up during a conversation than structured interviews or surveys. At the same time, semi-structured interviews ensure more comparability than exploratory interviews which rarely cover similar topics across interviews (Gläser and Laudel, 2009: 144).

In this thesis, interview guidelines were drawn up in a partly deductive, partly inductive procedure. The deductive construction of the guidelines was carried out in two steps, which are typically referred to as conceptual and instrumental operationalization (Kaiser, 2014: 56-57). First, the main concepts of the theoretical framework chosen for the investigation of a particular phenomenon were operationalized. Second, the operationalized concepts were translated into broad question complexes and, later, into concrete interview questions. The theory-informed guidelines that resulted from this procedure were tested during a first round of interviews. It was also during this phase that new questions were added to the guidelines whenever interviewees brought up subjects that existing questions did not yet cover but that seemed relevant for a holistic understanding of the phenomenon under investigation. As a result of this procedure, the final guidelines included a set of inductive and deductive questions, some of which were adapted to the backgrounds of individual interview partners.

Generally, interviewees were selected based on the sampling for range and purpose strategy as well as the snowballing technique (Small, 2009). For chapters two and four, interviewees were chosen according to purposeful sampling. This means that individuals were approached that had been identified as key actors in the case studies under investigation during the literature review on the respective subject (Tuertscher et al., 2014: 1583). For chapter three, interview partners were selected using a sampling for range strategy. According to this strategy, sub-categories of the group under study are identified and interviewed (Small, 2009: 13). To cross-check whether most relevant interview partners had been identified and to find additional interviewees where a particular stakeholder's perspective was still missing, respondents were also asked to recommend other interview partners, a practice which is commonly known as snowball sampling. For each chapter, interviews were conducted until saturation was attained. This was when additional interviews contributed very little new information (Small, 2009: 27).

All interviews were transcribed verbatim. The interviews conducted for chapter four were transcribed manually using the qualitative data analysis software MAXQDA. The interviews on which chapters two and three draw were transcribed automatically with the artificial intelligence-powered software Trint. Although Trint is relatively accurate, the transcripts still had to be cleaned manually. Once this had been taken care of, each transcript was shared with the interviewee in question, except where an interview partner expressed that they were not interested in cross-checking the transcription of the interview. After this "member-checking" process (Ademolu, 2023), interview transcripts were analyzed according to Gläser and Laudel's (2009) qualitative content analysis or Deterding and Waters' (2021) flexible approach to coding.

In addition to semi-structured expert interviews, this thesis relies on small-N case studies, which are "best defined as an in-depth study of [a few] relatively bound unit[s]" (Gerring, 2004: 342). One of the primary virtues of this method is the depth of analysis it offers, with "depth" referring to "the detail, richness, completeness or the degree of variance in an outcome that is accounted for by an explanation" (Gerring, 2007: 49). Across all chapters, cases were selected according to Gerring's (2007, 2016) case selection techniques. In chapters two and four, several typical, yet most-different, cases were compared and contrasted to identify commonalities and differences between them. Such a cross-case analysis facilitates the development of intermediate, relative, as well as time- and context-bound generalizations (Khan and VanWynsberghe, 2008). In chapter three, a single case was examined. Investigating a single case bears the advantage that a researcher can explore a significant phenomenon under rare or extreme circumstances (Eisenhardt and Graebner, 2007: 27). At the same time, findings from a single case are hard to generalize beyond the specific case under investigation.

For the description and analysis of each case, data were triangulated from expert interviews and a variety of documents, including policy papers, government records, academic articles, websites, and newspaper reports. Such a strategy is generally believed to increase the reliability of the inferences made (in: Webb et al., 1999: 2).

1.5. Thesis Structure and Outline

This thesis is article-based and includes three publications that make up chapters two to four. The publications do not directly build on each other but stand on their own. By extension, this means that chapters two to four have distinct research designs and advance different arguments, thus depicting separate research projects with separate literature reviews and original data.

What links the chapters is that they explore social processes that unfold within and around Big Science. Specifically, chapters two to four advance our understanding of interest representation and conflict emergence in the context of large scientific collaborations. They do so at two different levels, with chapter two concentrating on the state level, chapter three focusing on the group level, and chapter four bringing both levels together. Considering that Big Science collaborations bring a plethora of actors from different societal spheres together for a sustained period, such a multilevel perspective is paramount to understanding social phenomena that may unfold in large science projects.

The remainder of the thesis is structured as follows. Chapter two investigates the objectives that emerging powers of the Global South like South Africa and India pursue in Big Science projects such as CERN, ITER, SKA, and the African Lightsource (AfLS). In addition, the chapter explores the conditions under which southern emerging powers are likely to achieve their objectives in Big Science collaborations. In doing so, chapter two speaks to the thesis' first research objective of examining how different stakeholders pursue and negotiate their interests within Big Science.

Chapter three examines why the kiaʻi, a group largely composed of Native Hawaiians, were able to sustain opposition to TMT, an extremely large astronomy project planned for construction on Mauna Kea, Hawaiʻi Island. By focusing on how the kiaʻi expressed their grievances and enforced their interests in the TMT controversy, chapter three addresses the thesis' first research objective, just as chapter two does.

Chapter four proposes a mechanism-based model of conflict emergence in Big Science, thus attending to the thesis' second research objective of explaining how conflicts may arise between and among stakeholders as they pursue their respective interests within as well as in relation to Big Science. By applying the model to three typical, yet most-different, case studies where conflict developed at the state and/or group level, chapter four also provides a proof of concept for its validity.

Finally, chapter five outlines the main findings and contributions that chapters two to four make to the literature on Big Science and, more broadly, to the scholarship on science, technology, and innovation. It rounds this thesis off by addressing the limitations of chapters two to four as well as by describing future avenues for research on Big Science.

1.6. Authorship Statement[1]

Chapters two and four of this thesis have been published as original research articles in *Science and Public Policy* as well as *Minerva*. In May 2024, a revised version of chapter three was accepted for publication in *Technology in Society* (see Table 1 for an overview).

Table 1: Overview of publications

Publication Title	**Type of Publication**	**Publication Outlet**	**Status**
Science Diplomacy from the Global South: The Case of Intergovernmental Science Organizations	Collaborative	Science and Public Policy	Accepted
Sustaining Local Opposition to Big Science: A Case Study of the Thirty Meter Telescope Controversy	Single Author	Technology in Society	Accepted
Big Science, Big Trouble? Understanding Conflict in and around Big Science Projects and Networks	Single Author	Minerva	Accepted

Chapter two was written in collaboration with five co-authors from Rwanda, India, and Germany. Given the chapter's focus on the Global South, the composition of the research team was a deliberate choice and an attempt to diversify the perspectives on the research subject. I initiated the collaboration and assembled the research team with the help of one of my co-authors based in Berlin. This co-author and the remaining collaborators agreed that the project would form part of my PhD thesis. As a result, I took a leading role in the project, which meant that I managed and coordinated the research process. In collaboration with one of my co-authors, I formulated and developed the overarching research goals of the project. Moreover, I collected, transcribed, and cleaned the interview data for the article and co-authored two of the four case studies. Finally, I created the tables for the article and edited the entire manuscript. My co-authors contributed two of the four case studies and helped write the theory, methods, and discussion sections of the paper. In a conscious attempt to make the project as inclusive as

[1] The authorship statement is based on the so-called "Contributor Roles Taxonomy" (CRediT).

possible, I invested a great deal of time and effort to get feedback on all drafts and changes from my co-authors.

Although I also aimed to write chapter three with a co-author from Hawai‘i and reached out to several Hawaiian researchers, I was unable to find a collaborator in Hawai‘i. As a result, chapters three and four were submitted or published as single-author articles. Accordingly, I was responsible for each step in the research and writing process.

2. Science Diplomacy from the Global South: The Case of Intergovernmental Science Organizations

Chapter two was published as Anna-Lena Rüland, Nicolas Rüffin, Katharina Cramer, Prosper Ngabonziza, Manoj Saxena, and Stefan Skupien (2023) “Science Diplomacy from the Global South: The Case of Intergovernmental Science Organizations” in *Science and Public Policy.*[2] The chapter’s focus on the participation of southern emerging powers like South Africa and India in intergovernmental science organizations (IGSOs), a different term for Big Science collaborations, ties in with the thesis’ first research objective of investigating how different stakeholders pursue and negotiate their interests in Big Science collaborations.

2.1. Introduction

IGSOs address many challenges of the 21st century (Zapp, 2018) and resemble conventional collaborative research projects. Both IGSOs and traditional research projects are essentially scientific investigations that aim to achieve previously defined research objectives. However, as IGSOs are specialized international organizations (IOs) founded on an intergovernmental agreement among two or more nations, they differ from regular research projects in two important aspects. First, they are much more institutionalized than traditional research projects. Second, IGSOs are marked by a much stronger interlocking of science and politics than conventional research collaborations.

Similar to other IOs, many IGSOs have long been dominated by the Global North. In this study, we do not understand Global North and South as geographical concepts, but as

[2] The chapter was accepted for publication on 14 June 2023. It is available online via https://academic.oup.com/spp/article/50/4/782/7197178 and has been edited to ensure coherence with the other chapters of the dissertation.

characterizations of past and present power asymmetries of the global political economy (Prashad, 2014; Dados and Connell, 2012). Core principles of this economy benefit the Global North at the expense of the Global South, leaving the "majority world" (Doyle, 2005: 14-15) economically disadvantaged (Dados and Connell, 2012). Some emerging powers from the Global South were able to overcome some of these economic disadvantages. During the last decade, they have joined several European IGSOs and helped establish IGSOs in the Global South like the Synchrotron Light for Experimental Science and Applications in the Middle East. Although southern rising powers are becoming more visible in the global IGSO landscape, we know little about their interests in IGSOs. Our exploratory study addresses this blind spot by asking the following two questions:

1. Which objectives do countries of the Global South pursue in IGSOs?
2. Under which conditions are they likely to achieve their objectives?

In doing so, we concentrate on four IGSOs with formal and informal participation of policymakers and scientists from southern emerging powers:

1. CERN, an established European organization that over time has intensified connections to countries like India;
2. ITER, an emerging IGSO with participation from India;
3. SKA, an emerging organization with a strong South African component, and
4. AfLS, an example of a planned pan-African IGSO.

These four IGSOs are at different stages of completion. Emerging IGSOs like ITER are either in the late or early stages of construction, established organizations are fully operational, and in planned IGSOs construction has not yet begun.

We explore each case by drawing on insights from the literature on international research collaboration, SD, and institutionalism and advance two arguments. First, we contend that countries of the Global South pursue a multitude of political and scientific objectives in IGSOs which may range from strengthening science and technology (S&T) capacities to casting off political isolation. Second, we argue that southern countries have varying chances of attaining these objectives, depending on their domestic politics, scientific community, industrial capacities, and in some cases geographic location as well as an IGSO's institutional maturity. In doing so, our study contributes new insights to the literature on international research collaboration and institutionalism which have prioritized the study of conventional research projects or traditional IOs over that of IGSOs. It also adds to the SD literature which has predominantly focused on the SD practices, capacities, and experiences of the Global North (Polejack et al., 2022) while neglecting to study southern SD (for some exceptions see: Echeverría King et al., 2021; Ezekiel, 2020; Hornsby and Parshotam, 2018) as well as IGSOs (notable exceptions are: Robinson, 2020; Höne and Kurbalija, 2018). Finally, our findings have important implications for science policy.

The reminder of this article is structured as follows: in section 2.2. and 2.3., we outline our analytical framework and methods. In section 2.4., we present our case studies. We discuss the main findings of our analysis as well as their policy implications in section 2.5. and conclude by pointing out future research directions in section 2.6.

2.2. Analytical Framework

Our case study analysis is informed by empirical and theoretical insights from three strands of literature, each of which addresses an important IGSO characteristic.

First, because conventional research projects and IGSOs share some similarities, we draw on insights from the literature on international research collaboration. This type of scholarship demonstrates that many international research projects are plagued by North–South asymmetries. This is mainly due to the unequal distribution of S&T capacities between Global North and South (Madsen and Adriansen, 2021). For instance, because countries of the Global North possess the necessary economic resources, human capital, and technology, they typically initiate collaborative research projects and then look for suitable collaboration partners (Feld and Kreimer, 2019). Southern researchers are often invited to join when the broad lines of the work plan have already been drawn up (Feld and Kreimer, 2019). They thus lack room for maneuver during the early negotiations of a project (Perrotta and Alonso, 2020). Moreover, scientists from the Global South rarely determine the research agenda and the theoretical and methodological framework of a research collaboration (Chinchilla-Rodríguez et al., 2019). Under these conditions, it is difficult for them to develop and maintain capacity for (large) research infrastructures (Moyi Okwaro and Geissler, 2015).

Second, to account for the fact that IGSOs are marked by a much stronger interlocking of science and politics than conventional research projects, we consult recent SD scholarship.

This type of literature lends itself to our purposes because it seeks to conceptualize the role of science, technology, and innovation in three dimensions of policy:

1. SiD: Informing policy through scientific advice;
2. D4S: Leveraging political capital to advance scientific research;
3. S4D: Using science cooperation to improve international relations (The Royal Society and AAAS, 2010: vi).

In recent years, this threefold SD taxonomy has received much criticism. For example, some scholars argue that the differentiation between SiD, D4S, and S4D is artificial and rarely holds in practice (e.g. Penca, 2018; Copeland, 2016; Rüland, 2023). In line with this, recent studies show that SD often serves both scientific *and* political ends which can be collaborative and/or competitive in nature (e.g. Ruffini, 2020; Rüffin and Rüland, 2022). Building on these new insights, we employ a pragmatic definition of SD that includes all activities at the intersection of science and foreign policy that are meant to achieve scientific and/or political objectives.

Third, to honor the strong institutionalization of research collaboration in IGSOs and to systemize the comparative case analysis, we apply a broad institutionalist perspective. This institutional perspective, firstly, allows us to analytically distinguish two phases in the lifecycle of an institution. A first phase deals with questions of institutional design during the planning and construction of a new institution (initiation) that include but are not limited to funding, site selection, scientific access, and procurement (Hallonsten, 2014). A second phase addresses interactions in existing organizations that are shaped by previously established institutional rules (development). Second, an institutional perspective shows that recurring organizational features like centralization, membership, and control mechanisms shape power relations between member states, often in the long term (Koremenos et al., 2001).

2.3. Methods of Investigation

Against the backdrop of this analytical framework, we compare four IGSOs which we selected based on three criteria. First, we aimed for maximal organizational heterogeneity to learn from different contexts and to develop careful generalizations (Khan and VanWynsberghe, 2008). Accordingly, we chose IGSOs that are situated in different scientific fields and characterized by different institutional configurations (see Table 2). Second, we selected organizations that southern actors joined at different institutional phases of their lifecycle and during different science policy “regimes” (Elzinga, 2012). Third, to focus the case study analysis (Yin, 2003), we concentrated on the activities of one specific country of the Global South and covered an IGSO’s initiation and development in all cases but AfLS. Currently, AfLS is still in the phase of initiation and mainly driven by scientific actors, depicting an outlier in our case study analysis.

We combine a document analysis with qualitative interviews for the description and analysis of our case studies (for an overview of the interviews see Table 3). Pursuing such a strategy comes with a considerable advantage, as triangulating data from non-reactive and reactive sources is generally believed to increase the reliability of inferences (in: Webb et al., 1999: 2). In the cases of CERN and ITER, we supplemented the findings from a document analysis with interview data that we had collected in previous research projects. We made limited use of these interviews, as both CERN and ITER are well documented in the secondary and gray literature. For SKA and AfLS, in contrast, there was little academic literature available. As a result, we triangulated data from gray literature, for example project documents, some of which have not yet been published, and exploratory expert interviews that we conducted between February and September 2022. Exploratory interviews are generally considered a suitable method to examine under-researched topics such as southern participation in IGSOs (Kaiser, 2014: 29). However, since exploratory interviews are less structured, cross-case comparability is hard to achieve (Gläser and Laudel, 2009: 144). We tried to increase comparability by covering similar themes in the interviews. In addition, we transcribed all interviews and paid attention to differences and similarities between the interviewees’ accounts as we analyzed them using flexible coding (Deterding and Waters, 2021).

Table 2: Overview of IGSO case studies

Name	Discipline	Year of Establishment	Founding Members/ Proponents	Location	Phase in Life-Cycle	Initiated by
CERN	Particle Physics	1954	Belgium, Denmark, France, Germany, Greece, Italy, the Netherlands, Norway, Sweden, Switzerland, UK, Yugoslavia	Geneva, Switzerland	Established	Global North
ITER	Nuclear Fusion	2007	US, China, Russia, EU, South Korea, India	Cadarache, France	Emerging	Global North
SKA	Astronomy	2019	UK, China, Portugal, Italy, South Africa, the Netherlands, Australia	Karoo, South Africa Murchison Region, Australia	Emerging	Global North
AfLS	Inter Alia: Medical Sciences, Cultural Heritage Sciences, Geosciences, Environmental Sciences, Energy Sciences, Nano-Sciences, Material Sciences, Mineral Sciences	ca. 2030	South Africa, Ghana	To be determined	Planned	Global South

Table 3: Overview of conducted interviews for chapter two

	Case Study			
	CERN	ITER	SKA	AfLS
Number of Interviews	2	1	4	3
Code/Name	INT07	INT08	Wolfgang Reich INT02 Adrian Tiplady Justin Jonas	Tshepo Ntsoane INT06 Trevor Sewell
Affiliation	CERN	ITER IO	Max Planck Society - SARAO SARAO	South African Nuclear Energy Corporation - University of Cape Town

2.4. The Global South in IGSOs

2.4.1. CERN: European Laboratory Turned Global

2.4.1.1. Initiation

Founded in the 1950s near Geneva, CERN is the oldest European IGSO. Over time, it has become a major example of multilateral collaboration in HEP and a role model for several other IGSOs. The earliest negotiations on the laboratory included suggestions to open membership to the US and Commonwealth countries like Pakistan and India (Krige, 1987: 251). Yet the final compromise resulted in cementing the European nature of CERN in a convention that grants incumbent countries veto powers on new members.

The provisions of the CERN convention have important institutional effects to this day, particularly for countries that wish to join CERN. As a matter of fundamental institutional importance, CERN's Council decides on the accession of new members. Every member state dispatches two official delegates to the Council, where votes require various types of majorities. New member states are only admitted “by a unanimous decision of Member States” (CERN Council, 1953: Art. III, 2(a)). As a result, CERN’s governance system—although it is getting increasingly diverse and global—has largely remained under European control.

2.4.1.2. Subsequent Development

Despite this rigid institutional framework, nowadays, CERN collaborates with interested parties via a variety of membership types. India and Pakistan, for instance, have become associated members of the organization. In the past decades, CERN has moreover concluded a large number of agreements with additional countries around the globe (CERN, 2022a).This partial expansion of membership types is tied to the intricate relationship between scientific progress and CERN's mostly unchanged governance model, which, in turn, shapes opportunities and challenges for southern actors to pursue their objectives in this IGSO until today.

HEP has long been characterized by a need for ever-increasing cutting-edge facilities, which come at growing costs. For example, CERN's first particle accelerator, the Synchrocyclotron which was commissioned in 1957, measured about 16 meters in circumference and cost about 24 million Swiss franc (CHF) (Hermann et al., 1987). The Large Hadron Collider (LHC), which went into operation in 2008, in comparison, has a circumference of 27 kilometers and a price tag of 4332 million CHF (CERN, 2022b). Given these ever-increasing costs, each time CERN set out to build a new accelerator, questions of funding moved to the foreground. During large periods of the twentieth century, members were able to secure sufficient resources for new projects. This was particularly the case for the Super Proton Synchrotron and the Large Electron–Positron Collider commissioned in the 1970s and 1980s (Schopper, 2009). However, since then, it has become clear that the next accelerator would require resources that members were not willing to provide due to various economic and political circumstances (Smith, 2007). Scientific progress dictated the inclusion of new partners in CERN projects. As a result, during the negotiations leading up to the construction of the LHC, for the first time, contributions from non-member states became a valuable bargaining chip to trade for "a 'voice' in the [IGSO's] governance" (Smith, 2007: 284). Already existing collaborations at an executive level (i.e. with individual scientists and research institutions) supported these new interactions at the political level, enabling southern actors to get more involved in CERN even when the IGSO's institutional framework had not fundamentally changed. Institutionally, the LHC cooperation was consolidated in bilateral ad hoc agreements which usually specified the type of contribution, procurement provisions, and delegation of personnel (CERN, 2002). However, these ad hoc agreements were focused on the LHC and neither touched CERN's basic research program nor fundamental governance mechanisms.

India was one of the countries that tried to benefit from this changing environment. During the 2000s, due to agreements struck earlier between the Indian government and CERN, the country's scientists were heavily engaged in the development of the LHC's magnets (Chohan, 2007). From the Indian perspective, there were two main reasons for joining this specific collaboration within CERN. First, India's participation was driven by "the desire to increase the pace of accelerator development (…) and to give a thrust to [its] experimental high energy physics programme" (Sahni, 2004: 441). Second, Indian companies could showcase their technological capabilities within the collaboration, strengthening the country's image as a rising S&T power. Institutionally, however, the CERN Council only granted observer status to India in the wake of the construction of the LHC in 2002. Observer status gave India "the right to attend open sessions of the Council and to receive official documents," a step that had "mainly political significance" (CERN, 2002: 6). It took another 15 years for the country to become an associated member of the organization (CERN, 2017). Siddhartha (2017) argues that India was keen to obtain this status to "catch up" with its rival Pakistan which had become CERN associate member two years earlier. According to this reasoning, India's institutional commitment to CERN can be read as an attempt to use S&T cooperation to settle regional political rivalries. This seems plausible, given that associate membership gives a country the right to express its opinion in the Council, to appoint nationals to staff positions, and to bid for CERN contracts, all of which increase a country's political standing and prestige (CERN, 2002: 12-14; Cogen, 2012). Despite the privileges that come with the status of associated membership, the number of Indians on CERN staff and the number of users has remained at a low level for years; the full potential of exchanges has thus not yet been reached.

Although useful for non-member states, the extensions of interstate collaborations have not significantly changed the composition of full members in the Council as only three European countries (Cyprus, Estonia, and Slovenia) are currently associated members in the pre-stage to full membership. Countries of the Global South are not yet represented at this level. This may change in the future, enabling southern actors to pursue more ambitious objectives in CERN. For example, the LHC illustrates how southern actors and CERN are caught in a relationship of mutual dependency. On the one hand, countries of the Global South currently have few alternatives to CERN if they want to access cutting-edge HEP instruments. In fact, CERN cemented this special status in the 1990s when the US-based SSC was canceled (Riordan et al., 2015). Within a few years, CERN became the last HEP facility capable of constructing the next generation of colliders. On the other hand, it is increasingly obvious that budgetary constraints among current CERN members render contributions from additional international partners imperative for the construction of these colliders (European Strategy Group, 2020: 6; INT07 2017). Southern actors could make their financial support for future projects contingent on either getting more institutional rights at CERN or developing a new consortia framework in which CERN exclusively represents European interests much like EUROfusion does in ITER. As the specific trajectories for a successor to the LHC are still unknown, these considerations are primarily rooted in experiences of the past and expert opinions. Yet, given the ever-changing structure of the global science system, it is plausible to assume that southern countries will have a part in shaping the future of HEP at CERN.

2.4.2. ITER: A Missed Opportunity for India?

2.4.2.1. Initiation

ITER is an experimental nuclear fusion reactor in the billion-euro class currently under construction in Cadarache, France. Its objective is to demonstrate the viability of fusion as a future source of sustainable energy (European Commission, 2017). The ITER IO, the IGSO in charge of managing the reactor's construction and operation, was established in 2007 by the US, Russia, the European Union (EU), South Korea, China, and India.

The project resulted from a 1985 high-level meeting between Ronald Reagan and Mikhail Gorbachev during which the two leaders agreed to cooperate on a thermonuclear fusion project (McCray 2010). Shortly after the initiation of the project, the European Community and Japan joined ITER, as did China and South Korea at the beginning of the 2000s. In 2005, ITER welcomed India as a seventh and, to this day, last ITER partner during a meeting on Jeju Island, South Korea (EUROfusion, 2005).

As a newly accepted ITER partner, India was able to fully participate in the negotiations on Jeju Island and to determine some key institutional issues, such as decision-making procedures, intellectual property rights, and management within the prospective ITER IO (EUROfusion, 2005). It had little influence on ITER's scientific objective, however, because this issue had been settled during the project's engineering and conceptual design activities in the 1990s. During the negotiations on Jeju Island and subsequent discussions, India pursued two main interests. First, it wanted to strengthen its national capacities in fusion research and technology (Anupama et al., 2021). The country was particularly keen to further develop its blanket, divertor, and cryogenic technologies (Mattoo, 2006). Second, it sought to re-establish itself as a responsible nuclear state and to regain trust among international nuclear powers after it had been excluded from the nuclear mainstream over its nuclear weapons test and refusal to sign the Nuclear Non-proliferation Treaty in the mid-1970s (Joshi, 2018). Prior to this point in time, India had enjoyed civilian nuclear engagement with other states, but as a reaction to its nuclear tests in 1974, erstwhile partners sanctioned nuclear technology exports to the country (Ritch, 2006).

2.4.2.2. Subsequent Development

Currently, ITER is not yet operational, but the construction of the reactor has progressed considerably (Harvey, 2017). In theory, the IGSO's institutional rules enable India to pursue its scientific and political objectives in ITER: strengthening its national capacities in S&T and building a reputation as a trustworthy nuclear power. In practice, however, India either fails to use ITER's institutional framework to its full advantage or disregards parts of it, thus endangering the attainment of its objectives.

As a non-host, India shares nine percent of ITER's estimated costs during the construction phase. The ITER Agreement—the intergovernmental treaty which gave birth to ITER IO—specifies that contributions to the reactor can be made in cash or in kind. In a separate document, the partners determined that during the reactor's construction phase a majority of the contributions would be provided in kind. In the case of ITER, this means that member states manufacture components and hardware for the project, provide services and second scientific as well as administrative personnel to ITER IO. India's Institute for Plasma Research manages the country's in kind contributions. Ultimately, however, it is India's industry that produces components and hardware (Anupama et al., 2021). By doing so, India's industry has gained experience in key fusion technologies which is crucial for building an Indian DEMO, a machine that is capable of exploiting fusion energy commercially (Arnoux, 2014).

By seconding personnel to an IGSO, countries can further enhance their national S&T capacities as dispatched experts infuse their home institutions with novel knowledge upon their return. From an institutional perspective, dispatching staff is important because it increases a state's visibility in an organization. If a country's staff is placed in key positions, it can moreover exert control over IGSO decision-making processes. In ITER's case, India agreed to second staff proportional to its project contribution (IAEA, 2007). During the last few years, however, the country has not managed to fulfill this pledge. Instead of an agreed upon staff size of 86, between 2016 and 2020, India never had more than 36 staff members at ITER IO (ITER IO, 2021). This equals two percent of ITER's overall IO staff; seven percent less than what India would be allowed under the ITER agreement. India's inability or unwillingness to fill its full roster has two important consequences. First, it allows other countries, such as China, to have excess staffing (Bagla, 2020). This means that India cedes institutional control to other countries, as more staff often equals more influence (Parizek and Stephen, 2021), particularly if such staff fills key positions. Although Indians are comparatively well represented in management positions, among all ITER partners, India also supplies the highest share of construction workers (Personal Communication from ITER IO) and ITER project associates, individuals that work in supporting roles devoid of management responsibilities (Kamble, 2020). This effectively reduces India's ability to exert institutional influence through staffing. Second, India's personnel policy impedes knowledge transfer between its domestic fusion community and ITER IO, as there are few experts that infuse their home institutions with novel knowledge following their secondment. What complicates matters is that the few Indian experts deputed to ITER only stay for a short period of time which makes it hard for them to gain in-depth experience in fusion technology. Indian experts are deputed for short periods because regulations of the country's Department of Personnel and Training determine that government staff cannot be posted overseas for more than two years; experts from autonomous institutes cannot be dispatched for more than five years (Bagla, 2020).

Additionally, India provides in cash contributions to ITER IO. Like the US, India has not paid its full in cash contributions during the past few years. Currently, its outstanding contributions amount to approximately 131 million US dollars (USD) (Bagla, 2020). This has led to ill will among the remaining ITER parties because they have to make up for lacking funds and accept delays (INT08 2021). A downturn in India's domestic economy cannot account for Delhi's failure to provide its in cash contributions because while India withheld funds for ITER during the past few years, it lent a substantial amount of 36 billion USD in development assistance to 65 countries in almost the same period (Indian Ministry of External Affairs, 2022). A former member of the ITER Council instead implied that India's lack of financial commitment to and interest in the project relates to domestic politics and in particular the country's change in government in 2014 (INT08 2021). This change in government seems to have led to a focus on developing nuclear fusion technology *within* the country. In 2015, then ITER-India project director Deshpande stated that "the knowledge that we gain will be used to set up our own demonstrator reactors at home" (quoted in: Rupera, 2015). Indian nuclear expert Kakodkar equally suggested that "having done so much on ITER, we should actually prepare ourselves to set up the DEMO plant (…) on Indian soil" (quoted in: Bagla, 2020). This would also explain why India deputed a rather junior person to represent the country at a high-level ITER event in 2020 when all other ITER members dispatched their heads of state (Bagla, 2020). Coupled with its inability to meet its human capital contributions for ITER, the lacking financial commitment to ITER could endanger India's image as a reliable partner in civilian nuclear cooperation and fusion research, putting its political strategy of gaining trust among other civilian nuclear powers at risk. However, given that ITER is a long-term project—with key milestones set to be reached by the middle of this decade—the country can still make up for its temporary loss of focus.

2.4.3. SKA: From Afro-Pessimism to Afro-Empowerment

2.4.3.1. Initiation

SKA is a multi-billion euro astronomy project which aims to explore a range of fundamental cosmological questions (Pozza, 2015). In 2019, the United Kingdom (UK), Portugal, China, Italy, the Netherlands, Australia, and South Africa signed an intergovernmental treaty, the so-called SKA Observatory (SKAO) Convention, to establish SKAO, the IGSO responsible for building and operating SKA. The organization's headquarters is located in the UK, but Australia, South Africa, and eight other African countries will eventually co-host SKA's instruments.

Although SKAO was only recently established, deliberations for a large international astronomy project began already in the late 1980s (Baneke, 2020). Discussions intensified after 1993, when the possibility of realizing a large international astronomy project was raised in several fora, including the International Union of Radio Science (URSI), the International Astronomical Union, and the Organization for Economic Cooperation and Development (OECD) (Ekers, 2012). A so-called Large Telescope Working Group (LTWG) was first set up with the task of specifying scientific goals and technical requirements for a prospective large international telescope at URSI (Ekers, 2012). South Africa did not participate in the LTWG (INT Jonas 2022), but followed the developments through one of its URSI representatives (INT Jonas 2022). Apparently, at that point, no one was expecting significant technological or scientific contributions from South Africa (INT Reich 2022), mainly because the country only had five radio astronomers back then (Du Toit, 2021). However, early on, South Africa was aware that it held a geographic advantage for radio astronomy (INT Reich 2022), as it has several areas with low radio-frequency interference, a prerequisite for highly sensitive radio astronomy projects as the one discussed in the LTWG. Therefore, the country's S&T

department (DST) had identified astronomy as one of its focus areas for its S&T sector shortly after the downfall of South Africa's apartheid regime in 1994 (INT02 2022).

Discussions on a large radio telescope advanced further during the early 2000s. At that point in time, DST began to support a site bid for the project—which had by then been named SKA—for two main reasons. First, it saw SKA as a means to develop national S&T skills and capacities and to diversify the country's S&T sector which had historically been dominated by the defense industry (INT02 2022; INT Tiplady 2022). Second, participating in an international project like SKA promised increased interaction with international and regional scientific and political communities. Less than ten years after the fall of apartheid and following decades of scientific isolation (Sooryamoorthy, 2010), such interaction was crucial for the growth of South Africa's S&T sector. The country's motivation for getting involved in SKA thus clearly went beyond purely scientific rationales.

South Africa's 2003 site bid for SKA was met with considerable skepticism from some northern partners, such as the US and Australia (INT02 2022). The latter doubted that South Africa and its African partner countries would be able to "build the world's largest scientific instrument" (INT02 2022). This Afro-pessimism began to subside when South Africa made progress in developing SKA's precursors, KAT-7 and MeerKAT (INT02 2022; INT Tiplady 2022). Local engineers that had previously worked in the country's electronics and defense industry proved crucial for MeerKAT's success (INT02 2022). Convinced that South Africa could host and operate SKA, project proponents agreed early on that they did not simply want to "offer a piece of land" (INT02 2022). Rather, they were adamant about nurturing a radio astronomy community to "strengthen their position" in the project and to give SKA's remaining partners "confidence in [them]" (INT02 2022). Hence, South Africa established a Human Capital Development Program to develop the necessary S&T capacities for SKA. Ultimately, these efforts paid off, as in 2012 rumors spread that SKA's site advisory committee would recommend South Africa's site over that of its competitor Australia (Quick, 2012). Surprised and angered, Australia threatened to leave the collaboration (INT02 2022). As this would have depicted a big blow to SKA, the UK proposed to consider a dual-site solution. Although this option proved more expensive, politicians finally opted for it. As a result, South Africa will eventually host SKA's high- and mid-frequency dishes, while Australia will host its low-frequency antennas (SKAO, 2022). Moreover, both countries will host science and engineering operations as well as "science processing" centers (Chrysostomou et al, 2020: 16).

2.4.3.2. Subsequent Development

SKA is not yet fully operational. Due to the corona pandemic and subsequent economic fallouts, construction had to be delayed. Nevertheless, it is possible to assess how SKA's institutional features impact South Africa's political and scientific objectives in the project.

In line with a strategy of strengthening S&T capacities, South Africa was eager to ensure a fair return on investment from SKA for its national economy and to guarantee its scientific community access to the instrument and the huge amounts of data it would generate. In the SKAO Convention, return on investment is guaranteed by the principle of "fair work return" (SKAO, 2019: Art. 1). This principle is common practice in other IGSOs, but not uncontested (European Space Agency, 2014). It determines that the cumulative values of goods, works, and services provided by an IGSO member through the procurement process should broadly reflect its financial project contributions (SKAO, 2019). A manager that works for the South African Radio Astronomy Observatory (SARAO), the entity which manages the African component of SKA, puts it this way: with SKA "what you put in is what you get out" (INT Tiplady 2022). As in ITER, contributions to SKA can be made both in cash or in kind (SKAO, 2019). In kind contributions are manufactured locally and transported to the project site. This enables participants to maximize skills, knowledge, and technology transfer at the national level. South Africa bears a considerable share of SKA's construction and operation costs. As a result, the country will obtain substantial procurement contracts under the principle of "fair work return" from which it is likely to benefit.[3] Scientific access to SKA is organized on a similar basis as procurement: SKA members and associate members will have access to its telescopes proportional to their project share (SKAO, 2019: Art. 13). Through its financial contributions, South Africa secured valuable observing time for its domestic science community.

While the institutional principle of "fair work return" ensures procurement and observing time proportional to a country's project share, some scholars suggest that the centralization of SKAO management in the UK could perpetuate asymmetries that have haunted conventional research projects (Walker and Chinigò, 2018). They argue that this

[3] This is what a recent study on SKA's socio-economic impact suggests. It finds that SKA has had a positive impact on national and local economies, for example by providing training opportunities, strengthening tourism, and generating new jobs, see Atkinson D, Kotze H and Wolpe R (2017) Socio-Economic Assessment of SKA Phase 1 in South Africa. n.i.: n.i.. Yet, like Walker and Chinigo (2018), the study underlines that the land acquisition process for SKA could lead to a production loss for some local farmers.

centralization might lead to southern partners being sidelined when major project decisions are taken (Walker and Chinigò, 2018). A former SARAO manager, however, underlined that SKA's northern partners began to see South Africa as an equal partner soon after it joined the collaboration (INT02 2022). Personnel from SARAO further emphasized that South Africa had considerable influence on the project design and the negotiation for the SKAO Convention (INT Jonas 2022; INT02 2022).

Tensions could also arise among African project partners, endangering South Africa's goal of fostering both regional scientific and political cooperation through SKA. Within the African component of SKA, South Africa takes a leading role; so much so that its African partner countries are not even mentioned in the SKAO Convention. An interviewed SKA science manager said that the African SKA's partners chose South Africa as a representative for all project partners on the continent for reasons of practicality (INT02 2022). At the same time, this interviewee implied that South Africa got additional African countries involved in the project because SKA was intended to cover three thousand kilometers—an area "you could not fit into South Africa" (INT02 2022). This could be an indication that South Africa sees the remaining African SKA countries as means to an end rather than partners. However, given that South Africa invests considerable resources in S&T capacity-building in its partner countries, this seems unlikely.

2.4.4. AfLS: "By the Community for the Community"

AfLS is a planned South–South IGSO driven by the vision to establish the first pan-African lightsource. Such a source emits X-rays that serve as a tool for multidisciplinary scientific investigations in fields like biology or physics.

First brought up as an idea in the 1990s by the scientific community, the African Laser Centre was the first to formally call for a pan-African lightsource in its 2002 Strategy and Business Plan (Mtingwa and Winick, 2018: 12). Since then, AfLS has taken several steps towards institutionalization, including the creation of the AfLS Foundation in 2018. The majority of the foundation's executive committee is composed of researchers from African institutions and members of the African diaspora, but its advisory board features directors and senior scientists from lightsources around the world (African Lightsource, 2022b). On an institutional level, there is a strong connection between the ESRF and AfLS, with the former serving as a hub for training and education for African users and as a facilitator of conferences and workshops. This relationship probably is due to the strong historical ties between ESRF and African researchers reaching back to the 1990s (Connell et al., 2018).

Currently, the AfLS Foundation fulfills two main functions. First, it drives the initiation of partnerships with regional and international scientific networks and local capacity-building (Connell et al., 2019). In doing so, it is supported by stakeholders from the Global North, for example the UK Research and Innovation's Science and Technology Facilities Council which initiated the British Synchrotron Techniques for African Research and Technology scheme. This scheme aims to improve access to light sources for researchers from the Global South (Nicklin et al., 2022). In addition, AfLS gets considerable support for training young African researchers at lightsources in the Global North through the partnership with the Lightsources for Africa, the Americas, Asia, Middle East, and Pacific project which is primarily financed by the International Science Council (Newton et al., 2023). Second, the AfLS Foundation lobbies governments to support the project. Such support is necessary because although the project was referred to in the 2015 African Higher Education Summit (Trust Africa, 2015) and the Ghanaian government pledged support for it, as of now, there are no concrete funding and political commitments. Both, however, are crucial for key institutional decisions like site selection (INT06 2022). To convince African policymakers and funding agencies of the project's viability, the AfLS Foundation has established a "minister forum" that creates closer links between policymakers and project proponents at the 2021 virtual AfLS conference (INT Ntsoane 2022). In addition, it is in the process of drafting a Conceptual Design Report (CDR) that outlines AfLS science case, technical infrastructure, and governance (African Light Source, forthcoming).

AfLS proponents name the geographical distribution of the approximately 50 existing lightsources as a key rationale for a pan-African lightsource (Connell et al., 2019). The majority of these are concentrated in the Global North, as are technological equipment, knowledge, and skills. Yet, in theory, researchers from African countries can access all northern-located lightsources, even if their host countries do not have membership status because experimental time is allocated according to the scientific excellence of submitted proposals. As in conventional research collaborations, however, in practice, the largest financial shareholders of these facilities—predominantly northern countries—shape research priorities as well as procedural matters because financial contributions usually determine voting rights in the Council which, in turn, determines the scientific program. In addition, full membership is often linked to a certain financial threshold which many southern countries struggle to reach (Cramer, 2020: 109, 166 ff.).

The growing availability of remote data collection services provided by many lightsources gradually reduces access barriers to northern facilities (Nji et al., 2019). Yet proponents of an AfLS argue that a lightsource is crucial for African countries and scientific communities because it could advance African research agendas and capacity-building. For instance, the African Lightsource Manifesto, concluded at the end of the first AfLS conference in 2015, claims that AfLS "is expected to contribute significantly to the African Science Renaissance, the return of the African Science Diaspora, the enhancement of University Education, the training of a new generation of young researchers, the growth of competitive African industries, and the enhancement of research that addresses issues, challenges, and concerns relevant to Africa" (African Light Source, 2015: 3).

Proponents also hold that AfLS could provide a greater balance of institutional rights and obligations compared to northern-located lightsources. They argue that they can maintain this balance by relying on the concept of Ubuntu throughout the institutionalization process. Ubuntu is an African humanist concept which scholars conceptualize as an ethical harmony of values and identity between a person, humanity, and nature (Madise and Isike, 2020). Building on values such as inclusivity, equity, and empathy, it is seen as a relational and community-centered concept and an alternative form of political soft power that "does not conform to the normative foundations of international relations [based] on competition and the accumulation of power over others" (Madise and Isike, 2020: 2).

By prescriptively enshrining Ubuntu as the guiding principle for negotiations on AfLS, the project breaks new ground and distinguishes itself from European IGSOs. Founding phases of the latter can also be described as consultative as they involved a global community of scientists and policymakers. Yet studies have shown that in many of these IGSOs siting and financing issues have led to contention among stakeholders (e.g. McCray, 2010; Riordan et al., 2015). In the case of AfLS, an inclusive initiation process driven by Ubuntu aims to overcome such political frictions through different means (Newton et al., 2023). For example, in the current phase of AfLS's initiation, applications of Ubuntu range from symbolic uses of ceremonial calling and speaking sticks that link closely to the spirit and traditions of the concept as well as its inclusion in the draft version of the CDR (African Light Source, forthcoming). Through a consultative drafting process, which includes town hall meetings and community workshops, the CDR is expected to become a document "by the community for the community"

(African Lightsource, 2022a). Ultimately, key actors hope that AfLS emerges as a community-driven project of which African governments and researchers can claim ownership. For them, ownership is crucial because it is seen as a means to guarantee long-term funding from African governments as well as a solid and well-connected African user community (Connell et al., 2019).

Yet, at the current stage of initiation, it remains an open question whether the inclusionary principle of Ubuntu will prevail when it is faced with competing political interests that have been known to shape northern IGSOs. Although the AfLS Foundation has put forward basic requirements for hosting the lightsource, the draft version of the CDR does not make any site or funding proposals for AfLS (African Light Source, forthcoming) and it seems unlikely that it will do so in its final version. Past siting and funding negotiations in northern lightsources show that these issues can be difficult to resolve because they require political consensus at the highest level. This is why concrete funding schemes and site proposals are rarely included in CDRs (Cramer, 2020: 194 f.). In the case of AfLS, African countries that seek common ground for AfLS may thus not necessarily refrain from pushing their national political and scientific interests when it comes to siting and funding. Time will show whether AfLS's visionary approach and the rhetorical and procedural prescriptions of Ubuntu will withstand the reality of intergovernmental negotiations.

2.5. Discussion and Policy Implications

In our study, we examined which objectives countries of the Global South pursue in IGSOs and the conditions under which they are likely to achieve their objectives. In doing so, we compared four different IGSOs with southern participation. Concerning our first question, we found that southern actors pursue various political and scientific objectives in IGSOs. These include but are not limited to strengthening S&T capacities (CERN, ITER, SKA, AfLS), casting off international political isolation (ITER, SKA), as well as overcoming relationships of dependency and inequality (AfLS). Regarding our second question, the cross-case comparison shows that southern actors are more likely to obtain their objectives in IGSOs if four—in some cases five—conditions are met.

The first condition relates to an IGSO's maturity. Our analysis indicates that the younger an IGSO and the less rigid its institutional framework, the more far-reaching objectives southern actors can pursue. One reason for this is that the Global North established many now-mature IGSOs and cemented their rights and privileges in rigid institutional frameworks which make it difficult for newcomers, including those from the Global South, to pursue ambitious political and scientific objectives, for example, setting an IGSO's research agenda or initiating new research infrastructures. These are challenges that southern actors also experience in traditional research collaborations. If countries of the Global South pursue less ambitious objectives, it may still pay off for them to participate in mature IGSOs, as collaborations in these organizations expose them to cutting-edge technology and enhance their S&T capacities. Our case study of SKA further shows that countries of the Global South may be able to mitigate institutional constraints and take a leadership position in IGSOs. This seems to be the case if they get involved at an early phase, ideally as founding members, because as such they have greater chances of shaping institutional frameworks before institutional inertia sets in. The cases of ITER and AfLS partly support this finding.

The remaining four conditions are linked to a country's scientific community, domestic politics, industrial capacities, as well as its location if an IGSO has rigid geographic requirements. First, the cases of CERN, SKA, and AfLS underline the importance of an existing research community that champions participation and provides expertise for the active involvement of southern actors in IGSOs. For instance, India's nuclear physicists have collaborated with CERN even before the more institutionalized cooperation of the 1990s and 2000s. Similarly, the idea of AfLS is largely driven by African researchers and scientific diaspora nested in a global community of scientists. In the case of SKA, South Africa first lacked a community of radio astronomers, but its willingness to build capacities in this field was understood as a signal of commitment to the project. Second, continuous domestic political support and long-term national commitments, in cash and in kind, are essential. Where such political support is lacking and contributions fail to materialize, IGSO partners may quickly fall into disgrace, as the remaining ITER partner's ill will toward India and the US demonstrates. With respect to long-term national commitments, many southern actors have a considerable disadvantage compared to countries of the Global North as they have to plan and work under more acute political, economic, and human capital constraints. For example, one of our interviewees explained that South African policymakers currently consider it "risky" to spend public money on IGSOs when the country's limited resources could also be used to address more pressing domestic challenges (INT Sewell 2022). Third, IGSOs often rely on large-scale infrastructures to be built by industrial contractors. Possessing suitable industrial capacities can thus strengthen the position of southern actors in IGSOs. Indian companies, for instance, provided important hardware to the LHC. Similarly, South Africa relied on expertise from its advanced defense industry to build SKA's forerunners that showcase the country's capabilities. Fourth, while scientific, political, and industrial capacities matter for all IGSOs, geography is more crucial for some projects than for others. For example, geographic requirements are very clear cut in fields such as astronomy, but more flexible in HEP (CERN), nuclear fusion (ITER), and synchrotron-based sciences (AfLS). For SKA, geography played an important role because the conditions necessary for the proposed research were only met in a few places around the globe. For AfLS, in turn, the question of geography is one of identity, because for project proponents, a lightsource realized on the African continent symbolizes a fairer participation of African researchers in the global science system.

The findings from our cross-case comparison have two important implications for science policy. First, countries of the Global South may benefit from adjusting their investments in and objectives for an IGSO to an organization's institutional maturity. To do so, political and scientific actors first have to explicitly map out which objectives they seek to attain through IGSO participation. For example, if southern actors want to take a political and scientific leadership role in an IGSO, they are more likely to do so if they invest in an emerging or planned IGSO, as our study shows that mature IGSOs possess rigid institutional frameworks that make it hard for newcomers to pursue ambitious objectives. Second, our case studies in sum indicate that countries of the Global South are more likely to attain their political and scientific objectives if they are able and willing to mobilize their scientific community, secure continuous domestic political support, muster their industrial capacities, and, in some cases, leverage their geographic location for an IGSO. In contrast to S&T-lagging countries, emerging southern powers are likely to have the capacity to do so, at least in areas they deem important. Yet, compared to countries of the Global North, they face more scientific, political, and economic constraints. As a result, policymakers from the Global South may benefit from strategically investing into IGSOs instead of taking a scattergun approach. This also applies to the four factors that condition a southern actor's ability to achieve its IGSO objectives. For example, as the case of the radio astronomy community in South Africa demonstrates, it can be useful for countries of the Global South to invest into a domestic science community that conducts specialized research instead of spending big amounts of limited funding on an entire discipline. Such strategic investments may also increase chances that long-term commitments can be honored from an economic and political perspective.

2.6. Conclusions and Outlook

IGSOs are characterized by long-term perspectives, relatively fixed institutional frameworks, as well as high demands on financial, technical, and scientific capacities. Our study started off with an investigation of India's role in CERN, Europe's oldest IGSO, and concluded with AfLS, a planned southern IGSO. Throughout our analysis, we showed that the position of southern countries in IGSOs can range from one of dependency and junior partnership in established organizations (CERN) to one of (self-)empowerment in planned IGSOs (AfLS).

Although our study provides important empirical contributions to the literature on international research collaboration, IGSOs, and SD, further research is required. First, given that our study only looks at a small number of IGSOs, there is a need for additional in-depth case studies and large-scale case comparisons to refine our findings. As the Global South represents a rich diversity of socio-economic and scientific systems, such studies should ideally move beyond our focus on southern emerging powers. Second, our line of research should be extended because it may enable us to examine if certain global governance trends also have an impact on the global science system. For example, in recent years, we have seen that some southern states under authoritarian rule have begun to position their nationals at the head of a wide range of United Nations (UN) agencies to gain greater influence in world politics. Given the pivotal role that the UN system plays for global governance, some see this as an indication that "the arc of global governance is beginning to bend toward a more illiberal orientation" (Lee, 2020). Additional research on southern participation in IGSOs could illuminate whether similar developments are unfolding in the global science system and if so, what consequences this may have for academic freedom, international science collaboration, and, ultimately, scientific progress.

3. Sustaining Local Opposition to Big Science: A Case Study of the Thirty Meter Telescope Controversy

Chapter three was submitted as "Sustaining Local Opposition to Big Science: A Case Study of the Thirty Meter Telescope Controversy" to *Technology in Society* on 15 December 2023. A revised version of the chapter was accepted for publication in May 2024.[4] The chapter investigates why the kia‘i, a group largely composed of Native Hawaiians, have managed to sustain opposition to TMT. In so doing, it also outlines how the kia‘i have expressed their grievances and enforced their interests in relation to TMT. Like chapter two, chapter three thus contributes to the thesis’ first research objective of understanding how stakeholders pursue and negotiate their interests in relation to Big Science. Yet in contrast to chapter two, which mainly focuses on how state actors pursue their interests within Big Science, chapter three explores how non-state actors enforce their interests in relation to Big Science.

3.1. Introduction

Big Science is increasingly common in research, especially in the field of astronomy where scientists rely on ever bigger instruments in ever greater numbers for their research (Baneke, 2020). Big Science is typically defined as science made big in three dimensions, namely organizations, politics, and machines (Hallonsten, 2016: 17). Such a conceptualization of Big Science reflects that large scientific projects need substantial funding, which usually comes from the highest political level (Hackett et al., 2004: 750). Moreover, it indicates that the organization of these projects often centers around large scientific infrastructures (Hallonsten, 2016: 108). It is through such infrastructure, but ideally also through economic contributions and societal outreach, that Big Science is embedded in local communities.

Proponents of Big Science tend to frame it as a “win-win” for all stakeholders, including for local communities (Agrell, 2012), but research has shown that local opposition to Big Science is common (Stenborg and Klintman, 2012; Kaijser, 2016; Walker and Chinigò, 2018). In most cases, however, local resistance is short-lived. The story is different for the kia‘i mauna[5] (protectors of the mountain)—a group which is largely composed of Native Hawaiians—and their opposition to the Thirty Meter Telescope (TMT). With a price tag of nearly 4 billion US dollars, TMT is Big Science “at its biggest” (Swanner, 2017: 294). The kia‘i have opposed the construction of TMT on Mauna Kea, Hawai‘i Island, for 10 years. In this paper, I investigate why they have been able to sustain such momentum.

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[4] The revised version of the chapter was accepted for publication on 21 May 2024 and is available online via https://www.sciencedirect.com/science/article/pii/S0160791X24001453?via%3Dihub.

[5] From here on referred to as (the) kia‘i.

To explain the resilience of local opposition to TMT, I draw on social movement theory and the concept of place attachment. Sixteen interviews that I conducted with Native Hawaiians, local community members, astronomers, and policymakers form the empirical backbone of this paper. I also analyze kiaʻi testimonies that were collected for two documentaries (Inouye, 2019; Kaena-Lee and Espinosa-Jones, 2021), five interviews that Kuwada and Revilla (2020) conducted with kiaʻi, as well as academic and grey literature. Based on this empirical material, I argue that six factors have been decisive for the resilience of local opposition: multi-generational leaderful organization, grassroots resources, versatile tactics, anti-science counterframing, local and national political opportunity as well as place attachment-driven commitment.

The article's remainder is structured as follows: In section two, I provide an overview of the existing scholarship on local opposition to Big Science. Thereafter, in section three, I outline my theoretical framework that combines insights from scholarship on opposition to renewable energy projects (REPs) and social movements. I discuss research ethics, methods, and data in section four. Then, in section five, I contextualize TMT and local resistance to it. I present the six factors that have been decisive for the resilience of kiaʻi opposition in section six. Finally, in section seven, I discuss my findings and outline future research avenues.

3.2. Local Opposition to Big Science

While studies on public opposition to "conventional" technoscientific projects are abundant (Motion et al., 2015; Neresini and Lorenzet, 2016), there is little research on local opposition to Big Science. The latter differs from conventional science in that it carries (political) symbolism which often gives it special treatment in science policy (Hallonsten, 2016: 19). Within the Big Science literature, local opposition has mostly been dealt with in passing. Two exceptions are Stenborg and Klintman's (2012), as well as Kaijser's (2016), studies on local environmental opposition to the European Spallation Source (ESS), a multi-disciplinary research facility worth 1.8 billion euros. According to Kaijser (2016), opponents of ESS mainly failed to generate wider resistance because it was hard for them to appear legitimate to the public while criticizing a project that was associated with "development and progress" (p. 53-54). In addition to the above two studies, there is a growing body of research which investigates why and how marginalized communities voice opposition to Big Science. This research mainly focuses on the Square Kilometer Array (SKA)—an astronomy project currently under construction in Australia and South Africa's Karoo region—and TMT.

Examining SKA's local impact, Walker and Chinigò (2020) contend that there are two main reasons why parts of the host community in the Karoo oppose the project. First, they point to conflicts over SKA's land acquisition process (p. 401-402). Second, Chinigò and Walker (2020) argue that clashing interests and expectations between SKA's funders and the local community led to mistrust at the local level (p. 402). According to the authors, a lack of involvement in decision-making processes and untransparent communication between the local community and SKA galvanized this mistrust (Chinigò, 2020: 595). Although several scholars (Atkinson, 2019; Gastrow and Oppelt, 2019) highlight SKA's efforts to address these issues, Chinigò and Walker (2020) conclude that SKA's beneficiaries are "powerful constituencies in faraway metropoles," not SKA's host community (p. 393).

Scholarship on local opposition to TMT mostly focuses on the "how" and "why" of resistance. The Hawaiian scholars Case (2021), Maile (2019), and Goodyear-Ka'ōpua (2017), for example, provide overviews of the different protest activities that the kia'i engaged in between 2014 and 2019. Moreover, they describe how these activities were organized, which tactics were used, which principles were applied, and how local, national, and international actors reacted to the protests. With respect to the latter, Case (2021) and Maile (2019) highlight how the kia'i received and lent support to indigenous movements in New Zealand and on the US mainland. In doing so, they underline the great cultural, spiritual, and ancestral significance that Mauna Kea holds for many Native Hawaiians. Salazar (2014) and Swanner (2013) more broadly investigate the history of local opposition to astronomy development on Mauna Kea. Both scholars emphasize that a multitude of factors triggered opposition. Salazar (2014) argues that past mismanagement of the mountain and environmental concerns weigh heavily in the controversy. In a more recent publication, Casumbal-Salazar (2017) further contends that protests against astronomy development on Mauna Kea mirror a broader struggle to decolonize Hawai'i, whose annexation by the US in 1898 is politically and legally contested (Sai, 2004). To this, Swanner (2017) adds that astronomers' lack of engagement with Native Hawaiians has fueled local discontent. She also argues that in Hawai'i, science, embodied by telescopes and astronomers, is perceived "as the newest agent of colonization" (p. 294).

Adding to the literature on local opposition to astronomy development on Mauna Kea, this study examines why the kia'i have been able to sustain opposition to TMT and thus managed to halt project development. In doing so, it illuminates how marginalized communities can effectively make their voices heard in relation to Big Science, which is a neglected, yet fundamental question considering that Big Science not only requires large capital investments but also community consent and public acceptance.

3.3. Theoretical Framework

In my analysis, I bridge diverse theorizing strands, which is believed to generate more flexible interpretative frameworks with a broader explanatory scope (Borch, 2012). Specifically, I use structuralist and cultural approaches to social movement emergence. Compared to studies that exclusively rely on one or the other, my framework promises to capture both the meaning-making and material dimensions of collective action. Social movement theory lends itself to my purposes because although it is predominantly concerned with the question of when and why collective action emerges, research has shown that the factors which help collective action to emerge also play a role in it persisting (McAdam et al., 1996; Cai, 2016; Teo and Loosemore, 2011). Given that local resistance to Big Science is a form of collective action, I assume that social movement theory is a useful lens to guide my analysis. I combine social movement theory with the ideational concept of place attachment. As Mauna Kea is a place of great cultural, spiritual, and ancestral significance to many Native Hawaiians, I assume that the concept may help explain why local resistance to a project planned for construction on this particular mountain has persisted.

3.3.1. The Role of Resources, Political Structures, and Framing in Collective Action

Three influential approaches to the emergence of collective action and social movements are resource mobilization, political opportunity, and framing theory. RMT underlines the role of organizational structures and processes (Rohlinger and Gentile, 2017: 11). Theorists working in this structural–material tradition emphasize that collective action "if it is to be sustained for any length of time, requires some form of organization" (McAdam and Scott, 2005: 6). This includes leadership and resources, the latter of which can be tangible and intangible (Freeman, 1979). Important material resources for activists are money and supplies (Rohlinger and Gentile, 2017: 11), while people, their time, and tactics are vital in-kind resources (Rohlinger and Gentile, 2017: 11). Tactics are "noninstitutionalized forms of political expression" with which activists try to garner public support and put pressure on those in positions of power (Taylor and Van Dyke, 2004: 263). They may range widely from strikes to campaigning on social media (Taylor, 2007). Organizational features of a social movement may likewise lie on a continuum between formal and informal. Formally organized social movements are highly professionalized, while informal movements are usually grassroots efforts with volunteer staff, no clear leadership and limited resources (Rohlinger and Gentile, 2017: 12). Organization and leadership are crucial for collective action because they facilitate coordination. Strong leaders are instrumental as they help formulate strategies and deal with targets of collective action (Morris and Staggenborg, 2004: 171).

Similarly structural in focus as RMT, POT holds that the broader political context determines which objectives and tactics are chosen and how likely it is for them to succeed (Meyer, 2004: 127). The social movement scholar Tilly (1978) defines political opportunity as "the extent to which other organized groups, including state institutions, accept or oppose the objectives of collective action and reduce or increase its costs" (Rohlinger and Gentile, 2017: 14).

Finally, the "cultural turn" in the study of social movements introduced the concepts of framing and frames. Framing "refers to the meaning-making processes associated with the construction and interpretation of grievances, the attribution of blame and the creation of rationale for participation" in social movements, while frames are the outcomes of those meaning-making processes (Rohlinger and Gentile, 2017: 16). They tell the public what is at stake and outline the boundaries of the debate (Rohlinger and Gentile, 2017: 16).

3.3.2. Place Attachment

In the pertinent literature, place attachment is broadly defined as "emotional bonds between people and places" (Cass and Walker, 2009), where "place refers to space that has been given meaning through personal, group, or cultural processes" (Vorkinn and Riese, 2001: 252). The concept is used to explain why people object to REPs, arguing that opposition to REPs is driven by place-protective attitudes (Devine-Wright, 2009: 432) rather than "not-in-my-backyard"-ism (Sovacool, 2009; Cass and Walker, 2009; Devine-Wright, 2009; Devine-Wright, 2005).

According to the literature, place-protective attitudes and action can intensify or wane over time because place attachment is not a static phenomenon but involves a complex "interplay of emotions, cognition, and behavior" (Vorkinn and Riese, 2001: 252). Moreover, place-protective attitudes do not necessarily culminate in local opposition. If a project is seen to be "place enhancing" in a physical, symbolic, or economic sense, place attachment may even correlate with project support (Devine-Wright, 2009: 434). Opposition only emerges if individuals with strong attachment to a specific place perceive a project as having a negative impact on it (Devine-Wright, 2009: 434). This may be the case if a project infringes on how individuals experience a cherished place or if a place is symbolic of home and a project is seen as being imposed upon it without genuine public engagement (Devine-Wright, 2009: 434) in the form of information, consultation, and involvement in decision-making processes (Stadelmann-Steffen and Dermont, 2021: 2 ff.).

In the case of Big Science projects, engagement is particularly crucial because in contrast to other big infrastructural projects, big scientific projects harbor scientific communities that are expected to regularly interact with their local host communities through public outreach activities and by contributing to local education, particularly in science, technology, engineering, and math (STEM). The fact that the Next Generation Event Horizon Telescope, an extension of the existing Event Horizon Telescope, specifically emphasizes its ethical obligations towards local communities in one of its most recent publications (Galison et al., 2023: 4) illustrates this point.

3.4. Research Ethics, Methods, and Data

Researching indigenous-led activism as a non-indigenous scholar raises ethical issues which I approached in a critical-reflexive manner throughout the research process. This included familiarizing myself with decolonial methodologies (Liboiron, 2021; Tuhiwai Smith, 2021) and constantly reflecting on my positionality as a community outsider and a non-indigenous researcher.

Research on indigenous communities that is conducted by community outsiders has been and continues to be problematic for these communities (Tuhiwai Smith, 2021: 158), particularly if it lacks integrity. To ensure that my research is ethical, I first asked all interviewees for their written consent to participate in my research. Second, I perpetually considered how my research could benefit the local community. As I did not want to impose an approach, I asked my interviewees for feedback on this issue. In doing so, I learned that different community members have different conceptions of how research on Big Science may benefit their community. Some interviewees, for instance, underlined that academic research from community outsiders is in and of itself beneficial (INT11). Others stressed the importance of making my research accessible to a non-academic local audience (INT13). Third, wherever possible, I engaged in a "member checking" (Ademolu, 2023: 18) and "community review" process (Liboiron, 2021: 140), which meant that I sent interview transcripts to my interviewees and asked them for feedback on my draft article.

I chose local opposition to TMT as a case study based on the deviant case selection technique (Levy, 2008). According to this technique, a case is selected because "by reference to some general understanding of a topic, it demonstrates a surprising value" (Gerring, 2007: 105). This applies to opposition to TMT as it sustained momentum for much longer than opposition to Big Science typically does. Investigating a deviant case and explaining why it diverges from theoretical and/or empirical expectations is useful as it may help refine these expectations, extend them, or formulate new ones (Levy, 2008: 13). Yet findings from such a single case study cannot be easily generalized beyond the case under investigation.

For the description and analysis of my case study, I triangulated data from reactive (interviews) and non-reactive (documents) sources, a strategy which is believed to increase the reliability of inferences (in: Webb et al., 1999: 2). Overall, I conducted 16 semi-structured interviews with Native Hawaiians, local community members, policymakers, and astronomers in person and online between August 2022 and March 2023 (see Table 4). Such a "multiperspectival orientation" is vital to understand collective action as it is usually "embedded within a multiorganizational field consisting of protagonists, antagonists, and bystanders" (Snow and Trom, 2002: 154). I also draw on five transcribed interviews that Kuwada and Revilla (2020) conducted with the kiaʻi for a University of Hawaiʻi (UH) publication. Moreover, I transcribed and analyzed kiaʻi testimonies that were collected for two documentaries (Inouye, 2019; Kaena-Lee and Espinosa-Jones, 2021). All conducted interviews were guided by interview guidelines which varied depending on which stakeholder group I was talking to.

I used MAXQDA as well as Deterding and Waters' (2021) flexible coding method to analyze my sources. As Deterding and Waters (2021) recommend for projects with fewer than 30 interviews, I refrained from indexing my interview transcripts. Instead, I began analytic coding on the first reading. The coding scheme that emerged after several rounds of analysis contained deductive codes which were grounded in my theoretical framework, inductive codes which arose from the empirical material, and an independent code which pointed to passages where interviewee statements were particularly pertinent.

Table 4: Overview of conducted interviews for chapter three

Interviewee Code	Actor Group	Length of Recording
INT01	Environmental NGO	76 minutes
INT02	Big Island Community	64 minutes
INT03	O'ahu Community	84 minutes
INT04	Astronomy Community	36 minutes
INT05	Big Island Community	67 minutes
INT06	O'ahu Community	45 minutes
INT07	O'ahu Community	46 minutes
INT08	Big Island Community	44 minutes
INT09	Big Island Community	51 minutes
INT10	Big Island Community	133 minutes
INT11	O'ahu Community	56 minutes
INT12	Hawaiian Policymaker	44 minutes
INT13	O'ahu Community	60 minutes
INT14	Astronomy Community	49 minutes
INT15	Kai'i Supporting Group on US Mainland	54 minutes
INT16	Astronomy Community	49 minutes

3.5. Contextualizing TMT and Local Opposition to it

Mauna Kea is a dormant volcano on Hawaiʻi Island that stands 4,205 meters above sea level and is of great cultural significance to Native Hawaiians (Kiyuna, 2019). TMT is planned for construction on the mountain's northern flank. Today, Mauna Kea harbors 13 telescopes, of which TMT would be the biggest addition at 18 stories high. The existing 13 Mauna Kea observatories were constructed over a period of roughly 40 years, starting in 1967. At the time, the local economy of Hawaiʻi Island was recovering from the devastating effects of a tsunami (Swanner, 2013: 180). To attract investment to the island, local authorities encouraged the development of an astronomy precinct on Mauna Kea and entrusted the newly established Institute for Astronomy (IfA) of UH with a 65 year "master lease" for a substantial area on Mauna Kea's summit. Until a reform of Mauna Kea's stewardship was enacted in 2022, IfA was authorized to sublease Mauna Kea lands to other institutions through this master lease (Swanner, 2013: 183).

TMT is being designed and developed by the TMT International Observatory (TIO), a non-profit international partnership consisting of US, Chinese, Japanese, Canadian, and Indian stakeholders (TMT International Observatory, 2022). TIO chose to build TMT on Mauna Kea because its stable, dry, and cold climate ensures pristine observing conditions. Under these conditions, TMT's 30 meter mirror would allow scientists to peer into the universe with sharper vision than most of today's largest telescopes to probe many open and fundamental questions in astronomy (TMT International Observatory, 2022). Originally, TMT's construction was planned to begin in 2014 and to complete by 2021 (Sanders, 2013: 82). Local resistance to TMT, however, has considerably stalled project development.

Opposition began to emerge around 2011, shortly after UH first applied for a construction permit for TMT on behalf of TIO (KAHEA, 2016). At the time, a group of Native Hawaiian cultural practitioners and environmentalists filed for a contested case hearing regarding TMT's construction permit, a proceeding during which the legal rights, duties or privileges of specific parties are required to be determined by law (Department of Land and Natural Resources, 2023). Later, they also contested UH's proposed sublease of Mauna Kea lands to TIO (KAHEA, 2016) because they feared that TMT would threaten endemic flora and fauna and contaminate the island's aquifers and watersheds. Moreover, the petitioners argued that the telescope would infringe on Native Hawaiian cultural practices and rights. While such arguments could have been put forward against any other big infrastructural project, local discontent was and continues to be directly linked to the scientific nature of TMT. Some local community members, for instance, are exasperated that the telescope is unlikely to create STEM jobs for (Native) Hawaiians (INT10; INT08). Others deem the astronomy community's involvement in local STEM education insufficient (Kahanamoku et al., 2020: 7; INT16).

In October 2014, after the legal challenges of local environmentalists and cultural practitioners had been dismissed, TIO tried to break ground for TMT. A group of Native Hawaiians who had gathered for prayers at the mountain's base spontaneously decided to disrupt the groundbreaking ceremony (INT10). In spring and summer of 2015, opposition intensified as TIO prepared to begin constructing TMT. On two occasions in 2015, hundreds of protestors—who by then referred to themselves as kiaʻi—blocked Mauna Kea's access road, preventing crews from reaching the construction site. In the process, 31 kiaʻi were arrested (Kahanamoku et al., 2020: 5). Some US astronomers and media commentators reacted strongly to the protests, describing the kiaʻi as "a horde of [lying] Native Hawaiians" (Kruesi, 2015) and comparing their struggle against TMT to biblical creationists' persecution of scientists like Galileo (Johnson, 2014). To enable TMT's construction, authorities issued emergency rules which restricted the public's access to Mauna Kea. In October 2015, however, these rules were invalidated in court. TMT's construction permit and the sublease of Mauna Kea lands to TIO were likewise remanded in December 2015 and March 2016 (Hawaii Tribune Herald, 2016), prompting TIO to look for an alternate project site (KAHEA, 2016). Such an alternate site, albeit from a scientific point of view a less promising one, was found in La Palma, Spain (Feder, 2019).

After TMT's construction permit had been remanded, a second contested case was initiated in 2016. Hearings lasted several months, but in October 2018, the construction permit was eventually upheld in court (Witze, 2018), even after numerous appeals (INT10). TMT's construction was to commence shortly after, but once again the kiaʻi blocked access to the construction site. This time, protestors prevented construction through non-violent direct action (INT10) and by installing a permanent encampment at Mauna Kea's base. This area was a type of "refuge," called Puʻuhonua o Puʻuhuluhulu and included a medical tent, kitchen, makeshift university, and sanitary installations. As in 2015, 38 kiaʻi—most of them kupuna (elders)—were arrested, which galvanized local opposition further. The arrests also led to a wave of international and national solidarity, with some US-based astronomers signing an open letter condemning the use of force and a "science at all costs" approach, which in their view could endanger public support for science (Knapp, 2015). The kiaʻi finally vacated their encampment on Mauna Kea in early 2020 when COVID-19 hit (INT10).

3.6. Explaining the Resilience of Local Opposition to TMT

My analysis, which is informed by social movement theory and the concept of place attachment, reveals six factors which have made the sustained kiaʻi opposition possible. The first three factors—multi-generational leaderful organization, grassroots resources, and versatile tactics, as well as local and national political opportunity—correspond with the structural–material assumptions of RMT and POT. Anti-science counterframing and place attachment-driven commitment add cultural–ideational elements to these four factors (see also Table 5).

Table 5: Overview of how explanatory factors correspond with used theories and concepts

Theory/Concept	Underlying Logic	Explanatory Factor
Resource Mobilization	Structural–Material	
		Multi-Generational Leaderful Organization Grassroots Resources Versatile Tactics
Political Opportunity	Structural	
		Local and National Political Opportunity
Framing	Cultural–Ideational	
		Anti-Science Counterframing
Place Attachment	Cultural–Ideational	
		Place Attachment-Driven Commitment

3.6.1. Multi-Generational Leaderful Organization

The kiaʻi have been able to sustain opposition to TMT because their efforts have been supported across generations and led by several savvy leaders. When opposition to TMT began to emerge in 2011, it mostly came from Native Hawaiians who were part of a vocal generation with considerable experience in activism. This generation had lived through the Hawaiian Renaissance, a movement which revived Hawaiʻi's cultural practices and language during the 1970s, after generations of Hawaiians had been beaten for speaking their native tongue (Van Dyke, 2007: 225). Some of the cultural practitioners who first petitioned for a contested case hearing to challenge TMT's construction permit participated in the movement to demilitarize the island of Kahoʻolawe (INT10), which is considered a major success of the Hawaiian Renaissance (Van Dyke, 2007: 269). The US military had used Kahoʻolawe, which lies southwest of Maui and is considered sacred by Native Hawaiians, as a bombing range for several decades. Later, during the 2014, 2015, and 2019 protest cycles, here defined as "phases of heightened conflict across the social system" (Tarrow, 1993: 284), kiaʻi came from all generations (INT10, INT11, INT07, INT06). Several interviewees underlined that this multi-generational support was vital to sustain momentum for the struggle to stop TMT because different generations could contribute different skillsets which, in turn, were crucial for the effective organization of collective action:

"We have been advocating for justice for a long time. And we have been doing it trans-generationally. So we have passed on experiences from one generation to the next, and every generation that comes after has greater experience than the prior. […] So even our grassroots movements have begun to look extremely organized. And that is because at this point, we just are."(INT07)

Interviewees mentioned that kupuna were able to contribute the knowledge of which tactics had proven effective in previous Hawaiian struggles, while younger kiaʻi were savvy social media users able to disseminate information to the public via channels such as Twitter and Instagram (INT11).

As suggested by RMT, both when local opposition emerged and when it gained momentum, leadership has been instrumental for the kiaʻi to formulate strategies, coordinate action, and deal with local authorities. Cultural practitioners were among those who first petitioned for a contested case hearing on TMT's construction permit in 2011 (INT10) and remained instrumental during front line action on Mauna Kea in 2014, 2015, and 2019. Moreover, a kiaʻi who was part of a media team that reported on kiaʻi activities on Mauna Kea underlined that kumu (teachers) played important roles as spokespersons:

"So you look at people that were put on camera and I feel like if not all of them, most of them, they were teachers. You had [enumerates a few kiaʻi]. *We have these really articulate people, and it was so natural for them to just be able to speak in front of people."* (Ryan Gonzalez quoted in: Kuwada and Revilla, 2020: 648)

In addition, interviewees mentioned that leadership roles were first and foremost given to individuals and organizations that had direct ancestral connections to Mauna Kea:

"[…] we do have a tendency to elevate certain organizations, and that is because culturally we respect who comes from where. So we like to elevate the families that exist on that land. And we let them be the leaders, the ones who have a say and the rest of us stand with them." (INT07)

However, not everyone agreed with this principle (INT11), which led to tensions between Oʻahu- and Big Island-based activists (INT13).

Finally, a member of the kia‘i media team mentioned that the kia‘i leadership included "a larger group" (Kehaunani Abad quoted in: Kuwada and Revilla, 2020). When, as described by this kia‘i, "multiple leaders […] share power […] and drive collective decision-making," collective action is considered "leaderful" (Nardini et al., 2021: 120). In the case of local opposition to TMT, leadership was first restricted to a few individuals, but then became leaderful from 2011 onward (INT10). An interviewee indicated that a growing leadership base meant that people could take on different responsibilities (INT10) which facilitated effective task division over time.

3.6.2. Grassroots Resources

Equally in accordance with RMT, local opposition to TMT sustained momentum because between 2011 and 2019 a steady flow of resources ensured that the kia‘i could engage in protest activities on and off Mauna Kea. The most valuable resources that the kia‘i have been able to rely on were in kind, as one interviewee underlined:

"But it is the people that just came to donate their time to clean the bathrooms, to sweep the roads, to feed everyone [at the encampment]. *"* (INT09)

Material resources like monetary contributions also played a role. Interviewees stressed that most contributions, monetary or otherwise, came from the local community (INT11, INT10, INT03, INT13, INT01). Funds needed to challenge TMT in court were initially "out of pocket" expenses covered by the petitioners (INT01, INT03). Later, Hawaiian organizations, such as The Hawaiian–Environmental Alliance (KAHEA) and the Office of Hawaiian Affairs, chipped in to support kia‘i that were engaged in legal battles (INT01, INT11).

3.6.3. Versatile Tactics

As indicated by RMT, the kia‘i managed to maintain opposition to TMT because they employed versatile tactics which put those in positions of power under constant pressure. What is noteworthy is that some of these tactics were borrowed from past Hawaiian struggles, such as the movement to demilitarize the island of Kaho‘olawe (INT16, INT13), and other indigenous efforts to protect indigenous lands and cultural practices. The Dakota Access Pipeline Protests led by the Standing Rock Sioux in Dakota in particular had considerable influence on the kia‘i

(INT01, INT03, INT10, INT11). Some of the kiaʻi leadership lent support to Standing Rock and participated in workshops that were organized during the Dakota Access Pipeline Protests to learn how to engage in "peaceful resistance" (INT11, INT08). A Hawaiian policymaker said that the parallels between the tactics used in Standing Rock and on Mauna Kea were palpable:

"And the folks who were organizing the protests on the Mauna were very consciously using the same techniques that they used in Standing Rock […]." (INT12)

The tactics that the kiaʻi used throughout their efforts to stop TMT from being built ranged widely. When opposition first arose in 2011, it was mainly voiced within "state sanctioned spaces" (Salazar, 2014: 341-342), such as the courtroom. Later, in 2014, 2015, and 2019, when protest activities mainly took place on Mauna Kea, the kiaʻi considerably extended their tactical repertoire. This repertoire included but was not limited to campaigning on social media, front line action, chanting, and hula performances (Casumbal-Salazar, 2017: 2-4; Maile, 2019: 332). A kiaʻi summarized the change between the tactics that were employed in early phases of the struggle and those that were used during the later stages as follows:

"What shifted is that before we were operating within their scheme of life. So we were talking about the court case, the laws, and the reports. And with the Mauna, we were living our truth, we were living our culture, we were being who we are. […] When protocol is happening […] that is such a different story than us saying what is flawed in that report. Like, to heck with your process." (Kehaunani Abad cited in: Kuwada and Revilla, 2020: 680)

Interviewees moreover underlined that during later protest cycles, social media was crucial to inform people in Hawaiʻi and elsewhere about events on Mauna Kea, to keep them engaged in the struggle to halt TMT, and to gain sympathetic support:

"[…] the Native Hawaiian people were able to sustain opposition to the telescope, probably because of modern technology, the ability to get the word out there, get more people involved." (INT07)

As opposed to local authorities that used classic information dissemination formats, such as press conferences, using noninstitutionalized formats like social media helped the kiaʻi to reach people beyond Hawaiʻi, including celebrities like Jason Momoa, who joined kiaʻi activities atop Mauna Kea (Scheuring, 2015), and policymakers like former presidential candidate Elizabeth Warren, who tweeted her support (Nakamoto-White, 2019).

3.6.4. Anti-Science Counterframing

As suggested by framing theory, local resistance to TMT has also persisted because the kiaʻi frame the TMT controversy in a way that effectively counters (popular media) frames that reduce it to a struggle of "science vs. religion" (Johnson, 2014) and narratives that depict the kiaʻi as anti-science.

Instead of framing the TMT controversy as a struggle against science, the kiaʻi have presented it as a multidimensional issue in which economic and environmental concerns, as well as the question of indigenous consultation, were at stake (for example Jonathan Osorio quoted in: Flaherty, 2019). In addition, the kiaʻi especially made a point of framing their struggle as a fight against "the process [of how astronomers and politicians pushed for TMT], not the science [itself]" (Alegado, 2019: 7). In line with this framing, the kiaʻi criticized "mainstream" science, the TMT, and its proponents seen to be part of it, for not honoring essential research practices and ethics like getting (indigenous) consent for TMT (Alegado, 2019; Kagawa-Viviani, 2019). To the kiaʻi, the TMT controversy therefore also reflected "an erosion of trust in the […] scientific establishment" (Tachera, 2021). Science per se, at least if done pono (righteously), was not up for debate. Making this distinction in framing the TMT controversy was crucial for the kiaʻi because it helped them to be perceived as legitimate while criticizing a type of big scientific project that is typically considered "good in principle" (Van der Horst, 2007: 2706) and is generally associated with "progress and development" (Kaijser, 2016: 53-54).

In their media strategy, the kiaʻi made a conscious effort to clarify that it is possible "to love" science while being critical of how it is conducted. Their media team also invested considerable energy into getting this message out in "smaller, bite-size" social media posts (Ryan Gonzalez cited in: Kuwada and Revilla, 2020: 641). In doing so, the kiaʻi outlined the boundaries within which they deemed it acceptable for the debate around TMT to occur:

"The framing of the TMT conflict [culture vs. science] *in public and science circles was the most painful of it all. […] These statements that equate science to progress and upholding*

cultural values as backward are [...] not only incorrect but also dehumanizing." (Kagawa-Viviani, 2019)

As this excerpt from an opinion piece on the TMT controversy clearly demonstrates, depicting the kia'i as anti-science did not fall within the aforementioned boundaries.

3.6.5. Local and National Political Opportunity

Moreover, the kia'i have succeeded in sustaining momentum for their struggle because, as POT suggests, the local and broader political context in the US were conducive to it in three respects. First, efforts to protect a place of great significance to an indigenous population resonated with a greater awareness of indigenous (land) rights throughout the US, as this statement illustrates:

"One of the big reasons that I see that it [...] has stuck around for so long is probably due to an increasing focus on Native rights. A lot of the protesting coincided just chronologically with the Standing Rock protests [...] and a lot of other injustices against native peoples really being brought into the public spotlight." (INT02)

Second, Hawaiians in favor of TMT were not as well organized or media-savvy (INT02) as the kia'i. In addition, they experienced considerable pushback and in rare cases (INT02) verbal aggression from some community members for their pro-TMT activism. According to interviewees, it was this pushback which led many Native Hawaiians in favor of TMT to remain silent:

"There are a lot of people who support TMT, but they are not going to be coming out and shouting it in front of a camera or in front of other people. And part of the reason for that is because the people who did come out in support were receiving death threats. And just the social capital that you lose in being supportive of this project was not necessarily worth it." (INT05)

Third, the response from local authorities was piecemeal and uncoordinated (INT13), making it easier for the kia'i to push their agenda more effectively. Several interviewees commented that local authorities, such as the mayor of Hawai'i Island, Hawai'i's then governor and UH were caught off guard by the intensity of the protests in 2014, 2015, and 2019 (INT10, INT13, INT16). As a result, reactions, especially from the local authorities, were ad hoc and not conducive to easing tensions around TMT.

3.6.6. Place Attachment-Driven Commitment

Finally, local opposition to TMT persisted because, over time, the kiaʻi remained committed to the objective of preventing further astronomy development on Mauna Kea. In practice, this has meant that they are willing to take risks and entertain inconveniences to achieve their objectives (Freeman, 1979: 173). For instance, kiaʻi have "to take time off from work, rearrange their schedules, organize childcare, and spend money on flights or gas to get" to Mauna Kea (Kuwada and Revilla, 2020: 519). Between 2011 and 2020, this willingness to spend time, energy, and resources to uphold opposition to TMT did not waver. For instance, when opposition first began to emerge around 2011, the petitioners in the first contested case hearing invested considerable time and resources:

"For us, it is our own time and expense that covered everything. More than anything it is the time. You got to write a brief. […] The first time around [during the first contested case hearing for the construction permit]*, we were up until the wee hours of the morning to file our briefs and everything. […] we were doing it from scratch."* (INT10)

In 2015 and 2019, when local opposition to TMT peaked, commitment remained similarly strong as an interviewee who joined the protest activities at this later stage confirms:

"[…] people lived up there [the base camp at Mauna Kea] *for months in tents and in the backs of their cars. And like that kitchen one* [the person in charge of the kitchen tent at the base camp]*, she stayed there, lived there and just cooked and cooked […] I think it's the dedication and people recognize that."* (INT08)

That dedication was strengthened through a deep cultural, ancestral, and spiritual attachment to Mauna Kea. Interviewees articulated place attachment in different but strong ways. Two kiaʻi that I interviewed for this paper, for example, referred to Mauna Kea as their piko (umbilical cord; INT06) or as "sacred" (INT11). In line with what the literature on REP opposition suggests, this strong attachment to Mauna Kea helped fuel and sustain opposition because TMT was seen as having a direct negative impact, particularly on the mountain's ecosystem and cultural sites (INT10):

"There are really serious environmental impacts we need to consider: the impact to our water. Much of the water for this island is fed from that Mauna. As the state and other agencies […] try to break ground on that Mauna they threaten that water, they threaten our native plants, our native animals." (Jamaica Osorio in: Inouye, 2019: 00:01:16)

As scholars working on opposition to REP suggest, place attachment further triggered opposition to TMT because local community members felt that the project was imposed on a place that they cherished without involving them. They also felt that the scientists wanting to build TMT and living among them did not bother to engage with them:

"I am 63 years old. I have always lived in the community here, right here in Hilo. Why are you the first [telescope person] *ever* [to] *come talk to us? [...] You have 500 scientists on the island. Where are you?"* (Recounted by INT16)

Finally, the kiaʻi remained committed to their objectives because by participating in protest activities they felt connected to likeminded community members:

"And while it was a protest, it was a time for us to reconnect with people we have not chatted with or talked [to] *in a long time. Share stories. Teach each other new chants and dances and teach the broader community."* (INT11)

This connection to place and sense of community motivated the kiaʻi to take risks and endure inconveniences, such as camping on "pocky" lava fields (INT06). At the same time, the TMT controversy put some (Native) Hawaiians working in the STEM fields in a difficult position, as they felt torn between their identities as local community members and as STEM researchers (INT06).

3.7. Discussion, Conclusion, and Outlook

In previous studies on local resistance to Big Science, scholars have argued that Big Science opponents typically struggle to appear legitimate while criticizing Big Science because it is often associated with “development and progress” (Kaijser, 2016: 53). My analysis reveals that this legitimacy problem can be overcome and local resistance can persist if six factors are present. These six factors are: multi-generational leaderful organization, grassroots resources, versatile tactics, local and national political opportunity, anti-science counterframing, as well as place attachment-driven commitment. Some of these factors seem to interact. For instance, during the early phases of the protests, legal challenges to TMT were dominant. Later, when the national context was more attentive to indigenous struggles, legal challenges were combined with more attention-attracting tactics like non-violent direct action and ritual performances. The fact that kiaʻi leaders were individuals with strong connections to Mauna Kea likewise indicates an interaction between the leadership and the place attachment dimension of local resistance. Finally, it is unlikely that the frames that the kiaʻi used would have been as successful if they had not also been magnified through unorthodox tactics, such as the use of social media. Additional research should further explore these interactions.

To get a better understanding of how local opposition plays out in different contexts as well as why local opposition does not materialize in contexts that resemble Hawaiʻi (e.g. Australia), additional case studies are needed. Such studies could help address the question of whether Big Science can be governed in a way that takes each stakeholder’s most important interests into account. A closer examination of recent developments in the TMT controversy may prove insightful in this regard.

In 2020, a working group of community, business, and astronomy representatives was established with the objective of reforming Mauna Kea’s stewardship. This working group issued a report on how Mauna Kea’s governance could be reformed to mirror the diverse interests of local stakeholders. Based on the report, Hawaiʻi State Act 255 was passed and a new stewardship authority was installed. The authority consists of eleven voting members, two of which need to be Native Hawaiian and recognized practitioners of Native Hawaiian traditional practices (O’Meara, 2022). Moreover, the authority is guided by Hawaiian principles and values (State of Hawaiʻi, 2022: §3). While several interviewees were skeptical whether the new authority would adequately represent local interests (INT10, INT05, INT06, INT11), just as many were cautiously optimistic that its establishment would help address local grievances around Mauna Kea (INT02, INT07, INT08, INT09, INT12, INT13). One interviewee commented that this reform would likely not have occurred without local protests because the kiaʻi raised “awareness and recognition [among] state and county elected leadership that something need[ed] to be done” (INT13).

Almost in parallel, TIO revised its approach to community engagement. As part of the process, it first decided to move its core management team to Hawaiʻi Island. Previously, the team was based in California. Second, after the protests, TIO quietly reached out to the kiaʻi and Hawaiʻi's most deprived communities to get a better understanding of local needs and concerns (INT16). Prior to this, TIO had almost exclusively engaged with its local supporters, often in media-effective ways. Through its efforts, TIO hopes to have a lasting impact on how the astronomy and science community relates to indigenous people, culture, and lands. Ultimately, however, only time can tell what impact its new approach to community engagement as well as the reform of Mauna Kea's stewardship system will have.

4. Big Science, Big Trouble? Understanding Conflict in and around Big Science Projects and Networks

Chapter four was published as Anna-Lena Rüland (2023) "Big Science, Big Trouble? Understanding Conflict in and Around Big Science Projects and Networks" in *Minerva.*[6] By proposing a model of conflict emergence in and around Big Science as well as providing a proof of concept for its validity, chapter four helps explain how conflicts arise between and among stakeholders as they pursue their respective interests in large scientific collaborations. In doing so, the chapter attends to the thesis' second research objective of deepening our understanding of how conflicts arise between and among Big Science stakeholders. The chapter contributes a holistic perspective of conflict emergence at the state and/or community level and thus combines the two levels of analysis that were examined separately in chapter two and three.

4.1. Introduction

Recently, interest in Big Science has surged, among other things because it is increasingly seen as a means to help address some of the grand challenges of our time (Börner et al., 2021). In the pertinent literature, the term Big Science usually refers to large-scale technical projects that

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[6] The chapter was accepted for publication on 30 May 2023. It is available online via https://link.springer.com/article/10.1007/s11024-023-09497-w and has been edited to ensure coherence with the other chapters of the dissertation.

are “physically bound to a single infrastructural site” (Hallonsten, 2016: 19), serve clearly defined ends, and are operated by big teams of scientists and/or engineers (Hallonsten, 2020: 631). However, since not all large-scale science installations are physically bound to a single site, this article introduces the term Big Science network to describe massive science projects which are geographically dispersed and provide infrastructures, resources, or services for top-level research.

For political and scientific stakeholders, both types of Big Science depict a significant and long-term economic investment (Brown and Malone, 2004: 114) that has the potential to enhance or harm their prestige (Williams and Mauduit, 2020; Office of Technology Assessment, 1995; Krige, 2013; McCray, 2010; Riordan et al., 2015) and ability to define science and policy agendas for the coming years. Both from a policy and scholarly perspective, understanding conflicts in Big Science is of utmost importance. Conflicts over sites, resources, scientific objectives, and/or credit have the potential to disrupt or completely derail these undertakings. A failure to adequately address conflicts in and around Big Science projects and networks, such as SKA, ITER, ESS, HBP, or TMT, could cost taxpayers millions of euros and cause serious damage to the public perception of large-scale science collaboration. While the literature on science collaboration and Big Science has investigated conflict causes, it has neglected to outline which specific mechanisms connect conflict cause and outbreak. This study addresses this blind spot by developing a model which explains how conflicts emerge in Big Science projects and networks by drawing on the scholarship on strategic action fields (SAFs). The model holds that five interlinked mechanisms—attribution of threat or opportunity, mobilization of resources, coalition-building, boundary deactivation, and innovative action—drive conflict emergence in and around Big Science. To provide a proof of concept for the model’s validity, it is applied to three typical, yet most-different, cases of Big Science, namely ITER, HBP, and TMT.

By opening the black box between conflict cause and outbreak, the model adds value to existing scholarship on science collaboration, which is generally less interested in conflicts as such than in their effects on knowledge creation (Knorr Cetina, 1999; Traweek, 2009) or the longevity of scientific cooperation (Ulnicane, 2015). Understanding which mechanisms fuel conflict, however, is vital for conflict prevention and mitigation. The model proposed here can contribute to both since some of its mechanisms are observable and can therefore function as early warning signs to science managers.

The remainder of this article is structured as follows: First, in section 4.2., I develop a model that helps explain which mechanisms link conflict cause and outbreak in Big Science. I review the interdisciplinary literature on science collaboration and Big Science to identify major conflict causes in scientific projects. Using insights from SAF scholarship, I then propose mechanisms that connect conflict cause and outbreak. In section 4.3., I detail the methods which I use to apply the model to three case studies in section 4.4., 4.5., and 4.6. Next, in section 4.7., I discuss the findings of the case study analysis. Finally, in section 4.8., I conclude by pointing out the study's implications for management, limitations, and future avenues for research.

4.2. Towards a Mechanism-Based Model of Conflict Emergence in Big Science

In this study, the term conflict refers to open as opposed to latent or surface conflict. It is defined as a *visible* struggle between at least two parties that either perceive or have mutually exclusive goals and experience strong interference from others in achieving said goals (Hocker and Wilmot, 1978: 9; Fisher et al., 2000). In Big Science, conflict can occur at three different levels. It may develop at the interpersonal (micro) level, at the group (meso) level and/or at the state (macro) level. In this article, I will focus on the latter two because conflicts at the meso and macro level have the biggest potential to impact public support and perception of Big Science as well as its success. As Shrum et al. (2001) argue in their seminal study on trust and conflict in science collaboration, it is less likely that interpersonal conflict affects a collaboration as a whole (p. 689). If big parts of a local community reject and protest Big Science, however, public support for it may dwindle. A project or network may similarly fail if an entire group of scientists or managerial staff decides to leave a collaboration in the aftermath of conflict. Finally, a Big Science collaboration may never materialize if conflict erodes high-level political support.

To propose a model that connects conflict cause and outbreak in Big Science via a chain of mechanisms, it is necessary to first identify potential conflict causes. It is essential to consult literature on science collaboration *and* Big Science on this issue because Big Science collaborations are essentially conventional research projects made big on three dimensions, namely "organizations, machines, and politics" (Cramer et al., 2020: 10).

4.2.1. Conflict Causes in Science Collaborations and Big Science

At the meso level, conflicts in science collaboration and Big Science are most likely to arise over issues concerning funding, management, and organization, work and task division, research objectives, access to scientific resources and instruments as well as the distribution of scientific rewards (Knorr Cetina, 1999; Shrum et al., 2001; Traweek, 2009; Vasconcellos, 1990; D'Ippolito and Rüling, 2019; Cook-Deegan, 1994; Riordan et al., 2015) (see also Table 1 in the Appendix). At the macro level, issues concerning siting, financial contributions, scientific access, and procurement are seen to be the main conflict causes (Åberg, 2021; Krige, 2013; McCray, 2010; Williams and Mauduit, 2020; Arnoux and Jacquinot, 2006; Claessens, 2020) (see also Table 2 in the Appendix). According to Hallonsten (2014), all of these issues are most likely to create conflict between states, their representatives and/or funding agencies during the planning phase of a Big Science project or network, as this stage is generally considered the "trickiest" (p. 35). However, most of these conflicts, whether they develop at the meso or macro level, tend to be on the surface or remain latent. Reflecting this, the literature on science collaboration and Big Science rarely uses the term "conflict." Instead, it speaks of "tensions," "divisions," or "disagreements" in and around science collaboration and Big Science. For instance, in the case of the Human Genome Project (HGP), Hilgartner (1995) states that some critics of the HGP were "concerned" about "resource allocation" and "questioned whether the data produced by sequencing entire genomes would in fact be useful" (p. 303). In a similar vein, Mahfoud (2021) underlines that there were "disagreements between computational neuroscientists" before HBP had been selected as a European Future and Emerging Technology (FET) flagship (p. 333). The disagreements that Mahfoud describes specifically concerned the question of "what structural details could be excluded from neuron models without affecting the functional output" (p. 333). In the case of ITER, McCray (2010) stresses that there were "disagreements" over ITER's location. He shows how ITER site proposals from Canada, Spain, France, and Japan led to tensions between these contenders.

This does not mean, however, that open conflict does not develop in Big Science projects and networks. In the case of ITER, HGP, HBP, and TMT open conflict did in fact arise. It only did so, however, once a decision affecting or concerning a major project or network component (i.e. siting, scientific approach, or management) had been taken or was about to be made. For example, in the case of HGP, open conflict erupted when US commercial actors decided to directly challenge the HGP's open science strategy by starting a genome sequencing effort with the objective of patenting genes (Lambright, 2002: 20 ff.). In the case of HBP, open conflict emerged once the HBP leadership had decided to exclude the subproject on cognitive architectures from HBP's core funding (Mahfoud, 2021: 334). With regards to ITER's site, McCray's study shows that open conflict arose in 2003 when two site finalists were left and a decision concerning the reactor site was imminent (Claessens, 2020; McCray, 2010). Media reporting on TMT likewise indicates that open conflict between the international TMT consortium, consisting of US, Chinese, and Japanese research institutions as well as Canadian and Indian quasi-governmental agencies, and parts of the local and Native Hawaiian population was brought about by the consortium's decision to build TMT on Mauna Kea, Hawai'i Island (Overbye, 2016; Feder, 2019). Based on these insights from the science collaboration and Big Science literature, I therefore argue that the *immediate* cause of open conflict in and around Big Science is an imminent or executed decision that affects or concerns a major project or network component.

4.2.2. Opening the Black Box between Conflict Cause and Outbreak

Descriptions and explanations of why conflicts arise in Big Science are abundant in the pertinent literature. The specific mechanisms that link conflict cause and outbreak, however, remain opaque. There are two reasons for this. First, in the literature on science collaboration, conflictual episodes are typically only mentioned insofar as they are seen as an obstacle that scientific communities need to overcome to cooperate more effectively or to create new knowledge (Galison, 1997; Knorr Cetina, 1999; Ulnicane, 2015). Second, in the literature on Big Science, there is a general lack of "systematic comparative analyses" (Rüffin, 2020: 41-42) and of theory-building, including on critical phenomena such as conflict emergence.

A strand of scholarship able to open the black box of conflict emergence is that on SAFs. This type of scholarship is, among other things, concerned with the question of how contention arises in SAFs. SAFs are meso level social orders, in which different social actors vie for power. Building on social movement and institutional theory as well as Gidden's (1984) theory on structuration and Bourdieu's (1975) concept of the field (Kauppinen et al., 2017: 798), SAF theory identifies three interlinked mechanisms that are responsible for the onset of contention in SAFs (Fligstein and McAdam, 2012: 20). It is assumed that contention emerges if actors in a SAF:

1. Define an action as a threat to, or opportunity for, the realization of their interests (Fligstein and McAdam, 2012: 20);

2. Mobilize their resources, and
3. Use innovative forms of action to defend or push their agenda.

Initially, SAF scholarship focused on the analysis of social movement-like episodes of contention, such as the emergence of the civil rights movement in the US (Fligstein and McAdam, 2012: 115 ff.). More recent studies, however, have demonstrated that SAF theory also lends itself to the analysis of contentious episodes that have less in common with social movements, for instance developments in science policy. Even though Big Science is a high-stake science policy area, insights from the SAF scholarship have not yet been used to analyze phenomena in Big Science projects or networks. However, scholars have applied SAF theory to study more recent macro and meso level developments in science policy, such as the emergence of the European Research Area (Kauppinen et al., 2017) or the move of US academic science toward the market (Berman, 2014). Some of these scholars have contributed to the existing scholarship on SAFs by proposing additional mechanisms that set off contention in meso level social orders. For instance, in their study, Kauppinen et al. (2017) argue that the original mechanisms put forward in the SAF scholarship should be complemented by additional ones, among them coalition formation and boundary deactivation. Kauppinen et al. (2017) see coalition formation as "a mechanism through which [actors] are brought together" (p. 806). They understand boundary deactivation to be a mechanism that renders a boundary less salient "as an organizer of social relations on either side of it, of social relations across it, or of shared representations on either side" (Tilly, 2004: 223). Coupled with the existing mechanisms in the scholarship on SAFs, coalition formation and boundary deactivation contribute to a more nuanced understanding of contention in SAFs, including in science policy.

Given that Big Science projects and networks often bring several hundred if not thousands of people together to collaborate on a common scientific objective and are embedded in local communities (Börner et al., 2021), this study views them as SAFs. Mechanisms which SAF scholarship has identified as drivers of contention are therefore hypothesized to also play a role in conflict emergence in Big Science. Building on the above review of conflict causes in science collaboration and Big Science, this study moreover assumes that a(n) (imminent) decision affecting or concerning a major project or network component causes conflict in Big Science projects and networks. Taking these two assumptions as a starting point, it is possible to propose a mechanism-based model of conflict emergence in Big Science.

Central to the model on offer here are five mechanisms—attribution of threat or opportunity, resource mobilization, coalition building, boundary deactivation, and innovative action (compare Figure 1). They are seen to work as a link between conflict cause (imminent or executed decision affecting a major project or network component) and outcome (conflict outbreak). Drawing on SAF scholarship, the model contends that a(n) (imminent) decision affecting or concerning a major project or network component typically leads to two reactions among stakeholders. Either they perceive it as a threat, for example because stakeholders feel it jeopardizes their interests, or they consider it an opportunity to push their agenda, most likely at the expense of another stakeholder. This does not mean, however, that every threat or opportunity will lead to conflict. In fact, a certain level of jockeying for power is to be expected in and around Big Science without it necessarily leading to open conflict. A threat or opportunity will set off a range of mechanisms that eventually lead to open conflict if a threat is perceived as "existential" or an opportunity is considered "too good to pass." What I mean by this is that in both cases the risks of a wait-and-see approach far outweigh the costs of taking action. Whenever this is the case, stakeholders are likely to mobilize their social, political, or economic resources to defend or push their respective agenda. The mobilization of resources, in turn—particularly the activation of social networks—facilitates coalition-building. Such coalition-building is crucial for stakeholders who perceive a threat to or opportunity for their interests because the more actors they can rally behind their cause, the likelier it will be taken notice of and acted upon. In some cases, this may also require them to find allies outside their own field. To do so, stakeholder may have to deactivate boundaries between fields with different norms, routines, and purposes. For example, scientists may lobby high-level policymakers to push their cause. Boundary deactivation frees actors of some normative constraints of their own field, which may facilitate innovative action. Such innovative action consists of disruptive tactics, where disruptiveness implies that a chosen tactic breaks with previous conventions within a particular field or creates moments of genuine surprise. Typically, the more disruptive the tactics, the more attention they will generate for the actors using them. Attention, particularly from a broad and diverse audience, in turn, is crucial because it creates a stage that actors can use to argue their case. In doing so, they may employ tactics ranging from framing, publicly naming and shaming to withholding agreed upon project or network funds. Ultimately, such tactics accelerate the emergence of open conflict because they enable actors to actively interfere with another actor's objectives.

It should be noted that this process is not necessarily a linear one. Actors may, for example, fail to build a strong coalition, which may then require them to “fall back” on a previous mechanism. If coalition building has proven fruitless, for instance, actors may have to activate resources that they had not mobilized before.

The model depicted in Figure 1 is a condensed and simplified depiction of the mechanisms that connect conflict cause and outbreak. This strategy limits the model in the sense that it is unlikely to capture the empirical reality of conflict in all its nuances and messiness. For example, it may fail to uncover incremental mechanisms that lay in between the five proposed mechanisms. Yet condensation and simplification are needed to propose a model that is applicable beyond a single case.

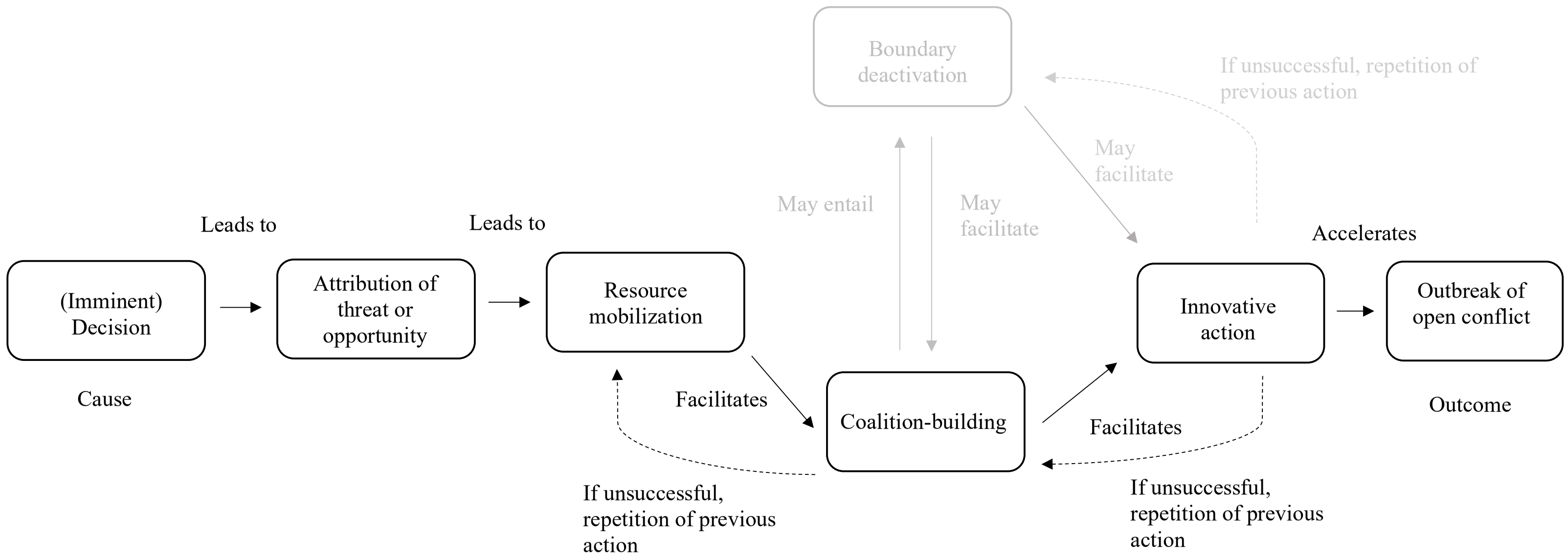

Figure 1: Model of conflict emergence

4.3. Methods and Data

This paper uses theory-testing process tracing to examine whether the proposed mechanism-based model holds in three typical, yet most-different, cases. Theory-testing process tracing lends itself for this purpose as its objective is to assess "whether hypothesized mechanisms are to be found between cause and outcome" (Beach and Brun Pedersen, 2013: 146). Checking whether such mechanisms are present necessitates two basic steps. First, it is important to specify which mechanisms plausibly link cause and outcome, for example by developing a model based on insights from the theoretical and empirical literature, as was done in section 2. Second, it is necessary to operationalize these mechanisms. To do so, mechanisms need to be rendered measurable, for instance by specifying their observable manifestations (compare Figure 2). This allows us to "examine the empirical fingerprints that the mechanisms should have left in the empirical material" (Beach and Pedersen, 2016: 93). By tracing these "fingerprints," we gain a more in-depth understanding of how cause and outcome are connected.

The objective of theory-testing process tracing is to examine whether hypothesized mechanisms exist in a small number of cases (Beach and Pedersen, 2016: 319). In the theory-testing variant of process tracing, several criteria guide case selection. First, only such cases where both cause and outcome are present can be considered (Beach and Brun Pedersen, 2013: 147). Second, in theory-testing process tracing, it is useful to choose cases that are at least partly documented in the literature as this allows "to move research to a context in which it is (…) possible to observe the workings of the mechanisms in (…) empirical detail" (Beach and Pedersen, 2016: 324). Third, to draw cautious generalizations, it is useful to select typical, yet most-different, cases from a relatively homogeneous population. A case is considered typical if it is representative of a broader set of cases (Gerring, 2007: 91). Two cases are most-different if they differ on all dimensions aside from cause and outcome (Gerring, 2009: 672).

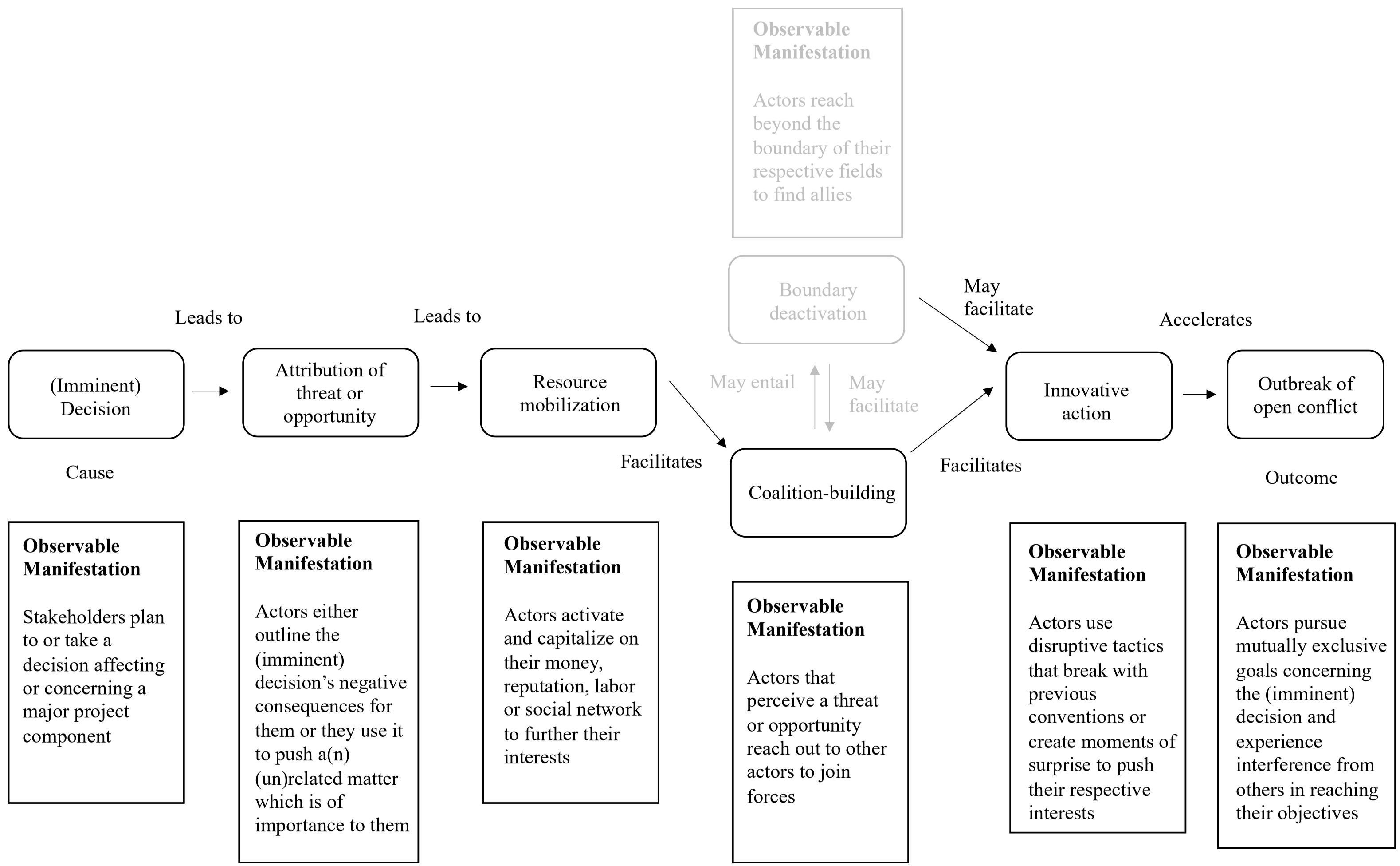

Figure 2: Operationalized model of conflict emergence

These criteria apply to ITER, HBP, and TMT. First, all three cases have lived through at least one episode of open conflict. In line with an embedded case study design, I focus on one particular instance of conflict within all cases (Yin, 2003). For each case, I selected an instance of "archetypal" conflict. With archetypal conflicts I mean such conflicts that can be traced back to a cause that the literature has identified as one of the most common conflict causes in science collaborations. Concentrating on one instance of archetypal conflict helps focus the case study inquiry (Yin, 2003: 45) and could potentially generate useful findings for practitioners because although these conflicts appear time and again, policymakers and managers seem to struggle to anticipate or to adequately address these conflicts before they escalate. In the case of ITER and TMT, I focus on site conflicts. In the case of HBP, I concentrate on the conflict that ensued over the network's funds, scientific approach, and management after one of its subprojects had been excluded from HBP core funding. Second, ITER, HBP, and TMT, including the conflictual episodes embedded in the cases, are sufficiently documented in the academic and/or grey literature. Drawing on insights from this literature, it is possible to trace the workings of the hypothesized mechanisms. Finally, choosing ITER, HBP, and TMT as case studies makes sense because they depict typical, yet most different, cases from the rather restricted population of Big Science projects and networks. Generally, Big Science can be divided into two main subtypes (compare Table 6). Big Science projects are "bound to a single infrastructural site" (Hallonsten 2016: 19) because they need one or several physical instrument(s) (i.e. a reactor) to attain their scientific objective. Big Science networks, in contrast, are geographically distributed projects that do not need such a physical instrument to attain their research objective. Thus, Big Science most commonly differs on two dimensions: its degree of centrality (high or low) and whether it needs a physical instrument to attain its objective (yes or no). ITER and TMT depict typical cases of a Big Science project, which is bound to a specific site and needs an instrument to obtain its objective. HBP, in contrast, is a typical case of a Big Science network. It does not need a physical facility to achieve its objective of building a digital research infrastructure for neuroscientists and is decentralized, as more than 150 institutes across Europe are part of it. At the same time, ITER, TMT, and HBP are most-different cases. They differ on all dimensions (e.g. funding, governance, objective) aside from cause and outcome.

Table 6: Big Science subtypes

		In Need of Physical Instrument?	
		No	Yes
Degree of Centralization	High		ITER, TMT
	Low	HBP	

For the two in-depth case studies of conflict in ITER and HBP, a variety of independent sources, such as academic papers, newspaper articles, and government records, formed the basis for theory-testing process tracing (for an overview see Table 3 in the Appendix). These non-reactive sources were complemented by 25 semi-structured expert interviews which were conducted between April and July 2021 via Microsoft Teams. Each interview was recorded, manually transcribed, and analyzed using MAXQDA. 25 interviews were conducted with scientists, science managers, or policymakers that are or were at some point involved in ITER or HBP (see Table 7) and guided by an interview guideline.[7] Questions that were included in this guideline touched on three main themes. A first set of questions concerned the interviewee's personal background and role in ITER or HBP. A second block of questions targeted a specific conflictual episode in ITER or HBP, which had previously been identified from the academic and grey literature. Questions included in this second block focused on the conflict sources, parties, settlements, and outcomes. Finally, a third group of questions concentrated on potential conflict mitigation strategies for Big Science projects and networks. In contrast to the in-depth case studies of conflict in ITER and HBP, the cursory analysis of conflict around TMT is mainly informed by three interviews that were conducted with Native Hawaiians between October and November 2022.

[7] Interviews were conducted in English, German, or French. Quotes (in italic) from interview transcripts were translated by the author. Twenty-four of the interviews were conducted specifically for this article; one interview was conducted as part of a European Research Council-funded project. This interview was kindly made available for this article by the project's Principal Investigator.

Table 7: Overview of interviews conducted for chapter four

Interviewee Code	Project	Affiliation*	Length of Recording
INT01	HBP	European Commission	36 minutes
INT02	HBP	HBP Management	51 minutes
INT03	HBP	HBP Mediation Committee	46 minutes
INT04	HBP	HBP Steering Committee	87 minutes
INT05	HBP	HBP Leadership	116 minutes
INT06	HBP	HBP Leadership	31 minutes
INT07	HBP	HBP Management	81 minutes
INT08	HBP	HBP Mediation Committee	40 minutes
INT09	HBP	HBP Mediation Committee	29 minutes
INT10	HBP	HBP Advisory Board	74 minutes
INT11	HBP	European Commission	76 minutes
INT12	ITER	Fusion for Energy	56 minutes
INT13	ITER	Max-Planck-Institute for Plasma Physics	70 minutes
INT14	ITER	ITER International Organization	71 minutes
INT15	ITER	ITER Council	56 minutes
INT16	ITER	European Commission	70 minutes
INT17	ITER	Fusion for Energy	84 minutes
INT18	ITER	ITER International Organization	45 minutes
INT19	ITER	ITER Japan Home Team	50 minutes
INT20	ITER	Max-Planck-Institute for Plasma Physics	Written communication
INT21	ITER	Fusion for Energy	72 minutes
INT22	ITER	ITER International Organization	57 minutes
INT23	ITER	European Commission	63 minutes
INT24	ITER	European Commission	101 minutes
INT25	ITER	ITER International Organization	73 minutes
INT26	TMT	Local Community	131 minutes
INT27	TMT	Local Community	49 minutes
INT28	TMT	Local Community	45 minutes

**Past or present*

4.4. Case Study I: HBP

4.4.1. Background

HBP is a five hundred million-euro Big Science network at the intersection of neuroscience and ICT which the European Commission (EC) selected as a flagship in the FET competition in 2013. From the very beginning of this competition, HBP was presented as an innovative project which would bring the two fields of neuroscience and ICT together (European Commission, 2011). Prior to the inception of HBP, European research at the intersection of neuroscience and ICT was organized in multiple “blue-sky”-type projects of small to moderate size. Henry Markram—one of the main proponents of HBP and later the project’s scientific director—considered this approach inadequate for the advancement of the two fields. He tried to persuade his colleagues to pursue *“one big approach”* (INT04). For Markram, this approach meant building “a single, unified model” of the brain (Mahfoud, 2021: 323). Not all his colleagues, however, welcomed this proposal. Some of them were interviewed for this study and stated that they valued *“diversity in interdisciplinarity”* (INT04), which for them meant that researchers follow different research questions and approaches in several smaller projects. Yet, despite this initial skepticism towards Markram’s vision, in 2011, the EC Directorate General Communications Networks, Content, and Technology (DG Connect) awarded him with one million euros in the FET preselection phase to create a proof of concept for HBP (INT01).

Together with his two main campaigners, Karlheinz Meier and Richard Frackowiak, Markram invested a great deal of energy to find as many allies in the neuroscience community for HBP as possible (INT06). To get renowned colleagues on board, he presented HBP as an inclusive project which would be able to accommodate the whole bandwidth of the fragmented neuroscience field (Hummel, 2015). HBP proponents also mobilized considerable resources to get this message across to the FET selection committee in the proof of concept. A professional writer and marketing specialist were hired to support scientists in the writing process (INT04; INT07). In addition, the EPFL hosted some of the scientists it considered key for the HBP for several months and ensured they could work on the flagship proposal uninterrupted (INT04). As a result, these scientists were able to write an extremely dense roadmap for HBP, which ultimately convinced the FET selection committee (INT08).

The approach Markram was planning to pursue in HBP not only persuaded the FET selection committee; it also inspired many of his fellow neuroscience colleagues. A former HBP advisory board member who was interviewed for this paper said that many of them were convinced that the HBP would “*usher in a new age of neuroscience research*” (INT10). At the same time, some scientists in the European neuroscience community were skeptical that HBP would attain its ambitious goal of simulating the brain, particularly within the comparably short timeframe (10 years) it would receive funding from the EC. Others considered its scientific focus “overly narrow” (Horgan, 2013). Ultimately, both groups of critics were concerned that the HBP would turn out to be "a waste of public money" (own translation; Schnabel and Rauner, 2013). Their concerns grew even stronger once it was announced that the EC would only contribute half of the originally pledged one billion euro for the flagships (Schnabel and Rauner, 2013). Previous studies have shown that such concerns related to the costs of Big Science undertakings are prone to arise among researchers that work in the prospective project's or network's field (see: Arnoux and Jacquinot, 2006; Lambright, 2002; Newton and Slesnick, 1990; Riordan et al., 2015). Sometimes, they can even accelerate the demise of a Big Science project (Ellis, 2019). Yet, in case of HBP, conflicts over funding issues remained largely latent, at least until the HBP leadership decided to remove the neuroscience subproject from HBP core funding, triggering open conflict.

4.4.2. The Emergence of Conflict

The decision to exclude the neuroscience subproject from HBP core funding was first taken by the HBP leadership in March 2014 (Destexhe, 2021: 2) and then officially announced in a Framework Proposal Agreement for a second round of EC funding in June 2014 (Neurofuture.eu, 2014). For HBP neuroscience researchers, it depicted a financial threat because it effectively meant that they lost access to HBP grant money. Neuroscientists inside and outside HBP also saw the decision as an epistemological threat. Since the HBP leadership presented the project as the "*future way of conducting neuroscience research"* (INT08), being excluded from HBP led neuroscientists to believe that they would have less of an impact on the future of their research field. Thus, for them, the very "*definition of what neuroscience is and what it means*" was at stake (INT07).

In July 2014, a month after the decision to exclude the neuroscience subproject from HBP core funding was announced, neuroscientists from across Europe and Israel clearly expressed this view in an open message to the EC—which has come to be known as "the open letter" (Mahfoud, 2021). In this message, they criticized the quality and implementation of HBP as well as "the lack of flexibility and openness of the consortium" (Neurofuture.eu, 2014). This latter point of criticism stemmed from the fact that during the HBP's ramp-up phase, Markam and his colleagues, Meier and Frackowiak, formed the project's Executive Committee, filled most of the instrumental positions of the HBP governance bodies, and controlled the Board of Directors, which depended on their votes to reach a two-thirds majority to take decisions (Marquardt, 2015: 8). Similar to early critics of HBP, the authors of the open message moreover suggested that the money allocated to HBP might be better spent on "individual investigator-driven grants" (Neurofuture.eu, 2014), implying that the EC's support of a single neuroscience flagship could threaten the funding of "much needed," more diverse European neuroscience research (Neurofuture.eu, 2014).

Despite such strong criticism, policymakers from DG Connect continued to support the HBP leadership in the immediate aftermath of the letter's publication. In a blogpost from July 2014, the Director General of DG Connect specified that there is "no single roadmap for understanding the brain" and that a certain level of contention in a "ground-breaking" project like the HBP is to be welcomed (Madelin, 2014). The EC hence perceived the decision to exclude the neuroscience subproject from the core funding as legitimate. A former high-ranking EC decision-maker who was interviewed for this article clarified that when *"the consortium leaders said, 'we need to put more resources here,' (...) we [the EC] said 'we trust you'"* (INT01). When the authors of the open message learned of the EC's reaction and realized that they would not receive any support from EU decisionmakers, they mobilized their professional network to further push their cause. Particularly French scientists capitalized on the good and close relations they had with the heads of major national research organizations (INT07). The latter had similar interests and objectives as the neuroscientists. Both wanted to prevent their research institutes from being excluded from a major initiative like HBP and EU research funds from being wasted on a mismanaged Big Science network. Joining forces, they reached across the boundary of the scientific field to lobby French and European politicians to induce change in HBP (INT07). Despite this coalition's lobbying effort, *"(...) the advantage [wa]s [still] with the defenders [the HBP leadership]"* because the EC continued to side with them. The EC mainly defended the HBP executive committee because if it *"[had said that] 'Yes, the attack is right,' they [would have had] to find a new consortium leadership"* (INT01).

However, backed by renowned and powerful heads of major national research organizations, neuroscientists intensified their protest against HBP through disruptive tactics. They pushed their criticism of HBP and its leadership by framing the flagship as a network that pursued a fundamentally flawed scientific approach and had been "oversold" to policymakers (Kelly, 2014). Neuroscientists voiced such harsh critique in popular science magazines and mainstream media outlets (INT03), therewith breaking with the practice of debating scientific controversies within the confines of the academe. An EU project officer and a HBP science manager who were interviewed for this paper confirmed that the tactics employed by HBP critics disrupted the entire network. According to the high-ranking HBP science manager they *"created an internal (...) and (...) external crisis"* in the network because *"its legitimacy (...)*

and leadership [were] questioned" (INT02). In the EC, in turn, no one was surprised to see Markram's scientific vision under attack. Yet policy officers responsible for HBP in DG Connect were taken aback "*by the method[s] these neuroscientists were ready to use to push their case"* (INT11). Within a few weeks, these "methods" accelerated the emergence of open conflict during which the HBP leadership and its critics pursued mutually exclusive goals concerning the decision to bar the neuroscience subproject from HBP core funding (for a graphic overview of conflict emergence see Figure 3). While Markram et al. were reluctant to reintegrate the subproject, their critics demanded just that. The latter strongly interfered with Markam et al.'s objective of reorganizing HBP funds by publicly naming and shaming the HBP leadership for its scientific and governance approach.

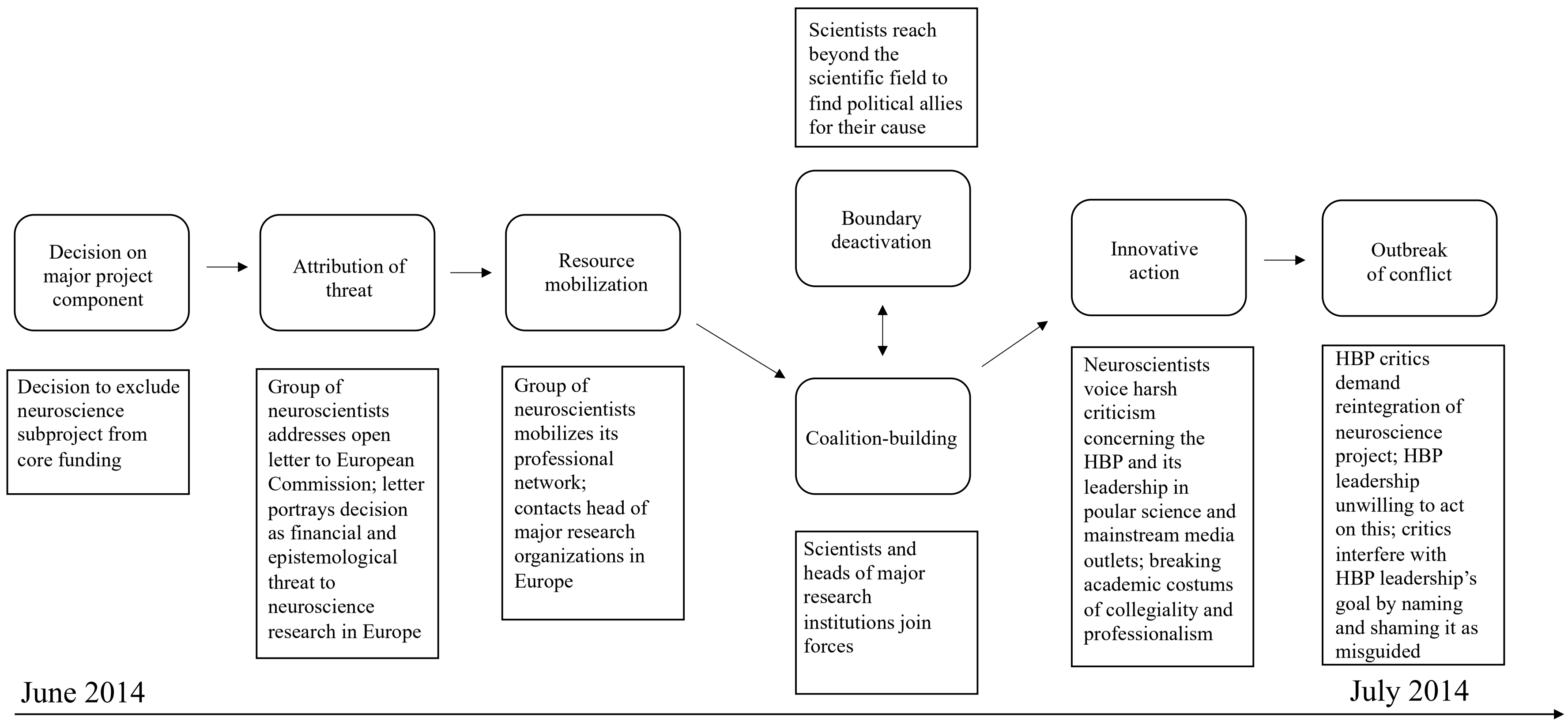

Figure 3: Model applied to HBP case study

4.5. Case Study II: ITER

4.5.1. Background

ITER is a controlled thermonuclear fusion experiment which aims to demonstrate the scientific viability of fusion as a future source of sustainable energy (European Commission, 2017). It was first proposed in the mid-1980s—at a time, when the need for more sophisticated, complex, and costlier instruments in fusion research spurred international collaboration (Broad, 1992). For instance, during the early 1980s, a team of scientists from across the world began to work on the so-called International Tokamak Reactor under the umbrella of the International Atomic Energy Agency (Claessens, 2020: 29). While Europe decided to join this collaborative effort (McCray, 2010: 291), the US were initially reluctant to support international cooperation in fusion research (McCray, 2010: 292).

In 1985, however, US Secretary of State, George Shultz, and Soviet science advisor, Evgeny Velikov, managed to add cooperation on nuclear fusion to the agenda of a high-level meeting between Reagan and Gorbachev which was to take place in Geneva. At the meeting's closure, the leaders issued a joint statement, in which they "emphasized the potential importance of (…) utilizing controlled thermonuclear fusion for peaceful purposes" and advocated for "the widest practicable development of international cooperation in obtaining this source of energy" (Reagan and Gorbachev, 1985). At the time, nuclear fusion depicted an ideal area of cooperation for political rivals like the US and the Soviet Union for two main reasons. First, an international fusion research community and "pathways for information exchange" were already in place (McCray, 2010: 293). Second, applications of fusion energy require several generations to materialize, mitigating security concerns regarding technology-sharing (INT19; Curli, 2024). Still, it took until 1988 for design work on ITER to begin. By then, the US and the Soviet Union had obtained support for the project from Japan and the European Atomic Energy Community (Arnoux and Jacquinot, 2006: 113).

4.5.2. The Emergence of Conflict

ITER is an extremely complex and technologically demanding project whose life cycle—from inception to full operationality—covers a long time span. Thus, it comes as no surprise that the project not only lived through one but several conflictual episodes. For example, during ITER's Conceptual Design Activities, latent conflict concerning the reactor's scientific specifications and its first director's management style emerged (Åberg, 2021). Later, during the Engineering

Design Activities (EDA), the question of where to build ITER created latent conflict among project partners. To ease tensions, ITER partners decided to split the engineering team across three sites and continents even though this made little sense from a project management point of view. Yet, because every country feared that the EDA location would have a competitive advantage in the final siting decision, this was the only solution all ITER partners could agree on (INT19).

Following the completion of the EDA in 2001 the siting issue re-emerged. Between 2001 and 2003, four countries—Canada, Japan, Spain, and France—signaled their willingness to host ITER. As during the EDA, the pending siting decision triggered latent conflict between ITER partners in general and the four site candidates in particular. Open conflict, meaning a visible struggle, between the ITER partners, however, only emerged after November 2003 when merely two site proposals, namely that of Japan and France, were still in the running. The US used this French–Japanese site duel as an opportunity to pursue its foreign policy agenda "by other means" (Krige, 2013). In particular, the country saw the site competition as a way to reward its ally Japan for supporting the US invasion of Iraq in March 2003.

Both international media outlets and EU policymakers suspected that this was the objective that the US were pursuing in the ITER site competition when it invited ministers from the project parties—which by then also included China and South Korea—to Reston, a suburb of Washington DC, in December 2003 (Claessens, 2020: 48). On the one hand, earlier that year, the US had implied that they preferred Spain's site over that of its direct European contender (Brumfiel and Butler, 2003). On the other hand, the meeting venue in Reston was swamped with US and Japanese journalists, while no European media outlets had been invited, indicating that the US and Japan were confident that they would be able to declare Japan ITER host at the end of the gathering (Claessens, 2020: 49). Spencer Abraham, State Secretary for Energy under the Bush administration, chaired the meeting at Reston. According to an EU official who was interviewed for this paper and present at the meeting in Reston, Abraham opened the gathering by stating that it was important to "move forward" and to "come to a decision" concerning ITER's siting (INT24). Abraham then proceeded to ask all parties present which ITER site they favored. China, Russia, and the EU preferred the French site, while the US and Japan were backing the Japanese site. South Korea, in turn, was undecided. As no consensus emerged, Abraham suspended the meeting and—according to the interviewed EU policymaker—leveraged his country's close economic and political ties to South Korea to convince it to join forces and support a Japanese site for ITER (INT24). This attempt to build a coalition for

Japan's proposal was successful as South Korea backed Tokyo's site bid during a second round of consultations, as did Japan and the US. The EU, Russia, and China, in contrast, favored the French site. To put an end to this stalemate, Russia suggested to open the negotiations by offering the candidate that would not obtain ITER a "consolation" prize in the form of a material research facility (INT24). Despite this conciliatory proposal, the parties were unable to come to an agreement at the meeting in Reston.

Thus, to further advance their preferred course of action—a Japanese ITER site—the US finally reverted to disruptive tactics. During a visit to Japan in early 2004, Secretary of Energy Abraham broke with long-established diplomatic conventions by publicly and strongly supporting Japan's site bid for ITER. As Japan had recently dispatched a battalion of non-combat troops to southern Iraq (Watts, 2003), he first thanked Tokyo for its "aid in the fight against terrorism in the (…) wake of September 11" in a luncheon address in January 2004 (US Department of Energy, 2004). He then went on to underline how "proud" he was to say that the US[A] strongly supported building ITER in Japan," which "from a technical standpoint" had "offered the superior site" (US Department of Energy, 2004). These public statements considerably disrupted the ITER site negotiations as they deepened the rift between those that supported a French site and those that did not—so much so that the French government promptly threatened to construct the reactor by itself after Abraham's visit to Japan (Buck, 2004). The US's Secretary of Energy's statements in Japan also accelerated the emergence of open conflict because they highlighted the goal incompatibility between the US and Japan on the one hand and the EU and France on the other (for an overview of conflict emergence see Figure 4). In addition, they demonstrated that the US were willing to interfere with the ITER siting competition to further its own foreign policy goals. France's reaction to Abraham's comments, in turn, showed that French decisionmakers were likewise willing to interfere with the US agenda.

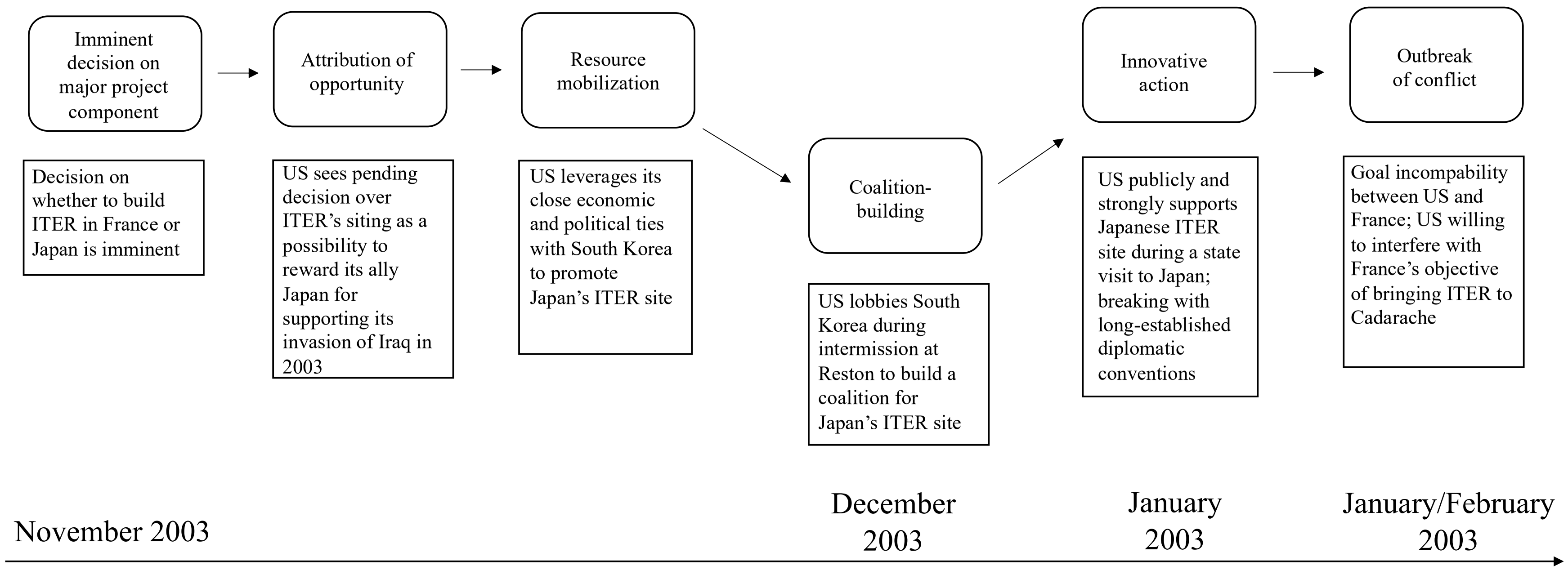

Figure 4: Model applied to ITER case study

4.6. Case Study III: TMT

While a third in-depth case study is beyond the scope of this paper, a cursory investigation of another conflictual episode around another Big Science collaboration, such as TMT, can provide further, even if only anecdotal, evidence for the model's validity. In addition to what was stated in the methods section, TMT is an interesting case study for two more reasons. First, the same cause triggered conflict on several occasions, which allows us to apply the model to several instances of conflict. Second, in the case of TMT, conflict spanned the macro and the meso level as TMT's partners, an international consortium consisting of US, Chinese, and Japanese research institutions as well as Canadian and Indian quasi-governmental agencies, and parts of the local and Native Hawaiian population were divided over the question of whether Mauna Kea can be considered an appropriate site for a large-scale telescope. Latent conflict between those two groups first emerged in 2011. At this point in time, UH set the administrative process of obtaining the necessary permits for building TMT in motion (KAHEA, 2016). Holding a 65 year "master lease" for a substantial part of Mauna Kea's summit region, UH had—at least until a stewardship reform in 2022—considerable decision power over the mountain's stewardship and the prerogative to apply for the permits on behalf of the TMT consortium. Several Native Hawaiians that opposed further development on Mauna Kea's sacred and "ceded" lands[8] filed legal challenges and lawsuits to prevent UH from obtaining permits for TMT. These legal battles went through several instances in the state judicial system and dragged on for several years (INT26).

In 2014, the TMT consortium's decision to proceed with a groundbreaking ceremony despite the ongoing legal battles triggered open conflict between project supporters and opponents. Opposition came from environmentalists that rejected TMT because of its potentially detrimental impact on Mauna Kea's ecosystem as well as from parts of the local and Native Hawaiian community. For the latter, the construction of TMT on sacred and ceded lands threatened to restrict access to cultural sites on the mountain and to infringe on indigenous land rights. In addition, TMT was seen to add to previous mismanagement of the mountain and to bring few direct socio-economic benefits to the local community. On the day of the TMT

[8] Ceded lands are Crown and government lands which were ceded to the US when the country annexed the islands of Hawai'i through Joint House Resolution 259. "Not all [in Hawai'i] accept the resolution as a valid means of annexation" and they argue that "Native Hawaiians retain rightful claims to these lands," see Uyeda C (2021) Mountains, Telescopes, and Broken Promises: The Dignity Taking of Hawaii's Ceded Lands. *Asian American Law Journal* 28: 65. https://doi.org/10.15779/Z38CC0TV0T.

groundbreaking, some Native Hawaiians made use of their local community bonds to gather a group for a ceremonial prayer vigil at the base of Mauna Kea. Parts of the group went up to the summit in a spontaneous effort to halt the TMT groundbreaking ceremony (INT26). Through innovative tactics, including blocking the road leading to the groundbreaking site and interrupting the event through chants (INT26), the group genuinely surprised the TMT consortium, which was expecting legal objections, but not non-violent direct action (INT26). The protests eventually led to a situation where the TMT consortium and Native Hawaiian TMT opponents were pursuing mutually exclusive goals. While the latter wanted to prevent the TMT from being built on Mauna Kea, TMT's funders wanted to go ahead with the groundbreaking. Due to the interference of TMT opponents, however, the TMT consortium could not proceed.

In 2015, the construction of TMT was scheduled to go forward, once again triggering open conflict between project supporters and opponents. This time, however, the threat to indigenous land rights and cultural practices seemed even more palpable because construction material was supposed to go up the mountain. Native Hawaiians in opposition of TMT, who refer to themselves as kiaʻi (protectors), activated their dense community network and asked other community members to come up the mountain to protest and stop TMT's construction on two occasions. Deactivating the boundary between local politics and the world of entertainment, kiaʻi also used familial ties to celebrities with connections to Hawaiʻi to build a strong coalition for the protection of Mauna Kea's sacred lands (INT27). These celebrities engaged in innovative action by campaigning for the protection of Mauna Kea through social media (Scheuring, 2015), generating nationwide attention for the controversy and supporting kiaʻi that blocked Mauna Kea's access road twice throughout 2015 to interfere with TMT's construction.

In 2019, when most legal challenges concerning TMT's permits had been decided in court and the TMT consortium tried to proceed with moving heavy construction equipment to the summit, the same mechanisms as in 2015 induced conflict emergence. This time, however, kiaʻi were able to rely on more resources and bigger networks from previous protests. Previous social media campaigning, for instance, helped kiaʻi to connect with and receive support from other indigenous movements across the globe, thus building transnational coalitions for indigenous land struggles (Case, 2021). In addition, they made use of disruptive tactics by forming front lines that were spearheaded by kupuna (elders), a group that is usually expected to be on the protest sidelines (INT28). Through these tactics, kiaʻi interfered with the TMT consortium's goal to begin constructing the telescope on Mauna Kea for a third time.

4.7. Discussion

The objective of this study was to provide a better understanding of conflicts in and around Big Science projects and networks. To do so, this study proposes a mechanism-based model of conflict emergence in Big Science that is applicable beyond a single case. The model holds that five interlinked mechanisms—attribution of threat or opportunity, mobilization of resources, coalition-building, boundary deactivation, and innovative action—fuel conflict emergence in Big Science. It adds value to the scholarship on science collaboration which typically only mentions conflicts insofar as they are seen as an obstacle for effective scientific cooperation or knowledge generation (Galison, 1997; Knorr Cetina, 1999; Ulnicane, 2015). In addition, it contributes to the literature on Big Science which generally lacks "systematic comparative analyses" and theory-building (Rüffin, 2020: 41-42).

A comparison of the case studies under investigation in this study indicates that there are three aspects in which conflict emergence differs and one aspect in which it does not. First, it seems that actors involved in conflicts at the macro level rely more heavily on their political and economic resources, while actors caught up in conflicts at the meso level are more prone to mobilize their social capital. For instance, in the case of ITER, where conflict developed at the macro level, the US mainly capitalized on their reputation as a world power as well as their strong economic entanglement with South Korea to convince the country to support Japan's ITER site bid. In the case of HBP and TMT, actors at the meso level used their dense social network to push their agenda.

Second, it could be argued that a conflict triggered by an imminent decision needs more time to emerge than a conflict caused by a decision which has already been executed or is in the process of being executed. In the case of ITER, conflict emerged after several months, while in the case of HBP and TMT open conflict emerged within a few weeks or days. In the case of the TMT groundbreaking, conflict even emerged on the spot, which explains why a time-consuming mechanism like coalition-building does not hold here. Reactions to an executed decision might be stronger than to an imminent one because reversing a decision that has already been taken is, or at least often seems, more daunting than revoking one that may or may not be settled in the near future.

Third, boundary deactivation seems to play a greater role for actors at the meso than at the macro level. Contrary to what happened in the ITER case study, actors in HBP and TMT reached across field boundaries to build strong coalitions for their cause. In the case of HBP, it is particularly noteworthy that by forging coalitions with policymakers, scientists managed to deactivate the boundary between the meso and macro level. This does not mean, however, that it cannot also prove strategic for actors at the macro level, for example politicians, to build coalitions with actors from another field. Policymakers wanting to cut the costs of a project or network might, for example, build a coalition with a scientific community that is in favor of using a cheaper technology. When a Big Science project with potential safety concerns is proposed, politicians may further deactivate boundaries between local and national politics to build coalitions with those parts of the local community that are in favor of the project to promote its realization.

Finally, while the specific tactics chosen by the actors in the case studies may differ on a case-by-case basis, all of them are characterized by a high degree of disruptiveness. Every tactic either breaks with previous conventions in a specific field or creates moments of surprise. In the case of ITER, Energy Secretary Abraham's remarks in Japan were disruptive because they broke with diplomatic practices. Typically, a project party that has no intentions of being project host does not interfere with the site competition by openly and publicly endorsing one site over another. In the case of HBP, the highly critical, harsh, and publicly voiced statements of some neuroscientists proved disruptive because they broke with academic traditions. Lastly, in the case of TMT, protestors' roadblocks, interruptions during groundbreaking, makeup of frontlines, and Hawaiian celebrity's social media involvement genuinely surprised the TMT consortium (INT26).

4.8. Conclusion, Implications for Management, and Limitations

Conflicts are prone to emerge in and around Big Science projects and networks because like other meso level social orders these undertakings bring a plethora of different actors with potentially conflicting goals and expectations together for a long period of time. Understanding which general mechanisms drive conflict in and around Big Science projects and networks is highly relevant, both from a policy and academic perspective, because a failure to address conflicts in and around these extremely expensive science undertakings can cause serious damage to the public perception of large-scale science collaboration. Given that many of today's grand challenges possess a pronounced scientific dimension and thus need to be addressed through international research (Parikh, 2021), public acceptance of and confidence in Big Science is all the more essential. The model on offer in this study is a first attempt at theorizing conflict emergence in Big Science, which is an important step in preventing and mitigating destabilizing processes in and around Big Science.

In this regard, there are two key take-away messages for Big Science managers. First, to be able to distinguish between surface and open conflict, managers have to develop a deep understanding of the expectations and interests with which different stakeholders join or perceive a collaboration. Only then will they be able to assess whether a decision that affects or concerns a major project or network component is likely to be perceived as a threat or opportunity. Organizing regular meetings with different stakeholder groups, especially at the beginning of a collaboration, is one way to achieve a better understanding of their expectations and interests. Such meetings are particularly essential if Big Science touches on topics that have major ethical, security, or health implications and/or if projects or networks encroach on sites that have symbolic, religious, or cultural value for historically marginalized groups. Native Hawaiians that oppose TMT's construction, for example, have repeatedly underlined that TMT promoters did not sufficiently acknowledge their grievances and concerns (Ku'iwalu, 2020). As stakeholders' expectations and interests are likely to change over time, regular check-ins with stakeholder groups should also remain a priority past the "storming phase" of a collaboration. Second, if Big Science managers notice that coalitions between different stakeholder groups form after a decision affecting a major project or network component has been made or is imminent, they should intervene and initiate a mediation process. At this stage, it might already prove useful to invite a third neutral party to lead said process because such a neutral third party is more likely to have the necessary standing and moral authority to uncover the grievances and hopes of those involved in the emerging conflict. Managing this phase of conflict emergence is also critical because if stakeholders cross boundaries to push their agenda, the emerging conflict might spill over into another field. If actors from an additional field get involved in an emerging conflict, in turn, it might prove even harder to mitigate or resolve it.

Further research on conflicts in Big Science could generate additional insights for project management. For instance, by shifting the focus from conflict emergence to conflict settlement, Big Science stakeholders could learn valuable lessons for effective conflict mediation. Additional research on conflicts in and around Big Science is further needed to refine and potentially extend the model on offer in this article. In doing so, future studies would benefit from a more diverse sample of interview partners, which balances voices from East and West, small and big project contributors as well as project proponents and critics. Although this study aimed for such a diverse sample, interview partners for the ITER and HBP case studies were largely recruited from major Western European laboratories and research institutions.

5. Conclusions

Big Science requires large capital investments, excellent researchers, innovative ideas, and, whenever it revolves around large and complex instruments that are physically embedded in a local host community, said community's consent and acceptance. The stakeholders that are involved in Big Science, their potentially diverging interests, and expectations, can be hard to reconcile. To find common ground, Big Science stakeholders often have to negotiate and to compromise. Where this is not possible, stakeholder conflict is likely to arise.

Against this backdrop, the objective of this thesis was twofold. First, it aimed to shed light on how different stakeholders pursue and negotiate their interests within and in relation to Big Science. Second, it aimed to explain how this may lead to conflicts between and among stakeholder groups. To address these two broad research objectives, chapters two, three, and four raised and responded to three more narrowly defined sub-questions. In doing so, each chapter contributes in distinct ways to the existing Big Science literature and, more broadly, to recent debates in the interdisciplinary scholarship on science, technology, and innovation.

5.1. Main Findings and Contributions

Chapter two investigated the interests that countries of the Global South pursue in Big Science and the conditions under which these countries are likely to achieve their objectives in large science collaborations. The chapter drew on three different strands of literature, namely international research collaboration, science diplomacy, as well as institutionalism, and compared the participation of countries of the Global South in CERN, ITER, SKA, and AfLS. The analysis of these four case studies showed that countries of the Global South aim to achieve a multitude of scientific and political objectives in Big Science. These may range from capacity-building in S&T, through casting off political isolation to settling regional rivalries in the political and scientific realm. Moreover, the analysis demonstrated that countries of the

Global South have varying chances of attaining these objectives in Big Science, depending on their scientific community, domestic politics, industrial capacities, and, in some cases, geographic location, as well as a collaboration's institutional maturity.

The institutional maturity of a Big Science collaboration conditions which interests countries of the Global South can pursue because in established large science projects like CERN, founding members, typically from the Global North, have successfully cemented their institutional rights and privileges. Countries of the Global South are rarely among the founding members of established Big Science collaborations because when these were set up after World War Two, many countries in the Global South had not yet gained independence from Western colonial powers. In addition, few countries of the Global South had the economic or scientific capacity to participate in Big Science collaborations at that point in time. As a result, countries in the Global South often lack the institutional rights and privileges to shape important decisions in established Big Science projects. If the objective is to substantially shape a Big Science collaboration, countries of the Global South are therefore well advised to join it during its earliest stages. This increases the chance that institutional inertia has not yet set in. Chapter two shows that where it is not possible for countries of the Global South to join Big Science early on, it may still pay off for them to participate in a collaboration, as this enables these countries to contribute to cutting-edge research and to strengthen their S&T capacities.

The cross-case analysis in chapter two further demonstrated that an active and outspoken scientific community often paves the way for countries of the Global South to become members of Big Science collaborations. Scientific communities do so by strengthening a country's reputation in S&T as they get involved in Big Science collaborations on an ad hoc basis or by lobbying local and foreign policymakers as well as scientists to support the establishment of new Big Science collaborations. Continuous domestic political support and long-term national contributions, in cash and in kind, are equally important for countries of the Global South to achieve their political and scientific objectives in Big Science collaborations. As the case study of SKA demonstrated, such contributions signal commitment to other members and can be used as leverage during negotiations. However, given that many countries of the Global South face more acute political, economic, and human resource constraints than countries of the Global North, it can be difficult for them to provide the necessary in cash and in kind contributions for Big Science. For similar reasons, there are only few countries of the Global South that have the industrial capacities to take on substantial contracts for the large infrastructures that many Big Science collaborations rely on. In contrast to these scientific, industrial, and political capacities which are needed for almost all large science projects, a country's geographic location only comes into play if a Big Science collaboration has specific climatic or environmental requirements. This is typically the case for astronomy projects, as these tend to work best in high altitudes as well as under stable, dry, and cold climatic conditions.

Chapter two contributes to the Big Science literature in two ways. First, it adds a comparative perspective to the stock of predominantly single case studies of Big Science. Second, it explicitly focuses on emerging powers of the Global South, a stakeholder group that is surprisingly often neglected in the literature on large science collaborations despite the fact that in recent years other disciplines have paid increasing attention to countries such as China, Brazil, and Indonesia due to their growing economic capabilities and (geo)political ambitions. By focusing on emerging powers of the Global South, the chapter also advances a relatively recent global and postcolonial turn in the broader science, technology, and innovation scholarship. The chapter's focus on the Global South is, for example, in line with an emerging research agenda in the field of science and technology studies that challenges "science and technology perspectives developed chiefly in the Global North" (Rajão et al., 2014) by investigating key science policy concepts from a Global South perspective (Wakunuma et al., 2021), critically questioning the role of technology in development cooperation (Fejerskov, 2017), and examining processes of technology translation in the Global South (Lu and Qiu, 2023). Chapter two's explicit focus on emerging powers of the Global South further responds to recent calls in the SD scholarship to shift the focus from the SD capacities, experiences, and practices of the Global North to those of the Global South (e.g. Polejack et al., 2022). In line with such calls but going beyond the single case study design that is prevalent in the burgeoning literature on southern SD (e.g. Echeverría King et al., 2021; Su and Mayer, 2018), chapter two contributes a comparative analysis of how emerging powers of the Global South may use S&T to advance (foreign) policy objectives in the context of Big Science.

Some of the chapter's findings complement those of existing studies which investigate how southern actors participate in Big Science collaborations or establish their own large science projects. For instance, in line with what Jang and Ko (2019) as well as Barandiaran (2015) argue, chapter two indicates that political, economic, and scientific asymmetries between the Global North and South continue to shape Big Science collaborations to this day. This finding largely reflects Barandiaran's (2015) argument that over long stretches of the twentieth century the needs and desires of foreign science communities and institutions dictated astronomy development in Chile. It also resonates with Jang and Ko's (2019) finding that countries of the Global South still depend on northern collaboration and Big Science facilities to produce high impact publications. However, on a more positive note, and in accordance with Jang and Ko's (2019) as well as Barandiaran's (2015) studies, chapter two also showed that countries of the Global South generally profit from participating in Big Science collaborations because, at a minimum, their scientists are involved in and exposed to cutting-edge research. Finally, the chapter adds new insights to existing Big Science studies because it outlines the specific conditions under which countries of the Global South can first maximize their benefits from Big Science and second, take on a leadership position in such collaborations. In doing so, chapter two provides value beyond the academe, as the policy implications that are drawn from its findings equip practitioners with pragmatic recommendations.

Chapter three examined when and why local resistance to Big Science persists. It did so by investigating why a group largely composed of Native Hawaiians was able to sustain opposition to TMT when local resistance to Big Science is typically short-lived. Using social movement theory and the concept of place attachment, the chapter found that six factors were decisive for the resilience of opposition. These six factors were: multi-generational leaderful organization, grassroots resources, versatile tactics, anti-science counterframing, local and national political opportunity, as well as place attachment-driven commitment.

The chapter argued that multi-generational support was essential to sustain local opposition to TMT because different generations of activists with different skillsets, knowledge, and experience facilitated effective task division over time. Younger activists, for example, were able to publicize local opposition on social media, while older generations shaped strategies by sharing their knowledge of which tactics had proven successful in previous Hawaiian struggles. Having several leaders was crucial for a similar reason. Specifically, chapter three contended that leaderful organization enabled the effective distribution of responsibilities among a group of individuals who had the willingness, capacities, and skills to take on leadership tasks. Over time, this organizational approach ensured that leaders did not burn out.

Chapter three also made the point that sustained local opposition would not have been possible without a continuous flow of tangible and intangible grassroots resources. This included but was not limited to human capital, time, funding, clothes, and food. Such resources enabled activists to engage in and apply a range of different tactics throughout their struggle. The strategy of combining tactics such as legal challenges, non-violent frontline action, and social media campaigning significantly stalled TMT's development and helped activists to raise awareness of their struggle. Particularly, campaigns on social media helped TMT opponents to recruit new activists and gain additional supporters, both of which were needed to sustain activities on and off Mauna Kea.

Another reason why local opposition persisted was that activists successfully framed the TMT controversy as a multidimensional issue, in which not science itself but the research practices and ethics of "mainstream" science were up for debate. Making this distinction in framing the TMT controversy was crucial for activists because it helped them to counter popular media frames which presented the issue as one of "science vs. religion" and portrayed activists as being anti-science. Criticizing "mainstream" science for not honoring basic research practices and ethics like getting (indigenous) consent for TMT instead of questioning science per se was also key because it enabled activists to cultivate legitimacy while opposing a big scientific project of a type that is typically considered beneficial. Moreover, activists succeeded in sustaining momentum for their struggle because the local and broader political context in the US were conducive to it. The chapter argued that at the national level, efforts to protect a place of great cultural, ancestral, and spiritual significance to an indigenous population resonated with a greater awareness of indigenous (land) rights. Locally, collective action persisted because Hawaiians in favor of TMT were not as well organized and media-savvy as those that were against it. In addition, pro-TMT groups experienced considerable pushback from some of the community members that opposed the project. Ultimately, this pushback led supporters to keep their opinions to themselves. As a result, the messages of TMT opponents remained mostly unchallenged over time. Finally, and most importantly, chapter three argued that local opposition to TMT persisted because activists were deeply committed to preventing further astronomy development on Mauna Kea. To a large extent, this commitment was driven by a strong ancestral, cultural, and spiritual attachment to the mountain and its unique flora and fauna.

The chapter contributes to the literature on local resistance to Big Science, which has so far either concentrated on opposition from non-marginalized local communities (e.g. Stenborg and Klintman, 2012; Kaijser, 2016) or investigated rather short-lived local opposition (e.g. Walker and Chinigò, 2018; Chinigò and Walker, 2020). Chapter three adds to these studies as it reveals the conditions under which a marginalized host community succeeds in sustaining opposition to Big Science. In doing so, it also provides insights into the why and how of local opposition. For instance, as other studies have argued, chapter three indicates that a (perceived) lack of local engagement and benefits, a troubled history of land dispossession, environmental concerns, and diverging ontologies may trigger opposition to Big Science (cf. Kaijser, 2016; Walker and Chinigò, 2018). The chapter also showed that TMT opponents raised their concerns during public consultations and amplified their claims via (social) media, just as local environmental opponents to ESS did (Kaijser, 2016: 52).

Chapter four, lastly, proposed a theoretical model of conflict emergence in distributed and centralized Big Science to address the question of why and how conflicts emerge in such science collaborations. To do so, the model drew on insights from the interdisciplinary literature on science collaboration and Big Science as well as scholarship on SAFs. Five mechanisms—attribution of threat or opportunity, mobilization of resources, coalition-building, boundary deactivation, and innovative action—work as a link between conflict cause and outcome. The model holds that an imminent or executed decision affecting or concerning a major component of a Big Science collaboration typically leads to two reactions among stakeholders: it is perceived either as a threat or as an opportunity. In either case, stakeholders are likely to mobilize their resources and to build coalitions to defend or push their respective agenda. Building such coalitions, in turn, may require stakeholders to reach across the boundary of their own field. Once strong coalitions exist, stakeholders push their causes through innovative action which consists of disruptive tactics. These tactics break with previous conventions within a particular field or create moments of genuine surprise and accelerate conflict, as they enable stakeholders to interfere with each other's objectives.

To provide a proof of concept for the model, the chapter traced its mechanisms in ITER, HBP, and TMT, three Big Science collaborations which have experienced at least one conflictual episode. In all three cases, the model helped to explain why and how conflict emerged. The cross-case analysis in chapter four moreover showed that the tactics stakeholders revert to during conflictual episodes are characterized by a high degree of disruptiveness as each tactic broke with a previous convention in a field or created genuine moments of surprise. At the same time, the chapter demonstrated that there is variation across cases. First, the analysis uncovered that the resources stakeholders use to push their agenda may differ depending on whether conflict develops between communities and/or states. For example, in the case of ITER, political decision-makers mainly capitalized on their socio-economic resources. In the cases of HBP and TMT, in contrast, scientific and local communities leveraged their social networks to further their interests. Second, the cross-case comparison showed that conflict emergence may vary on a temporal dimension. Specifically, the analysis revealed that conflicts which are triggered by an imminent decision unfold more slowly than conflicts which are caused by a decision which has already been executed or is about to be made. Third, chapter four indicated that the mechanism of boundary deactivation only plays a role when conflict emerges between or among communities. This could indicate that scientific and local stakeholder groups are more reliant on forging coalitions with actors outside their field than political stakeholders.

Like chapter two, chapter four adds to the stock of existing Big Science literature in two respects. First, it contributes a comparative perspective on Big Science, which, so far, is rather rare in the pertinent literature. Second, by proposing a model of conflict emergence in and around large science collaborations, chapter four adds to theory-building on Big Science. Such theory-building has so far largely been neglected in the scholarship on Big Science as most studies use at best existing mid-range theories or concepts to examine large science collaborations. Many of these theories and concepts are borrowed from other disciplines, for example from political science, sociology, or economics. Concepts that feature prominently in the Big Science literature include but are not limited to science diplomacy (Höne and Kurbalija, 2018; Claessens, 2020; Åberg, 2021), trading zones (Lenfle and Söderlund, 2019), pork barrel politics (Hallonsten, 2016), and moral economy (McCray, 2000; Baneke, 2020). Principal–agent theory is one of the few mid-range theories that is used in the Big Science scholarship (Hallonsten, 2016). Contrary to these theories, which were tried and tested in other disciplines before they were transferred to the Big Science literature, chapter four proposes a model that builds on said literature and has specifically been developed to understand a recurring phenomenon in large science collaborations.

Taken together, the chapters demonstrate that, in contrast to conventional science, Big Science carries significant symbolism for the involved stakeholders. Unsurprisingly, it symbolizes different things to different actors. As the case study of the diplomatic negotiations for ITER in chapter four and the enshrinement of the principle of fair return in the SKAO Convention in chapter two have shown, large science projects often epitomize "real money" to policymakers (Stichweh, 2013: 144), as Big Science typically gives a region or nation a competitive advantage in an increasingly interconnected knowledge economy. For scientists, Big Science may symbolize one of two things, depending on whether researchers expect to financially profit from the establishment of a large scientific project or not. As the case study of the HBP controversy in chapter four and TIO's justification for building TMT on Mauna Kea indicate, large science projects often exemplify frontier research to scientists that profit from or rely on Big Science for their experiments. The analysis of the HBP controversy also demonstrates that scientists who are not benefitting from or do not need ever bigger science projects tend to equate Big Science with the downfall of "small science." For them, Big Science represents a kind of "coup d'état" of one discipline against many others because it ties scarce resources up in one single project (Stichweh, 2013: 144). Finally, to local host communities, Big Science is typically a symbol of the globalized knowledge economy. As the literature review on local resistance in chapter three has demonstrated, in marginalized contexts like South Africa's Karoo region or Hawaiʻi Island, Big Science often epitomizes the shortcomings of the knowledge economy. These include but are not limited to the (perceived) devaluation of unskilled labor as well as a disregard for other forms of knowledge.

5.2. Limitations and Future Research

From a methods point of view, this thesis has two limitations which should inform future research on Big Science. First, it relies entirely on qualitative methods and data, as do most Big Science studies (for an exception, see: Vincenzi, 2022). Given the exploratory character of chapters two to four, a qualitative research design was an adequate choice. Future studies on Big Science, however, should move beyond an exclusive focus on qualitative methods, for example by using mixed methods designs such as "nested analysis," as proposed by Evan Lieberman (2005), or a variant of qualitative comparative analysis (QCA) (Rihoux and Ragin, 2009; Berg-Schlosser et al., 2009). Typical for mixed methods approaches is a triangulation of quantitative and qualitative methods. Scholars have argued that mixed methods designs increase transparency (O'Cathain et al., 2010) and validity (Pickel, 2009), "give a deeper, broader, and more illustrative description of the phenomenon" under investigation (Hurmerinta-Peltomäki and Nummela, 2006: 452), and, most importantly, are more robust because in such a method mix one method can compensate for another's weaknesses (Pickel, 2009). The technique of QCA, in turn, allows researchers to combine the benefits of quantitative and qualitative methodologies although as a research technique it cannot be fully situated in one or the other (Buche and Carstensen, 2009: 65). QCA "offers procedures for the systematic comparison of case study material in a small- or medium-N design" (Thomann, 2020: 259), enabling researchers to merge the "intensiveness of case-oriented research strategies and the extensiveness of variable-oriented approaches in a single framework" (Ragin et al., 2003: 323). Considering that the objects of interest to Big Science scholars and practitioners are often "naturally" limited in number, the technique of QCA lends itself to the study of large science collaborations. On the one hand, its ability to produce "empirically well-grounded, context-sensitive evidence" (Thomann, 2020: 259) resonates with the tradition of descriptive–historical Big Science studies. On the other hand, it stimulates systematic comparative approaches and middle-range generalizations which are so far largely lacking in the literature on Big Science.

Second, as indicated in section 1.5., some of the methods used in this thesis come with distinct drawbacks. The findings from small-N case studies, for example, are difficult to generalize. Where, as in chapter three, a single case is used, it is virtually impossible to generalize findings beyond the case under investigation. For cross-case analyses, as they were conducted in chapters two and four, one can at most generate intermediate, relative, as well as time- and context-bound generalizations (Khan and VanWynsberghe, 2008). Large(r) case comparisons, ideally based on bigger data sets, are needed to confirm, refine, extend, or refute the findings of this thesis. Given the above-discussed advantages of QCA, it might prove useful in this context. In cases where large case comparisons draw on expert interviews, they should aim for maximal diversity in terms of an interviewee's profile. Although this was the objective of chapters two to four, it was difficult to balance all stakeholder perspectives. It proved particularly difficult to find interview partners from East and South Asia for chapters two and four, possibly because of cultural differences. In the case of chapter three, it was generally challenging to establish contact with potential interview partners. During the field work for chapter three, potential interviewees were hesitant to speak with a community outsider and preferred other means of communication over email. As a result of these difficulties, the chapters may overemphasize some perspectives while sidelining others.

Keeping these methodological considerations in mind, future studies on Big Science could explore a variety of questions that remain unexplored in this thesis. Many of these questions emerged from conversations or written exchanges that I had with interviewees after sharing my published or draft articles. For instance, when providing feedback on chapter two, a proponent of AfLS underlined that a former scientist-turned-union leader played a pivotal role in getting SKA to South Africa. This made me wonder what role individual actors, especially scientific ones, generally play in getting Big Science onto the agendas of policymakers and how exactly scientific communities promote the establishment of a large scientific project. So far, the pertinent scholarship has largely neglected to study the intricacies of Big Science policy agenda-setting and has simply asserted that scientists engage in some form of "lobbying" (Hallonsten, 2014) and "maneuvering" (Modic and Feldman, 2017) to put a large scientific project that they want to get funded on the map. Studies that investigate the specific mechanisms through which scientific actors promote Big Science could help fill this blind spot.

A former EU policymaker responsible for the HBP, in turn, drew my attention to the role that certain personality traits in Big Science researchers and managers may play in the emergence of conflict, after I had shared the published version of chapter four with him. Previous research on Big Science indicates that charisma, for example, can be a double-edged sword because it is on the one hand, seen as a prerequisite to attract funding for and establish a leadership structure in a large science project. On the other hand, an increased focus on a single or a few charismatic researchers in Big Science may leave other renowned scientists that are also involved in the collaboration feeling frustrated and envious. Further research is needed to grasp whether and how certain personality traits influence conflicts in Big Science. Such research would tie in with recent attempts to investigate the effect of certain behaviors, for example self-interestedness, on scientific collaboration (Ngwenya and Boshoff, 2023) and could potentially also clarify whether Shrum et al.'s (2001) claim that interpersonal conflicts are unlikely to affect an entire science collaboration holds. Finally, after having read a draft version of chapter three, an astronomer I had interviewed for the paper argued that local resistance to the TMT was "more about creating a sense of mutual identity than opposing a telescope project." While my research indicates that the movement to protect Mauna Kea can indeed be interpreted as a "second" Hawaiian Renaissance, it also clearly shows that science and its (perceived) lack of local engagement and benefit-sharing played a considerable role in the TMT controversy. The interviewee's comment thus highlights the need to further sensitize scientists, particularly those that are embedded in marginalized communities, to the importance of local engagement and benefit-sharing, as well as practices of participatory research (Atalay, 2012) and community review (Liboiron, 2021).

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Appendix

Table 1: Overview of conflict causes at the meso level in Big Science

Author(s)	Case Studies	Identified Source(s) of Conflict
Shrum et al. (2001)	Projects in particle physics, geophysics, oceanography, space science, ground-based astromony, material science & medical physics	Resources Communication Credit Control of project
Vasconcellos (1990)	Brazilian R&D centers	Organizational objectives and priorities Work and task division
Knorr-Cetina (1999)	Particle physics & molecular biology laboratory	Authorship quarrels Resources Access to scientific resources Work and task division
Traweek (2009)	Stanford Linear Accelerator Center (SLAC) Ko-Enerugie butsurigaku Kenkyusho (KEK)	Access to scientific instruments Funding Cultural differences User groups
D'Ippolito & Rüling (2019)	Institut Laue-Langevin (ILL)	Work and task division
Mahfoud (2021)	Human Brain Project (HBP)	Project objective Epistemology Funds Organization of scientific work
Hilgartner (2011)	Human Genome Project (HGP)	Resource allocation Distribution of scientific rewards Ethics Project objective Epistemology Access to scientific resources Project management
Lambright (2002)	Human Genome Project (HGP)	Resources Science policy
Cook-Deegan (1994)	Human Genome Project (HGP)	Resources Project management Science policy
Claessens (2020)	International Thermonuclear Experimental Reactor (ITER)	Technology
McCray (2000)	Gemini Telescope	Funding Access to scientific instruments
Riordan et al. (2015)	Superconducting Super Collider (SSC)	Resources

Table 2: Overview of conflict causes at the macro level in Big Science

Author(s)	**Case Studies**	**Identified Source(s) of Conflict**
Hallonsten (2014)	European Organization for Nuclear Research (CERN) II European Southern Observatory (ESO) Institut Laue-Langevin (ILL) European Synchrotron Radiation Facility (ESRF) European X-ray Free Electron Laser (XFEL) European Spallation Source (ESS)	Siting Financial contributions Scientific access Procurement
Krige (2003)	European Organization for Nuclear Research (CERN) II	Siting
McCray (2010)	International Thermonuclear Experimental Reactor (ITER)	Siting
Claessens (2020)	International Thermonuclear Experimental Reactor (ITER)	Funding Siting Schedule
Aberg (2021)	International Thermonuclear Experimental Reactor (ITER)	Siting Organization Funding
Williams & Mauduit (2020)	Astronomy	Scientific access
Arnoux & Jacquinot (2006)	International Thermonuclear Experimental Reactor (ITER)	Funding

Table 3: Overview of analyzed documents for chapter four

Author Name	Year	Title	Document Type
European Commission	2011	Digital Agenda: Commission Selects Six Future and Emerging Technologies Projects to Compete for Research Funding	Press release
Waldrop	2012	Brain in a Box	Magazine article
Hummel	2015	Dicke Schädel, falsche Versprechen	Newspaper article
Horgan	2013	Do Big New Brain Projects Make Sense When We Don't Even Know the "Neural Code"?	Opinion piece
Sample	2014	Scientists Threathen to Boycott 1.2bn euro Human Brian Project	Newspaper article
Schnabel & Rauner	2013	Ein Hauch Apollo	Newspaper article
Destexhe	2021	In Silico, Computer Simulations from Neurons up to the Whole Brain	Academic article
Neurofuture.de	2014	Open Message to the Europan Commission Concerning the Human Brain Project	Press release
Marquardt	2015	Human Brain Project Mediation Report	Report
Kelly	2014	Brainstorm: Neuroscientists Protest against Europe's Human Brain Project	Magazine article
Broad	1992	Quest for Fusion Power Is Going International	Newspaper article
Claessens	2020	ITER: The Giant Fusion Reactor	Book
McCray	2010	Globalization with Hardware. ITER's Fusion of Technology, Policy, and Politics	Academic article
Reagan & Gorbashev	1985	Joint Soviet-United States Statement on the Summit Meeting in Geneva	Government document
European Commission	2017	EU Contribution to a Reformed ITER Project	Government document
Madelin	2014	No Single Roadmap for Understanding the Human Brain	Government document
US Department of Energy	2004	Remarks by Secretary of Energy Spencer Abraham	Government document
Buck	2004	Paris Urges EU to Build Fusion Centre Alone	Magazine article
Brumfiel & Butler	2003	US Support for Spain Triggers Unease over Fusion Project	Magazine article
Arnoux & Jacquinot	2006	ITER: Le Chemin des Étoiles?	Book
Watts	2003	End of an Era as Japan Enters Iraq	Newspaper article
Lambright	2002	Managing Big Science: A Case Study of the Human Genome Project	Academic article
Mahfoud	2021	Visions of Unification and Integration: Building Brains and Communities in the Human Brian Project	Academic article

Aberg	2021	The Ways and Means of ITER	Academic article
Cook-Deegan	1994	Origins of the Human Genome Project	Academic article
D'Ippolito & Rüling	2019	Research Collaboration in Large Scale Research Infrastructures	Academic article
Hallonsten	2014	The Politics of European Collaboration in Big Science	Book chapter
Hilgartner	2011	The Human Genome Project	Book chapter
Knorr Cetina	1999	Epistemic Cultures	Book
Krige	2013	The Politics of European Scientific Collaboration	Book chapter
McCray	2000	Large Telescopes and the Moral Economy of Recent Astronomy	Academic article
Shrum et al.	2001	Trust, Conflict and Performance in Scientific Collaboration	Academic article
Traweek	2009	Beamtimes and Lifetimes	Book
Vasconcellos	1990	Managing Conflicts between Line and Staff in Interdisciplinary R&D Projects	Book chapter
Williams & Mauduit	2020	The Access and Return on Investment Dilemma in Big Science Research Infrastructures	Book chapter

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Curriculum Vitae

Anna-Lena Rüland was born in Bonn, Germany, on 6 December 1993 and grew up in Jakarta, Indonesia, as well as in Bonn and Berlin. She holds a bachelor's degree in politics, administration, and organization from the University of Potsdam and spent a year studying at the Institut d'études politiques (Sciences Po) in Paris, France, during her undergraduate degree. Anna-Lena obtained her master's degree in international relations from the University of Potsdam, the Free University of Berlin, and Humboldt University of Berlin. As part of her master's degree, Anna-Lena studied a semester at Université de Montréal, Canada. Before starting her PhD in the European Research Council-funded project "Addressing Global Challenges through International Scientific Consortia" at Leiden University in January 2021, Anna-Lena gained professional experience during an internship at the World Academy of Sciences in Trieste, Italy, and as the coordinator of the international study programs at the Otto-Suhr-Intstitut of the Free University of Berlin.

List of Publications

Rüffin N and Rüland A-L (2022) Between Global Collaboration and National Competition: Unraveling the Many Faces of Arctic Science Diplomacy. Polar Record 58(e20): 1-12. https://doi.org/10.1017/S0032247422000158.

Rüland A-L (2022) Learning from Rivals: The Role of Science Diplomats in Transferring Iran's Health House Policy to the US. Globalizations 19(8): 1311-1327. https://doi.org/10.1080/14747731.2022.2062845.

Rüland A-L (2023) The Effectiveness of Science Diplomacy between Adversarial States: Insights from US-Cuban and US-Iranian Science Collaborations. The Hague Journal of Diplomacy 18: 1-25. https://doi.org/10.1163/1871191x-bja10147.

Rüland A-L (2023) Big Science, Big Trouble? Understanding Conflict in and around Big Science Projects and Networks. Minerva 61: 553-580. https://doi.org/10.1007/s11024-023-09497-w.

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Rüland AL and Rüffin N (2024) A Comparison of British and German Parliamentary Discourses on Science Diplomacy Over Time. Global Policy Online first: 1-13. https://doi.org/10.1111/1758-5899.13338.

Rüland A-L (2024) Sustaining Local Opposition to Big Science: A Case Study of the Thirty Meter Telescope Controversy. Technology in Society 78: 102597. https://doi.org/10.1016/j.techsoc.2024.102597.

English Summary

Public attention to and academic interest in Big Science has surged in recent years, amongst other things because some policymakers and scientists frame this type of science as a way to address some, if not all, of the great challenges of our time. In the pertinent scholarship, Big Science is most commonly defined as conventional science made big in three dimensions, namely organizations, machines, and politics. This definition reflects that the organization of large scientific projects requires hierarchical structures and big teams that are typically, but not always, formed and organized around large scientific instruments as well as substantial funding, which usually comes from the highest political level. Due to its political, scientific, and organizational prerequisites, Big Science brings a plethora of different stakeholders together, often for a long period of time. This includes policymakers, scientists, (scientific) managers as well as local "host" communities. Each group has considerable, though often different, stakes in Big Science. These diverging interests require stakeholders to negotiate and to compromise between and among one another. Where this is not possible, conflict is likely to arise in and around Big Science. The three articles which form the backbone of this thesis aim to contribute to a deeper understanding of stakeholder interests and conflicts in and around Big Science in two distinct ways. First, they seek to shed light on how different stakeholders pursue and negotiate their interests within and in relation to Big Science. In doing so, the articles pay particular attention to non-Western and indigenous actors, two stakeholder groups that the existing literature on Big Science has so far largely neglected. Second, the thesis aims to theorize how conflicts emerge and develop between and among stakeholders, thus advancing theory-building in the largely undertheorized Big Science literature. In pursuing these two research objectives, the thesis uses qualitative methods, such as semi-structured expert interviews and (comparative) case studies, and combines various theoretical approaches and concepts, ranging from institutionalism to science diplomacy.

Keywords: Big Science, policymakers, scientists, local community, interests, conflict

Nederlandse Samenvatting

De publieke aandacht voor en academische interesse in Big Science is de laatste jaren sterk toegenomen, onder andere omdat sommige beleidsmakers en wetenschappers dit type wetenschap zien als een manier om enkele, zo niet alle, grote uitdagingen van onze tijd aan te pakken. In de relevante wetenschap wordt Big Science meestal gedefinieerd als conventionele wetenschap die groot is gemaakt in drie dimensies, namelijk organisaties, machines en politiek. Deze definitie weerspiegelt dat de organisatie van grote wetenschappelijke projecten hiërarchische structuren en grote teams vereist die typisch, maar niet altijd, gevormd en georganiseerd zijn rond grote wetenschappelijke instrumenten en substantiële financiering, die meestal afkomstig is van het hoogste politieke niveau. Vanwege de politieke, wetenschappelijke en organisatorische vereisten brengt Big Science een groot aantal verschillende belanghebbenden samen, vaak voor een lange periode. Hieronder vallen beleidsmakers, wetenschappers, (wetenschappelijke) managers en lokale gastgemeenschappen. Elke groep heeft aanzienlijke, maar vaak verschillende belangen bij Big Science. Deze uiteenlopende belangen vereisen dat belanghebbenden onderling onderhandelen en compromissen sluiten. Waar dit niet mogelijk is, kunnen conflicten ontstaan in en rond Big Science. De drie artikelen die de ruggengraat van dit proefschrift vormen, beogen op twee verschillende manieren bij te dragen aan een beter begrip van de belangen en conflicten van stakeholders in en rond Big Science. Ten eerste proberen ze licht te werpen op de manier waarop verschillende stakeholders hun belangen nastreven en onderhandelen binnen en in relatie tot Big Science. Daarbij besteden de artikelen in het bijzonder aandacht aan niet-westerse en inheemse actoren, twee groepen belanghebbenden die in de bestaande literatuur over Big Science tot nu toe grotendeels zijn verwaarloosd. Ten tweede beoogt deze dissertatie te theoretiseren hoe conflicten ontstaan en zich ontwikkelen tussen belanghebbenden, om zo de onderbelichte theorievorming in de Big Science literatuur te bevorderen. Bij het nastreven van deze twee onderzoeksdoelen maakt het proefschrift gebruik van kwalitatieve methoden, zoals semigestructureerde interviews met experts en (vergelijkende) casestudies, en combineert verschillende theoretische benaderingen en concepten, variërend van institutionalisme tot wetenschapsdiplomatie.

Sleutelwoorden: Big Science, beleidsmakers, wetenschappers, lokale gemeenschap, belangen, conflict

Propositions

accompanying the dissertation

Who Gets What, When, and How?
An Analysis of Stakeholder Interests and Conflicts
in and around Big Science

1. A global and inclusive study of social processes in and around Big Science requires researchers to examine the perspective of historically marginalized actors, such as that of the Global South and indigenous communities. [this dissertation]
2. Lasswell's famous definition of politics as "who gets what, when, and how" captures the root cause of many conflicts in and around Big Science. [this dissertation]
3. An interdisciplinary research field like the study of Big Science warrants creative ways of using and building theory, such as analytical eclecticism. [this dissertation]
4. Conducting research on and with marginalized communities necessitates a reflexive approach. [this dissertation]
5. The lack of a common terminology in the Big Science literature leads to fragmentation and inhibits interdisciplinary dialogue. [field of study]
6. A disproportionate focus on single case studies in the Big Science literature impedes broader generalizations that are needed to advance the field. [field of study]
7. Big Science collaborations are more likely to fail when they bring research communities together that have no tradition of systematically organizing their key initiatives around large, strategic projects. [field of study]
8. To secure substantial funding, Big Science collaborations need one or a few charismatic and eloquent advocate(s). [field of study]
9. Researchers should engage with decision-makers to influence public policy in their area of expertise. [own choice]

Anna-Lena Nicola Rüland

Leiden, 4 July 2024