7. Emerging technology fields

The previous two chapters analyzed institutional barriers in the areas of incremental and radical innovation. It turned out that a strategic approach to collaborative innovation was rarely pursued. Only at certain stages of technology development, such as joint R&D, technical specification or material testing, could an innovation praxis characterized by horizontal negotiations and knowledge interdependencies be observed. Thus, contrary to the assumption that complex technologies are developed either on the basis of technical standards (incremental innovation; P1) or on the basis of processes for establishing common working standards (radical innovation; P2), the strategic institutionalization of a collaborative innovation praxis is a rare occurrence.

The observed quality deficits and significant time delays could support the author's main argument: A collaborative innovation praxis is based on shared working standards because it integrates all relevant partners, including certification and approval authorities, which – according to linear models of innovation – are usually not integrated until the end of the innovation process. However, it is the involvement of all relevant actors and the provision and promotion of knowledge integration between them that gives the innovation partnership the normative power needed to define and develop a radically new technology from scratch.

To further substantiate this argument, this chapter presents two final cases of technology development that were studied in the emerging field of the German offshore wind energy industry. Chapter 3 argued that in emerging fields where neither technical standards nor innovation networks are established, innovation projects are likely to adapt technical solutions from adjacent fields. This chapter argues that, even under such conditions, the development of new technologies is likely to be successful.

7.1 An emerging field of technology development

This section analyzes the organization of technology development in the emerging field of offshore wind. A new field usually emerges around a new issue. In the offshore wind industry, environmental regulations provided such an issue. Regulations have been put in place to protect marine life, particularly marine mammals such as porpoises, from noise emissions from construction. These regulations require wind farm developers to find technical solutions that meet the regulatory requirements and get their wind farm projects approved for construction.

In this field, four major players were involved in the technology development. First, an offshore engineering specialist and system developer; second, large utilities specializing in the construction of wind farms that were looking for technical solutions to meet environmental regulations; third, a public authority that checked the compliance of offshore constructions with these regulations; and fourth, a measurement body that was officially certified to monitor the performance of the systems at sea. This area is described in more detail below.

7.1.1 New environmental regulations

Since 2001, a public authority has been responsible for approving the construction of offshore wind parks in the German Exclusive Economic Zone (EEZ). In close coordination with federal environmental agencies, this public authority monitors legally defined limits of noise emissions caused by the installation of offshore wind turbines. As an R&D expert of a system supplier (E-Org07) points out, these regulations have induced a new field of technology development:

> *In this context, one thing is very important to understand, namely that this is not a pure market process, but that there are also authorities in the background. They also have to approve certain concepts. They can say that you can't use this system because they don't believe it will work.*

At the time of the empirical investigation, offshore structures such as wind turbines or accommodation platforms were installed using the impact driving method[36] (von Estorff et al., 2013). In this method, large steel pipes, approximately 80 meters long and up to 10 meters in diameter, are driven into the seabed.[37] In the early years of the offshore wind energy sector, there were no standards to protect the offshore environment, as a scientist and consultant to the offshore wind energy industry (E-Org06) recalls:

It was quickly apparent that there were no national or international standards or norms to support this. They didn't even know how to do it. The second

36 Impact drive is an installation procedure that rams steel pipes which measure over 6.5 meters in diameter and up to 80 meters in height into the sea bed. One expert specified this problem as follows: "*Now this becomes relevant for the acoustics. If you take a monopile, it has a large surface area. If you hit it, you firstly need more energy to overcome the frictional resistance in the floor. Secondly, this higher energy and the large surface area then lead to a high level of sound radiation. This means that a system must actually generate a high reduction. Roughly in the order of 20 decibels*" (E-Org07, R&D noise mitigation systems).

37 Those so-called "XL-monopiles" are designed for deep-water foundations installed over 40 meters below sea-level (E-Org09, Monopile foundation supplier).

*thing that was discovered was that the measurement technology was not even available to monitor the environment, for example. So how can you determine the noise level under water with certain foundation methods?*Over the years and in close coordination with other authorities such as federal ministries or environmental associations, the public authority responsible for con- trolling offshore constructions strengthened environmental protection. Since the 1st of March 2010, new regulations strictly prohibit the killing, injury or disturbance of animals (E-Org01, Approval expert). Therefore, to get the installation of wind tur- bines approved, construction firms must now prove that noise emissions are reduced or sufficiently mitigated, as the office manager of an offshore industry foundation (E-Org08) points out:

> *[Wind farms] may not be built if these requirements cannot be met. The industry therefore has a great interest in being able to fulfil these requirements.*

When the first regulations were introduced, the offshore wind industry seemed divided over how to deal with the new environmental rules. As a result, utilities discussed the idea of a joint R&D project to kick-start technology development in this area. A representative of a major utility recalls: "*[A]t that time, I was of the opinion that they all wanted to carry out a research project on noise mitigation, but not everyone had the same interest. (...) Everyone had always believed that other problems were more important and that they would take care of environmental protection*" (E-Org05, Expert noise mitigation). Today, the offshore wind industry is working closely with authorities and technology companies to meet environmental standards and get offshore wind farms approved, he says:

> *[The individual companies report [to the authority] which noise protection measures are planned and how they can better fulfil [the public requirements] as a result. They report that they are configuring [their systems] in such and such a way and are then commissioned to do so. They then receive an addendum to the planning permission. It then states that they have to do this and that for the next eight, nine, ten piles.*

In summary, following the introduction of new environmental regulations for offshore construction, a new field of technology development has emerged around the question of how to reduce noise emissions from offshore construction. In this field, the following four main actors were involved: (1) a public authority; (2) a certified measuring body; (3) utilities and wind farm planning companies; and (4) offshore engineering specialists and system developers. The next section shows how these actors formed a new field of technology development.

7.1.2 The major players

In addition to the regulatory authority mentioned above, the other major players in the new field of technology development were large utilities that plan and operate offshore wind farms, such as RWE, E.On, EnBW, EWE, EnBW, Vattenfall or Ørsted (formerly Dong Energy). The top management of these utilities perceived the new regulations as an economic risk and decided to look for technical solutions to reduce or mitigate noise emissions during construction, as the manager of a wind farm planning department of one utility (E-Org04) recalls:

> *The fact that the limit value alone was anchored in the authorizations naturally meant that the issue of noise protection was very high on our risk map. This was particularly because we were unable to estimate what the authorities would do if we were unable to comply with this value, as there were no suitable noise reduction systems on the market, for example. (...) It didn't take long for the issue to reach the very top of the board's agenda. (E-Org04, Offshore engineering manager)*

At the time, the utilities were searching in vain for new technical solutions. An industry association provided a public forum to discuss the options available, and representatives from all the utilities decided to systematically search for technical solutions together by setting up a joint research project, the offshore manager continues: "*We then sat down with the partners through [a foundation] and thought about what we could do. (...) On a technical and scientific level, we had a special working group, which eventually led to this research project.*"

These quotes indicate that the offshore wind industry initiated a joint R&D project to compare existing technical solutions to meet regulatory requirements, to generate basic knowledge on underwater noise emissions and, most importantly, to initiate innovation projects in the offshore wind industry. A joint R&D project based on both public and industry support has been set up to act as a "catalyst" for the creation of a market for noise abatement systems, as the same expert explains:

> *We earn our money afterwards with the wind farm. This means that although we saw ourselves as a catalyst for initiating developments through this project, it was clear from the outset that we would buy the noise reduction service on the market. (E-Org04, Offshore engineering manager)*

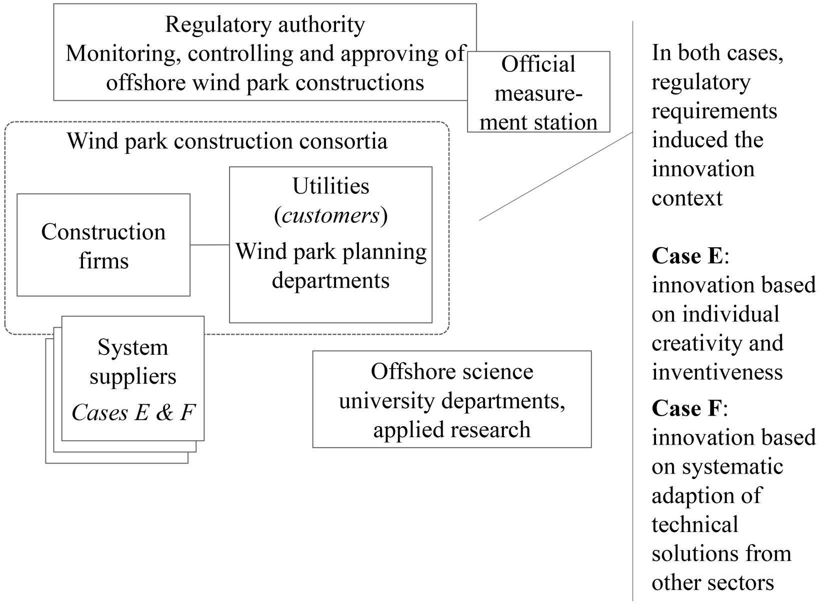
System developers are a third major actor in the field, alongside regulators and large utilities, as a representative of a large utility points out: "*This noise protection is characterized by large companies like [names anonymized] or small companies that operate like start-ups*" (E-Org05, Expert noise mitigation). The main clients of these system developers are construction companies commissioned by the large utilities. The contractors integrate the system developers' technical solutions into their wind farm installation procedures, as specified by the utility manager: "*At the end of the day, noise control is just a purchased part for us, like a hammer. There is also no installer who develops his own noise control systems. That's not our job, but then you go to the market and ideally the internal development is so far advanced that you know what you want*" (E-Org04, offshore engineering manager).

The empirical cases discussed in this chapter tell the story of two system developers offering two different systems for reducing noise emissions. Case E deals with a noise abatement system, while in case F, the developer company wanted to introduce a "quieter" foundation system by adapting a state-of-the-art technology used in the oil and gas industry. In both cases, the system developers were newcomers to the offshore wind energy sector who saw the new environmental regulations as a business opportunity.

The final major actor included in the research was a certified measurement organization. A representative of this body described the organization as officially authorized to measure noise emissions during offshore construction and to assess system suppliers on behalf of the public licensing authority: "*We are independent. We evaluate all noise control manufacturers and are in great demand by the federal authorities in our advisory role*" (E-Org06, Measurement specialist and consultant).

In summary, two development projects were observed in an emerging area of technology development around new environmental regulations in the offshore wind industry. As shown in Figure 7.1, this field emerged from interactions between four key actors: (1) a public authority; (2) utilities and wind farm planning companies; (3) offshore engineering specialists and system developers; and (4) a certified measurement body. In contrast to the examples of incremental and radical innovation discussed in the previous two chapters, neither technical standards nor innovation networks had yet been established in this field. The projects had to create both technical and working standards from scratch.

Figure 5: An emerging field of technology development



7.1.3 Cases E & F: Two system suppliers, two solutions

Both cases involve an engineering service provider that saw the new environmental regulations in the offshore wind industry as a business opportunity. Both companies were newcomers to the sector, but differed in terms of size, competence and practical experience in implementing projects for the offshore wind energy industry.

Case E deals with noise abatement systems, which are used to reduce noise emissions caused by the construction of offshore wind farms. Typically, offshore engineering services are contracted by large utilities planning the installation of offshore wind farms. One of the system suppliers involved in the investigation was an entrepreneur specializing in steel construction. This company was a newcomer to the offshore wind industry, as he explains:

> *I have to say that I was still pretty green behind the ears in that sector back then. (...) I had to completely rethink things. There wasn't as much literature about it as there is today that you could fall back on. (E-Org02, Managing director)*

In addition to this firm, a second supplier of noise mitigation systems was also interviewed for *case E*. Relying on decades of experience as a solution provider to the offshore industry, this firm turned into the entrepreneur's main competitor. Its managing director stated: "*We mainly specialise in coming to the customer's aid when they are experiencing a problem. Their needs are met by something that is tailored precisely to them.*" (E-Org03-Managing director).

In *case F*, the focal firm was a well-established engineering service provider in the international offshore oil and gas industry. This firm also perceived the offshore wind energy industry as a new market and designed an alternative foundation procedure for offshore wind turbines that is far more silent than the established method of pile ramming, as the firm's senior manager (F-Org01) stresses:

> *It has been proven that a foundation with [this procedure] would represent a quantum leap in noise reduction. (...) If you put it in popular scientific terms, then this is a low-noise foundation in comparison (...) We are now in the process of using this innovative technology for wind turbines, because that is where the ecological added value can be found.*

The next section shows how both companies established collaborative knowledge integration processes despite the lack of technical and working standards in this emerging field.

7.2 Analysed practices of knowledge integration

After introducing the major players in the emerging field of noise mitigation in the offshore wind industry, this section shows how the two engineering firms studied developed technical solutions despite the fact that no technical standards, working standards or innovation networks had been established in the field. In fact, at the time of the research, no technology existed that could meet the new regulatory requirements, as two experts pointed out:

> *Nowadays, there is no system that fulfils all requirements to the same extent. The requirements are good manageability at sea, i.e. small and relatively low weight as well as maximum noise reduction. There is no such system. (E-Org07, R&D noise mitigation system)*

> *There is no serial system that can be said to work in every case. (E-Org05, Expert wind park permission)*

Below, it will be shown that both firms combined their technological know-how gained in other sectors such as steel construction or offshore oil and gas with the technical requirements of the offshore wind energy industry to develop new technical solutions. However, the two companies pursed different strategies. The entrepreneur in *case E* mainly drew on her/his inventiveness to create a solution "*in [her/his] mind*", while the firm in *case F* adapted a technical standard from the offshore oil and gas industry and drew on scientific knowledge gained in an earlier joint R&D project.

7.2.1 Case E: Relying on individual creativity and inventiveness

The solution for a noise reduction system in Case E was developed by an entrepreneur and newcomer to the wind energy industry. During the economic crisis that hit German industry after 2008, the entrepreneur saw the new environmental regulations as an opportunity to expand his business, he recalls: "*That was in 2009. The [alpha ventus wind farm] was in its early stages, people were desperately looking for noise control solutions, and I took part in a symposium and realized that there was a lot of development and production potential here*" (E-Org02, Managing Director and Entrepreneur). For his first invention, the entrepreneur drew mainly on his technical experience in steel construction and combined this knowledge with the technical requirements of installing offshore wind turbines, as the expert continues:

> *In terms of statics alone, I was able to learn a lot from steel construction. I was also able to learn something about construction and sound insulation, although sound insulation under water is different from sound insulation in the air, but once you have understood the basic principle, you can still draw a lot on this knowledge.*

The entrepreneur's innovation strategy relied mainly on his individual creativity and inventiveness, as well as his ability to quickly implement technical ideas based on his own manufacturing facilities, as he explains: "*What was a big advantage in the whole story was that I have my own production company. This means that I can definitely come up with new ideas every day and implement them immediately without having to look for manufacturing companies*" (E-Org02). In this way, the entrepreneur creatively invented a new technical solution in the absence of technical standards.

Thus, in this case, knowledge integration took place very much in the mind of an entrepreneur who was able to draw on his own creativity, ingenuity, and pragmatism to combine steel construction know-how with the technical requirements of installing offshore wind turbines. A strategy of collaborative innovation with other development partners was not pursued, as the entrepreneur openly stated:

> *The ideas for my systems only ever come from me. (E-Org02, Managing director and entrepreneur)*

> *[This entrepreneur] (...) knows down to the last detail how everything works. But he can also realize it because he has a steel construction company, because he welds, because he has a cutting machine. He did everything on the system himself, right down to the procedures. He has everything in his head. (E- Org05, Expert noise mitigation system)*

7.2.2 Case F: Technology transfer from oil and gas

While case E is an example of an entrepreneur who relied mainly on individual know-how and creativity to invent a new prototype, in case F an engineering service provider tried to adapt a technical standard for offshore constructions in the oil and gas industry to the installation of offshore wind turbines.

To accomplish this technology transfer, the company drew on its technological and logistical expertise gained over "*decades*" of construction projects for clients in the oil and gas industry, as the senior manager (F-Org01) explains: "*We have done a lot of work on steel structures for oil and gas. This could then be applied more or less one-to-one when it came to designing the foundation structure.*" Thus, in contrast to the entrepreneur in Case E, who was a newcomer to the offshore industry, this firm was able to draw on professional offshore engineering competencies3 that included a broad bundle of technological knowledge and skills, such as simulation-based engineering routines and experience with offshore logistics, as the manager continues:

> *[We were able to learn what equipment can be used to install something like this quickly and effectively. (...) We also brought in all the experience of how to go from production to loading to transportation and installation at sea. But also the calculations, the proof and the forecasting of the weather window in which something like this can be done are experiences that have been gathered here for decades. We can also take a very critical look at an operation, looking at what works and what doesn't.*

The company's innovation strategy was to adapt an installation procedure and foundation structure used for converter stations to the technical requirements of the offshore wind energy industry, he adds: "*It has been considered to apply this concept to the foundations of wind turbines, but there are some difficulties at the moment. The loads are different and we don't know exactly how the geotechnics and the soil will react.*" To solve such problems, the company's experts usually work completely independently of external specialists. The manager (F-Org01) explains that when designing a new technology, they can rely on internally standardized, software-based engineering procedures:

> *With external partners to the extent that we bring in specialist expertise. If we have very specific soil mechanics problems, the question arises as to who we can work with to solve them. (...) Otherwise, we actually solve everything ourselves. We have software that is also recognized by international classification societies and inspectors. This means that we are in line with the international standard.*

However, during the study, the interviewees emphasized that additional basic scientific knowledge was needed for the implementation of the project. In particular, the experts needed geotechnical knowledge to adapt the new foundation structure to the loads and weights of the wind turbines mounted on the foundation structure, as the manager (F-Org01) points out: "*From the point of view of design, the load on the structure is extremely different from that of fixed platforms, because you have to deal with these oscillation problems, for example, in a constructive way*." To gain access to the necessary geotechnical expertise, the company participated in a joint R&D project with scientists from an applied research institute and a university department specializing in the calculation and simulation of foundation structures, as the expert explains:

> *First you have to create a model and have an idea of what is important. Then I have to create a mathematical model that can map all the effects. Then I have to carry out element experiments. For example, I can carry out small laboratory tests with the model. (...) Then you hope that the FE model, which simulates the prototype, will have the same behavior as in reality. (...) You don't just press a button and then the things are finished. It's basically manual work. It takes time. (F-Org03, Expert geotechnics)*

The scientific expert describes the engineering skills needed to develop a quieter foundation structure as manual work. The manager of the focal company adds that these skills also include information systems that allow the simulation of new foundation structures, but which are too specialized to be available internally, as the design engineer (F-Org01) specifies: "*There is special R&D software for geotechnical problems, i.e. finite elements. We don't need it often enough. On the other hand, there is still a lot of research going on in this area, and new soil models are being developed all the time*."

To conclude, in this case the focal company developed a prototype of a new foundation structure and installation procedure, mainly by adapting a technical standard established in the offshore oil and gas industry. This technology transfer was possible because the company had the necessary technological know-how and skills (such as engineering and offshore logistics) gained from decades of construction projects. In addition, the company strategically collaborated with scientific experts to fill its knowledge gaps:

> *This means that the geotechnical design basics are passed on to the relevant institutes. We are then told that they should give us an assessment or evaluation. Of course, this has to end with us being told whether it is possible or not. (F-Org01, Senior manager)*

7.3 Realizing technology development

The previous section presented two examples of offshore engineering firms attempting to introduce a new technology into an emerging technology field. For both companies, the implementation of new environmental regulations for the construction of offshore wind farms opened up new business opportunities.

It could be shown that both firms followed different knowledge integration strategies. In case E, an entrepreneur relied mainly on his personal ability to invent technical solutions by creatively combining know-how gained in steel construction with the technical requirements of wind turbine installation.

In case F, a small engineering firm relied on its professionalized engineering routines and expertise gained from decades of construction projects for the offshore oil and gas industry to transfer an existing technical standard to the offshore wind industry. In contrast to the first case, this company collaborated with scientists to develop fundamental knowledge and gain access to testing facilities. This section analyzes in more detail how each company attempted to establish a position as a systems supplier in this new field.

7.3.1 Case E: Technical invention vs. trial-and-error learning

Below we show how the entrepreneur in Case E tried to establish a position in the offshore wind energy industry. His innovation strategy is elaborated by contrasting it with that of his main competitor. In fact, the reader will learn that the competitor was able to establish a position as a trusted system supplier, while the entrepreneur failed to do so until the time of the interviews.

7.3.1.1 Imagining new solutions "in the mind"

The entrepreneur entered the offshore wind energy sector at a time when utilities were "*desperate*ly" searching for technical solutions to meet new environmental regulations, as the managing director (E-Org02) recalls: "*There was a desperate search for [technical solutions]. I attended a symposium and realized that there was a huge potential for development and production*." Drawing on his creativity and experience in reducing noise emissions in other industries, the entrepreneur quickly invented a first solution, which he offered to all potential customers in the offshore wind energy sector:

> *I had an idea and thought that could be used. That was [solution A]. I suggested it and from one day to the next, within a week, I was known to the whole group. There was only one provider at the time.*

Since the entrepreneur did not find a buyer for this solution A, he developed solution B by adapting a technical principle already established in the field and offered by his main competitor: "*I stood there and thought about what I would do if there was no need and what I would do then. (...) Then I came up with [solution B]*" (E-Org02, manager and entrepreneur). Within a few weeks, the entrepreneur reports, he/she sold this solution to a customer who was under pressure to incorporate noise abatement into an ongoing offshore construction project: "*Then I went [to the client] and we talked about the system. I also described the process, what the project looked like and how it worked. I didn't have a drawing, nothing. Not even a picture. Nothing at all. Just my stories. This is how we would do it and this is how it works*" (E-Org02, Manager and entrepreneur).

As these findings show, the entrepreneur's first solution, which was basically invented from scratch, did not find customers, but – in line with P3 – the second solution was successful because it was an adaptation of a solution that was already in use. The entrepreneur built this solution and quickly established first customer relationships mainly by relying on personal creativity, ingenuity and pragmatism rather than strategic collaboration with external partners.

The entrepreneur did not take a strategic approach to collaborative innovation, but mainly did technology development "in the head. At the time of market entry, the entrepreneur (E-Org02) admits that she/he had no further insight into related scientific expertise: "*I had no idea about impedance jumps and frequencies and speed of sound* (laughs)." Over the course of two interviews, the CEO came across as a typical entrepreneur, relying on his or her unique individual skills to perform autonomous technology development and come up with quick technical solutions: "*I have it in my head and then I try to communicate it to the people. That way we can be as efficient as possible because we're immediately faced with the product and don't have to spend a lot of time at the drawing board thinking and calculating whether it fits*." In this particular case, the entrepreneur's cognitive ability to imagine technical solutions "in his head" and a supporting "gut feeling" were the source of technology development:

> *Alone, when you've already reached a certain age – that may sound a bit arrogant – but then you have a certain gut feeling. And that's pretty strong in my case and it hasn't let me down very often. And you can let the context of what's happening run completely through your head. (E- Org02, Managing director and entrepreneur)*

In conclusion, the entrepreneur in this case did not take a strategic approach to collaborative innovation. Technology development took place mainly "in the head" of an entrepreneur who adapted a technical solution from a competitor, but – more interestingly – creatively combined know-how gained in steel construction with the technical requirements of installing wind turbines, thereby imagining new technical solutions and quickly establishing new customer relationships.

7.3.1.2 Personal conviction instead of collaborative innovation

Above it appeared that the entrepreneur did not try to develop a technical solution together with external partners. In fact, the entrepreneur describes her/his position in the field as that of a "lone fighter" with little support from partners, for example in the form of financial risk sharing: "*I would approach the market a bit differently. Maybe I would also look for a partner who would support the whole investment from the beginning and make money out of it, because I am always the lone fighter and I have realized that I am alone in the wilderness and I have no one. Anyone can talk my system to pieces if they want to, even though it's undoubtedly good.*"

Against this background, it was interesting to observe that the entrepreneur's main competitor company was more successful in strengthening its position as a trusted system supplier. According to the entrepreneur, he/she had the "*lobby*" and "*experience*" that the main competitor possessed, which was experience in offshore engineering services for over three decades, as the entrepreneur explains:

> *[My direct competitor], for example, has been on the market for 30 years and has a completely different lobby to [me]. You don't know the [new entrepreneur]. He's never been noticed anywhere, suddenly arrives and offers [his own system]. That's something that really bothers me and that's how the customers outside react. We'd rather go with someone who has the experience.*

The entrepreneur's main competitor has decades of practical experience as an offshore solution provider, as its managing director (E-Org03) explains: "*I've been traveling the world for [the company] since the early 80s. (...) What we do is everything that has to do with oil on the water and air in the water. We don't do oil spill response, we make the equipment for it.*"

The entrepreneur, on the other hand, was a newcomer to the offshore wind industry. With few references and limited engineering capacity, his company struggled to establish a position in the field based on stable customer relationships, as the CEO (E-Org02) suggests:

> *But I don't have a lobby. (...) First of all, I'm not based by the sea. Secondly, I'm fairly new to the market and thirdly, I don't have a manufacturing company with 20 engineers and designers, I do it on my own and nobody has any confidence in that.*

During the investigation, it became clear that the entrepreneur was unable to establish a position as a trusted system supplier. In contrast, the entrepreneur's main competitor succeeded in doing so. This was because, unlike the competitor, the entrepreneur did not take a strategic approach to collaboration and financial risk-sharing, as the following quote from the entrepreneur (E-Org02) illustrates: "*Before we now build [solution A] on a large scale, [which] costs* *several million, the question remains: is it any good at all? We won't get any research funding for it. Zero! We're doing it all on our own*."

Apart from shouldering the financial risks alone, the entrepreneur also hardly cooperated with scientists to gain access to new knowledge, as the following quote shows: "*At the end of the day, the research institutions are just a confirmation of what I was doing. It confirmed to me that I was on the right track and that I had done my work properly and thought it through technically. That's all it really did for me. It's always good, I'm more of a practical thinker.*

In summary, the entrepreneur managed to quickly invent technical solutions without the support of development partners. His innovation strategy did not include strengthening the FRM's position as a system supplier by sharing financial risks or systematically collaborating with scientific experts to improve the system. Thus, instead of collaborative innovation, personal "conviction" or visionary thinking was the dominant mechanism for introducing a new technology into an emerging technological field, as one of the entrepreneur's employees points out:

> *His conviction was his motivation to drive the system forward in the way he did, so that he could then deliver the performance to satisfy the customer. Nobody does that unless they are so convinced that it won't work the way they have designed it in their head. (E-Org02, Technical assistant)*

7.3.1.3 A collaborative approach to technical invention

In the technology development case described above, one entrepreneur's technical creativity, visionary thinking, and personal conviction emerged as the dominant mechanism for introducing a new technical solution into an emerging field. The entrepreneur's competitor, however, seemed to have adopted an opposite strategy: a strategic approach to collaborative innovation.

The competitor was already an established system supplier when the entrepreneur entered the field. The competitor had adapted a solution that was already in use to mitigate noise from submarine explosions. The competitor incrementally improved this idea in close coordination with scientists, customers, and government regulators.

For example, from the start of its involvement in the offshore wind energy industry, the company has worked with scientists responsible for measuring and reporting noise emissions to regulatory authorities, as the managing director (E-Org03) explains: "*For example, we often work with [a measurement facility]. It is a very fruitful connection. (...) Because they have measured and said what can be done better, you also have opportunities or see ways in which something can be done better*."

One of the scientists involved (E-Org06) confirms this "*close cooperation*" in which trial-and-error learning and system testing were improvised. As the expert explains, the partners combined practical knowledge with theoretical knowledge of underwater acoustics to improve the technical solution step by step during the construction of offshore wind farms:

> *A relatively close cooperation then developed and we spent a lot of time at sea together with [the competitor]. You then realized that you would like to try out one thing or another and he/she then said whether you can do it or whether it is simply not technically feasible. (...) You then approach it from both the theoretical and the practical side and simply try out a few questions.*

Comparing the entrepreneur with his competitor, a strategic approach to establishing a collaborative innovation praxis was observed only in the latter case. The competitor collaborated with scientists to improve offshore system testing, facilitate trial-and-error learning, and further adapt the company's technical solution to the needs of the wind energy industry, as the following quote illustrates:

> *If you have built a noise protection system, the technical aspects are restricted. During operation, you can't completely rebuild it, but you can vary the set screws within certain limits. That was considered at the time and it really is done bilaterally. (E-Org06, Measurement specialist and consultant)*

For the competitor, these collaborative relations not only provided access to offshore system tests, but also enabled trust-building and the establishment of a shared innovation praxis. For example, as the managing director of the competitor firm (E-Org03) suggests, collaborating with scientists enabled her/him to explain to the functioning of the system to customers, thereby establishing some trust that the solution was working:

> *Of course, it also depends on whether you have the physicist with you when you talk to the customer. He/she will explain that the floor is constructed in such a way that the pile does not penetrate as quickly and vibrates more. He/she can simply explain this better. In return, she/he is the made woman or man.*

In another example, the competitor explains that working with scientists strengthens the company's position vis-à-vis the regulatory authorities, as the manager (E-Org03) adds: "*When the [scientist] explains it to the [authority], everyone understands. We also had a joint presentation once, which was great. I did all the practical work and she/he did the theory.*" In retrospect, this strategy of building trust and strengthening social relations with relevant innovation partners appeared to be particularly successful in an emerging field of technology development where reliable technical standards were lacking, as one expert suggests:

> *No one will give a guarantee for a certain value [of noise reduction] because the technology is still being tested and developed. (E-Org05, Expert wind farm approval)*

These findings illustrate that, in contrast to the entrepreneur who remained socially isolated, the competitor strategically collaborated with scientists to gain access to offshore system tests, to flexibly adapt the firm's solution to specific wind farm construction projects, to explain the functioning of the solution to customers and representatives of public approval authorities, and thus to build trust in the solution. In this way, the competitor was able to establish an innovation praxis and strengthen the company's position in the field. As confirmed by the entrepreneur (E-Org03), customers perceived the competitor as a "*safe*" supplier:

> *The large corporations see the secure suppliers first. You have to see it that way: They also carry out risk assessments. (...) Now the small [entrepreneur] comes along... What if he/she stretches his/her wings in between? (...) So let's take a company that is supposedly efficient and use it. Even if this company then costs three million euros more? It doesn't matter, we'll have peace of mind. That's how the large corporations think. (E-Org02, Managing director and entrepreneur)*

As a result, after almost five years in the offshore wind industry, the entrepreneur has decided to leave the sector, as she explains: "*But regardless, I am in the process of selling my company. Completely gone. This dishonest fight is not my profession. I've been in business too long to play these games and I don't want to*" (E-Org02, manager and entrepreneur). In fact, looking back on his experience, the entrepreneur admits that he did not build enough trust in the eyes of customers and public authorities: "*I would present myself differently. Probably with other partners too, so that I can carry more weight for my company. People always say: 'Oh, is that going to work with [the entrepreneur]? So there are always these doubts in the room.*"

The entrepreneur admits that a strategic approach to establishing a joint innovation praxis with external partners might have been more effective: "*That's why I would maybe look for a cooperation partner. This could be an installer or a large company that would support the whole thing financially and also make a profit from it. That would give me a lot more security and I wouldn't have to take a big risk on my own*" (E-Org02, manager and entrepreneur).

At this point in time, innovation processes in this field were far from being regulated. However, as one expert mentions, personal trust was no longer sufficient to prove the effectiveness of technologies, which is a sign of the professionalization of technology development in the sector. Thus, according to the expert, companies began to demand "experience", technical references and even contractual guarantees for system performance:

> *On the other hand, experience is welcome, the results from previous projects, what can you really count on and what can be guaranteed. I know from the construction*

companies that the contract system has changed completely this year. (E-Org06, Researcher and consultant)

7.3.1.4 Preliminary conclusions

Based on the empirical case of an entrepreneur introducing a noise reduction system in the field of offshore wind energy, some first conclusions can be drawn. In sect. 3.3 assumed that an *innovation project operating in an emerging field of technology development is likely to adapt technical solutions from adjacent fields* (P3). The results of Case E only partially support this assumption.

It could be shown that one entrepreneur adapted the solution of a competitor already established in the new field. Most interestingly, the entrepreneur relied on personal "*conviction*" and technical imagination to invent a new solution independently of external partners. Technology development took place mainly "*in the mind*" of the entrepreneur. Personal determination and visionary thinking thus appeared to be the dominant mechanism for introducing the new technology into the emerging field. However, a strategic approach to establishing an innovation praxis was not found.

It was also interesting to observe that the entrepreneur did not establish a position as a trusted system supplier, while its competitor succeeded in doing so. It could be shown that the competitor firm strategically collaborated with scientists to improvise its offshore system tests and incrementally improve its solution based on trial-and-error learning. In a field characterized by high technological uncertainty, this innovation praxis built trust with customers and government regulators and strengthened the competitor's position as a trusted system provider. The competitor thus relied on personal trust as the dominant mechanism of technology development.

Table 18: Innovation praxis in emerging fields

Technical standards	**Working standards**
In an emerging field, no technical standards are available	In the example of the entrepreneur, technology development was based on individual creativity, personal conviction and technical imagination (no strategic approach to collaborative innovation was found)
	In the example of the entrepreneur's competitor, collaborating with scientists allowed the firm to improvise offshore system tests and establish trust among customers and authorities

7.3.2 Case F: Creatively combining technical standards

The previous section illustrated the case of an entrepreneur who relied on individual creativity, personal conviction, and technical imagination to introduce technical solutions to an emerging field. In the second case discussed in this chapter, an engineering service provider specializing in technology development for the offshore oil and gas industry pursued a very different strategy. The company worked with scientists to adapt a technical standard from the offshore oil and gas industry to the needs of wind farms, as the senior manager (F-Org01) puts it:

> *The other point is that we have now completed the first research project. We have a positive result. Everybody knows it works. Now it would be nonsense to say we've done a great study and then put it in a drawer and that's it. That can't be the case. Now we have to put it into practice.*

This company tried to realize a technology transfer from the oil and gas industry by relying solely on its professionalized engineering skills.

7.3.2.1 A unique offshore engineering competence

In contrast to the entrepreneur, the engineering firm in Case F had technical problem-solving competencies, especially for offshore environments, that it had acquired over decades. To remind the reader, competence is defined here as a "*generative ability of actors or systems to cope with concrete tasks and solve problems, but to apply general, cross-situational knowledge in the process*" (Sydow, 2014a, p. 311; own translation). Case F zooms in on the competence of adapting a technical standard from an adjacent field to the technical requirements of the offshore wind energy industry.

In offshore engineering projects, as the senior manager of the company (F-Org01) explains, the main development partner is usually the customer-usually a large technology company specializing in energy technologies such as converter stations, oil and gas platforms, or wind turbines: "*The requirement comes from the design of the energy technology manufacturer. On the other hand, you have to operate the interface, which the shipyard can do. (...) These are practically the cooperation interfaces that we need. The composition comes from that. This is a normal project. At least for us.*"

In addition to customers, offshore engineering projects involve shipyards that provide additional technical expertise and build the required technologies. As a result, offshore engineering projects typically rely on a "complex collaboration matrix" to address both technical and logistical issues,[38] as the expert puts it:

> *In practice, this is a relatively complex matrix of requirements that must be examined from both a cost and a speed-of-assembly perspective.*

Offshore engineering projects are interesting to study because offshore technologies must be customized to specific contexts of use by creatively combining the technical expertise and requirements of different project partners, while also addressing non-technical, logistical challenges. However, in order to control the complexity inherent in such projects, customers tend to clearly define the technical interfaces between the collaborating partners. As a result, innovation tends to occur within each component, as in the case of an engineering service provider that adapted a foundation structure from an adjacent field, the offshore oil and gas industry, to the requirements of offshore wind farms. The technical standards provided by other project partners are then simply incorporated into the respective component, as the senior manager (F-Org01) points out:

> *Basically, we are not developing new technology. We build on our experience. We know what the steel grades are. We know how to build [a foundation structure]. We know what the welding technology is. So there is little change. The changes are in the heart of the plant. That is the plant technology. We have absolutely no influence on that. We are pure designers. If you like, we'll build a beautiful*

38 4For example, logistic questions refer to the transportation and lifting of components, which requires specialized ships with enough space and loading capacity. Logistic questions also involve the coordination of construction works within tight weather windows or under conditions of high waves/special soil characteristics, the elaboration of detailed work procedures, health and security precautions, deploying systems during ongoing installations, controlling the costs of offshore working hours (e.g. 250,000 – 500,000 Euro for an installation vessel per day), or maintenance work under water, for instance.

> *table here, but we don't really care what you put on it. (...) We just react to the requirements. (F-Org01, Senior manager)*

In Case F, the engineering service provider needed not only technological and logistical know-how and practical experience, but also creativity to integrate the technical expectations of the project partners into a working wind energy technology. Like "architects," says the senior manager, the company's engineers combined the customer's technical requirements with its in-house technical expertise to develop a foundation structure that could be installed under the customer's offshore wind turbines: "*How do you combine the top [of the system] with the bottom? (...) In principle, it's like an architect planning a house. One prefers the Bauhaus style, the other the Tyrolean style. That's how you have to think about it. (F-Org01, Senior manager)*

These quotes illustrate what enabled the engineering services provider to introduce an innovation to the offshore wind energy sector. Based on technological knowledge, logistical know-how, practical experience and creativity, the technology specialist was able to adapt an existing technical standard from a related field to a new application context. In this way, the company created a customized solution to meet the needs of a specific wind farm. As the senior manager (F-Org01) puts it, the work of combining different technical standards was done "in dialog" with different parties (e.g. technology developers, system manufacturers and certification bodies). Metaphorically speaking, the offshore engineering specialist "*pieced together*" a new technology:

> *That's how you put it together. That's how it comes about afterwards. So that means that you can never say that this thing has only one signature. The basic concept of what it looks like is already there. The details come in the dialog.*

The company's unique innovation capability was thus rooted in a project organization that involved all relevant partners. As the senior manager (F-Org01) explains, the company generally designs new offshore solutions based on close, face-to-face interaction with other partners: "*We basically have a project team here. Then we have a mirror team on the other side. On the one hand, this involves exchanging plans. But at these project meetings it's also important to exchange ideas personally. So you have regular team meetings to check how everything is being implemented and what the requirements are. It's quite an illustrious bunch that sits together.*

The project organization therefore played an important role in bringing together "an illustrious bunch of experts" from different organizations, as the expert put it. Through inter-company "design loops", the manager continues, the partners combined their technical requirements and controlled the development effort: "*The implementation always also means what costs will be incurred, so a product is always created in dialogue or in coordination. The design* *features are constantly reviewed and updated. Loops are run*“ (F-Org01, Senior manager). In the end, the project resulted in an individualized technical standard for a specific offshore wind farm, as the senior manager (F-Org01) concludes:

> *Standardization certainly stops when you look at the floor. There is no standard floor. The floor is different in every place. But by standardization I also mean coordinating the design and standardizing the installation methods so that you can rely on the existing installation vessels and technologies. and technologies. (F-Org01, Senior Manager)*

In conclusion, this case demonstrated a unique, professionalized offshore engineering competence. Based on a broad bundle of knowledge and skills – technological knowledge, logistical know-how, decades of practical experience, and a cross-company project organization – the offshore engineering company was able to creatively and collaboratively adapt technical standards from an adjacent field and individualize a foundation structure to the specific requirements of offshore wind farms. An “*extreme creativity*", as the senior manager (F-Org01) puts it, is an important component of such innovation competence:

> *If we weren't international, we wouldn't exist. We wouldn't be able to make a living from it. There is a lot of competition in the standard sector. There are a lot of them, and you're just one of many. We can't serve the German market with the creativity we have here. That extreme creativity is not necessary. That's why we're better positioned and that's why there are actually very few offices in Germany that have the continuity that you have in oil and gas. In this respect, the others retreat into standard designs for port or bridge construction. (F-Org01, Senior manager)*

7.3.2.2 A strategic approach to trust-building

It has been shown above that the engineering service provider in Case F has developed a professionalized offshore engineering competence that involves the creative and collaborative adaptation of technical standards from the oil and gas industry as well as the individualization of technical solutions to the context of specific wind farms. In addition, the offshore engineering company has also strategically collaborated with scientific experts to improve its system and build trust in the eyes of customers, as the senior manager (F-Org02) explains: “*The crucial factor with this system is how the foundation behaves in the long term in terms of soil mechanics and geotechnics, but also how to deal with any scour that may occur.*"

The technology specialist joined a joint R&D consortium that included partners from applied research institutes and university departments. The company worked with these scientists to gain access to geotechnical expertise and testing facilities, This allowed the company to simulate offshore system tests, conduct engineering experiments, and prove the functionality of its prototype.

During the course of the project, the applied research institute coordinating the R&D project also attempted to recruit a utility company as a potential partner that would be willing to provide access to system testing under real-world conditions, i.e., in the context of an offshore wind farm construction project. However, the research project manager (F-Org02) reported that at the time of the investigation, German utilities and wind farm operators showed little interest in such collaborative testing of a new foundation structure:

> *Large companies tend to be risk-averse. They only ever assess risk. In other words, they want to shift the risks somewhere else, if possible, or have them eliminated. (...) That's why there are two main lines in the project. One is experimental and the other is prototyping.*

The research project manager (F-Org02) points out that the main objective of the R&D project was to create new science-based knowledge in order to compete in the emerging market for offshore solutions. A major competitor in this endeavor was the Danish utility company Ørsted (formerly Dong Energy), which specializes in offshore energy production technologies:

> *We, in turn, say that we must also examine the fundamentals. They are not clear. Dong Energy is saying the same thing. I have the impression that they are more courageous in this respect. But they also have more confidence because they have been working in this direction for more than ten years, and they are also artists at sea.*

These findings indicate that the engineering firm took a strategic approach to building trust with potential clients by working with scientists and proving the functionality of the new foundation structure. Given the lack of technical standards in the field, the project manager explains that building trust was a key focus, relying on systematic, science-based, collaborative engineering, testing, and certification:

> *[When somebody puts it [at sea], it brings the simple message that it works and that they have the confidence to put it there. It should work, but everybody knows that there are some reserves in terms of load-bearing capacity that are not in a book. that are not in a book, but nobody gives us that. We can't call them up and ask what ratio they're using to get that verification. You have to do it yourself. There is no guideline either. You can't look at some standard and say you should use this and that. So it's research and development until Germanischer Lloyd or BAM [Federal Institute for Materials Testing] or some working group comes up with design rules and makes them binding. It's not there yet. It's not state of the art.*

In summary, the offshore engineering firm, together with scientists, established a collaborative innovation praxis of adapting a technical standard from the oil and gas industry to the technical requirements of offshore wind turbine installation. In contrast to Case E of an entrepreneur who autonomously designed a new noise mitigation system, this firm strategically pursued a trust-building strategy based on collaborative system testing and certification. Collaboration with scientists provided the company with access to basic scientific knowledge and systematic, simulation-based offshore system testing, as the following statement by the senior manager (F-Org02) illustrates:

> *We wanted to work with [a central German university] because they have more geotechnical expertise and they also have a large testing center. (...) They can test steel structures for fatigue strength. (F-Org01, Senior manager)*

Despite these efforts to build trust, the senior manager (F-Org01) points out that at the time of the study, the new foundation structure had not yet been introduced to the offshore wind energy sector. The main challenge was to find a German utility willing to participate in the innovation project by providing access to real-world system testing: "*The [research institute] is on the ball, so the question is, which of the wind farm operators can we motivate to give us a site within a field where we can test this prototype? (...) This would have the advantage that the infrastructure could also be used. So there is a grid that you can feed into*" *(F- Org01, Senior manager).*

Compared to the entrepreneur who quickly invented and implemented a new solution, the second solution, the second innovation project discussed in this chapter was still in the basic research stage at the time of the interviews. The absence of a wind farm planning company in the R&D consortium left the innovation network incomplete.

7.3.2.3 Preliminary conclusions

Based on these findings, some additional conclusions can be drawn about the social processes underlying technology development. P3 suggested that *if an innovation project is operating in an emerging field of technology development, it is likely to adapt technical solutions from adjacent fields*. In Case F, it was found that an offshore engineering specialist adapted a technical standard from the oil and gas industry to develop a quieter foundation structure for wind turbines. This supports the predictions of P3.

To realize the technology transfer, the engineering firm drew on a unique engineering expertise that it had professionalized over decades of involvement in offshore construction. Based on a broad bundle of knowledge and skills – technological and logistical know-how, practical experience and a cross-company project organization – the offshore specialist creatively and collaboratively combined technical standards to customize its technology to the specific context of offshore wind farms.

In addition to its professionalized offshore engineering expertise, the company used trust building as another innovation strategy. For example, the engineering firm worked with scientists to adapt its technical solution to the geotechnical conditions of offshore wind turbines. This collaboration also gave the company access to testing facilities and simulation-based testing methods, which helped certify the technology and build trust with customers.

But the innovation network remained incomplete. No utility or customer was part of the innovation project. In other words, the innovation praxis was not fully established at the time of the study. As the results indicated, an established innovation praxis would likely become more hierarchical because the customer would (1) grant access to system testing at sea, (2) select system suppliers, and thus (3) define membership rules.

The two examined examples of technology development in an emerging technological field provide additional empirical evidence in support of the author's main argument that a collaborative innovation praxis is key to the introduction of complex technologies. In emerging fields where technical standards and technology markets are lacking, innovation partners such as firms, scientific institutes, and certification or licensing authorities must be integrated into the innovation praxis. In this praxis, technical standards are combined in a creative and collaborative way.

Table 19: Innovation praxis in emerging fields

Technical standards	**Working standards**
A technical standard from the offshore oil and gas industry is adapted to the installation of offshore wind turbines	Creatively and collaboratively combining technical standards (based on technological and logistic know-how, decades of practical experience, and an inter-firm project organization)
	Collaborating with scientists to access basic scientific knowledge, testing facilities and simulation-based system tests as a means towards certifying the technology and building up trust in the eyes of customers

7.4 Institutional barriers and what they caused

At the time of the study, neither technology company had established a stable position as a trusted system supplier in the industry. In fact, while the entrepreneur was about to leave the sector (case E), the offshore engineering specialist (case F) lacked a customer willing to participate in the innovation project. Both firms remained excluded from established system supply networks, an observation that is interpreted as an unintended outcome.

7.4.1 Case E: Lacking trust in system suppliers

In Case E, the entrepreneur did not establish a position as a system supplier, an outcome that is linked here to the entrepreneur's inability to build trust in the eyes of customers and licensing authorities.

At the time of the study, all noise control systems in the field were still at the prototype stage, which meant that there was no technical standard to meet the newly introduced environmental regulations, as one expert pointed out: "*Noise protection is of course a huge problem, because there is no state of the art or proven method for it, and especially in our project we were driven through the village by the approval authorities with ever higher and additional requirements*" (E-Org05, Expert foundation structures).

Respondents from customers and large utilities explained that their choice of noise mitigation system is based on empirical evidence, rather than assessing system performance based on standardized engineering procedures, as the head of an offshore wind farm planning department pointed out (E-Org04): "*Our biggest challenge is that we still work very empirically. (...) That's a risk, because it's like a dance every time.*"

Typically, the same executive continued, the performance of systems is evaluated on the basis of simulation-based engineering routines. In this emerging field of technology development, however, decisions are based on "*gut feeling*" or trial-and-error learning:

> *Ultimately, probability values are needed for a risk assessment. This is normally the result of a numerical simulation. What is the probability that we will exceed 160 dB? At the moment, it's a lot of gut feeling. (...) Ideally, we would design the system so that we simulate it and know relatively precisely that the system will give us a value of plus/minus five decibels for this soil, this pile, this hammer and this thickness. At the moment it's trial and error. (E-Org04, Offshore engineering manager)*

Under such conditions of high technological uncertainty, contractual control over system suppliers was not possible. At the same time, technology development could not be based on trust in the technological competence of system suppliers, as the same expert suggests: "*The system has to be tested a year in advance. If it doesn't work, or if it turns out during the year that it doesn't work, you won't get a construction permit*" (E-Org05, Expert wind farm permit). In a mature technology field, trust could grow based on the proven effectiveness of a noise mitigation system, which is critical for offshore projects that are characterized by high costs, technological risks, and hardly controllable weather conditions. However, in the case studied, neither the customers nor the system suppliers were able to predict the performance of the system as specified by the manager:

> *We know relatively well what a system has to do. (...) But the point is that I can't prove it mathematically. On the other hand, the provider can't prove to me mathematically that he can do it either. Of course, the moment we ask a provider whether he is contractually liable if I want him to pay me a million euros in damages, he will immediately fall to his knees. (E- Org04, Offshore engineering manager)*

As these quotes show, contractual control of noise abatement system suppliers was not a viable option. Large utilities have little confidence in system suppliers who are unable to develop solutions based on standardized engineering procedures.

When it comes to more established offshore technologies, trust usually comes from standardized engineering procedures and methods such as Computational Fluid Dynamics (CFD). Using numerical simulations, utility engineers then estimate system performance, define the technical requirements for a specific wind farm project and select a suitable system supplier, the same manager adds: "*If you are not clear about the simulation, it is not so easy to define the system parameters.*"

In the case of the noise abatement system, not only was there a lack of standardized, simulation-based engineering methods, but also a lack of basic scientific knowledge to improve the system's effectiveness. As a result, technology development has had to rely on trial-and-error learning in parallel with ongoing offshore construction, as the representative of a utility company points out:

> *What I have always valued, especially in relation to [the noise mitigation system], is that the theoretical foundations have actually not been explored. Research is being conducted, things are being done, and the same questions keep coming up, but no one takes the trouble to answer them. It's more of a trial-and-error approach. (E-Org05, Expert noise mitigation)*

These results show that in the absence of standardized, simulation-based engineering praxis and basic scientific knowledge, customers have little confidence in the effectiveness of a new technology such as a noise control system. At the same time, purchasing off-the-shelf solutions and contractually controlling system suppliers is not a viable option in the absence of technical standards. Therefore, it would be necessary to establish personal trust between the system supplier and the customer.

As a result, without trust in system suppliers, customers themselves have engaged in trial-and-error learning to improve the effectiveness of noise mitigation. That is, utilities improvised system tests during ongoing construction, "*playing*" with different system parameters and using the resulting empirical evidence to improve the systems they were using, according to representatives of two different utilities:

> *During each ramming operation, measurements were actually taken. An attempt was made to establish correlations between the introduced air, the compressor pressure, and the noise emissions. (…) We then started experimenting with this in collaboration with the researchers. For example, we made the holes narrower or wider and observed how that affected the results. (E-Org05, Expert foundation structures)*

> *The biggest challenge is that you get very variable values out there. That means it's not the case that when you make a change, it consistently results in the same noise reduction gain. (…) You really have to conduct a lot of measurements at many different locations so that, over time, it becomes clear what is actually the true effect. (E-Org05, Expert wind park permission)*

> *At the moment, I have to design my system for the worst location and then use it in the same way at all other locations. (E-Org04, Offshore engineering manager)*

It was interesting to observe that the knowledge created in the field of offshore noise mitigation was largely socially constructed, rather than the result of systematic technology development. For example, one expert points out that some licensing decisions seemed to be based on "beliefs", which in turn were based on individual recommendations: "*There were also reports from various BMUV-funded projects that contained recommendations. However, these were neither scientifically substantiated nor questioned. In [the regulatory authority], they became beliefs.*" *(E-Org-05, Expert on noise abatement).*

Similarly, the entrepreneur interviewed expressed the impression that individuals have a strong influence on approval decisions when system performance can hardly be assessed on the basis of objective technical criteria:

> *There are few decision-makers here, because there are no committees responsible for making soundproofing decisions. It could be just one person who, for example, is convinced that a particular supplier is excellent.*

In conclusion, in this case the entrepreneur did not succeed in establishing a position as a trusted system supplier in the field. This was related to the entrepreneur's inability to build trust with customers and public regulators. In more mature fields, trust generally comes from standardized, simulation-based engineering that allows customers to buy off-the-shelf technologies in markets and to contractually control their system suppliers. When technical standards are lacking, building trust based on an established engineering praxis is not a viable option. Under such conditions of high technological uncertainty, a more successful innovation strategy is to build trust based on collaborative, pragmatic trial-and-error learning. This strategy was used successfully by the competitor, but not by the entrepreneur, who worked largely autonomously. At the time of the study, however, this situation was about to change, as one expert pointed out:

> *As recently as last year, installation companies were not required to guarantee noise levels to wind farm operators. In the meantime, some have started demanding guarantees, as otherwise, financial discussions arise. Increasingly, these contractual provisions are also being passed on to noise protection manufacturers, for example, requiring a certain state of the art or a specific noise protection value to be guaranteed. (E-Org06, Scientist and consultant)*

7.4.2 Case F: Lacking customer cooperation

While in case E the entrepreneur eventually left the field, in case F the offshore engineering graduate was still looking for a customer willing to grant access to system tests under real conditions at the time of the interviews. Despite these efforts, the company had not yet managed to establish a stable position as a trusted system supplier:

> *We are looking for a wind farm operator who is capable of installing a wind turbine. (F-Org01, Senior manager)*

Normally, the senior manager (F-Org01) continues, it is common praxis in offshore engineering that the customer is also an important cooperation partner: "*The customer is actually always also a cooperation partner. They have an idea of what kind of equipment they want, and we have an idea of how to implement it*" (F-Org01, Senior Manager). Furthermore, since the technical interfaces between the various components of an offshore structure (e.g. a converter station) are clearly defined, different system suppliers merely exchange technical requirements with each other.

In this case, however, no German utility supported the innovation project. As the interviewees explained, large utilities generally prefer to externalize the technical risks associated with the engineering, procurement, commissioning and installation (EPCI) of offshore wind farms. In an ideal world, utilities therefore contractually control an entire offshore project on the basis of a single large contract – a so-called EPCI contract, as explained by the senior manager (F-Org01):

> *If you want to put it very simply, this is turnkey construction. Essentially, it's the worry-free package for a wind farm operator. Their involvement is then limited to a supervisory role. They don't have to get involved in engineering or push through any permits. They can delegate that and might pay a bit more for it, but their team is relieved of the burden.*

In contrast to German utilities, foreign wind farm planning companies such as Ørsted (formerly Dong Energy) take a different approach. According to the senior manager (F-Org01), foreign companies with a long tradition in the offshore oil and gas industry have an international customer network and rely on sophisticated technical departments. These companies are largely able to internalize the technical risks of offshore wind farm construction and develop offshore solutions in close coordination with trusted partners from industry and academia:

> *That is exactly the difference between a company like Dong Energy, which has a large team of engineers and brings its own designs to the market. They come from the oil and gas sector and are used to this approach. They are also well connected with laboratories, test facilities in Denmark, and universities. The corporate philosophy there is different. (F-Org01, Senior manager)*

In fact, the corporate communications officer of one of these foreign wind farm developers confirms that its offshore engineering expertise is deeply rooted in technical standards that are well established in the oil and gas industry: "*Offshore wind technology is so specific and specialized that you can't just copy and paste things. But when it comes to project planning, you can. (...) Certain standards have been adopted from the oil and gas industry. If you just look at the substations, they are built in a similar way.*"

These findings provide empirical evidence that the development of offshore wind technologies is moving towards the creation of technical standards controlled by a few large utilities and their exclusive innovation networks. However, at the time of the research, the offshore engineering specialist included in this study had not become part of such a network.

7.5 Interim conclusions

The findings of this chapter reinforce the author's main argument that a common innovation praxis is key to the development of innovative complex technologies. In the absence of technical standards and technology markets, as in an emerging field, the forced imposition of standards is not a viable innovation strategy. Instead, an innovating firm needs to establish a stable position as a trusted, accepted and reputable development partner.

The observed engineering firms were active in the emerging fields of offshore noise abatement and offshore wind turbine foundations. In case E, an entrepreneur invented a new noise mitigation system. In case F, an offshore engineering specialist attempted to adapt a technical standard already established in the offshore oil and gas industry to the installation of offshore wind farms. However, both companies did not establish a position as a trusted system supplier.

This chapter first described the field of offshore wind energy technologies and its main players. Second, the practices of knowledge integration observed in the two cases were analysed. Thirdly, it showed how the collaboration was organized in each case, and fourthly, it discussed the project's unintended outcomes. This section summarizes the main findings of the chapter.

Table 20: Emerging technology fields

	Case E: Noise mitigation system	**Case F: Alternative foundation procedure**
Knowledge Integration	Relying on individual creativity, inventiveness and pragmatism to combine technical knowledge from steel construction with the requirements of wind parks	Drawing on professionalized competences such as creatively and collaboratively combining technical standards, or individualizing solutions to a specific context of use
Realizing technology development	Relying on the individual ability to quickly invent a new technology (entrepreneur) vs. trust-building based on pragmatically improving offshore system tests (competitor)	Creatively combining technical standards from different industries based on a unique, professionalized offshore engineering competence
Institutional barriers	Attempt of trust-building (would require simulation-based engineering or improvised offshore system tests)	Remaining excluded from existing innovation networks as well as from the creation of technical standards (a process controlled by large utilities)

The two companies followed two different knowledge integration strategies. In Case E, the entrepreneur and newcomer to the offshore wind industry relied mainly on his individual creativity to quickly realize a new technical solution. In this case, knowledge integration took place mainly "in the mind" of the entrepreneur, who combined his technical experience gained in other industries with the technical requirements of installing offshore wind turbines, including technical principles used by a competitor.

In Case F, an offshore engineering specialist adapted a technical standard from the offshore oil and gas industry, relying on an acquired, professionalized competence to creatively combine technical standards and customize solutions to specific application contexts. In contrast to the entrepreneur, this company engaged in collaborative research to gain access to scientifically based testing procedures and facilities.

Overall, the results of this chapter only partially support the assumption that an innovation praxis operating in an emerging field of technology development is likely to adapt technical solutions from adjacent fields (P3). Such a strategy was only observed in the second case analyzed above. While the entrepreneur remained a “lone fighter", the offshore engineering specialist tried to establish an innovation praxis together with a large utility company in order to build trust in the eyes of the customer and public approval authorities. However, the company remained excluded from existing industry networks that create new technical standards for the offshore wind industry. Thus, there was a lack of innovation praxis that included large utilities.

The results showed that even in emerging fields of offshore wind energy technologies, new technologies are developed by hierarchically organized innovation networks, with utilities at the top controlling technical standards, selecting system suppliers, granting access to offshore wind farms, and thus defining membership rules. In both cases, the engineering firms studied did not become part of such an innovation network.