TITLE

Not in transition: inter-infrastructural governance and the politics of repair in the Norwegian Oil and Gas offshore industry

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Abstract

In the past three decades, there has been an increasing interest in transitions as crucial analytical moments of socio-technical change, with infrastructures being strategic loci from where to leverage these transformations. In this article, we argue for the necessity to re-engage with not-in-transition periods, which have theoretically and analytically been oversimplified. By focusing on the socio-technical practices of repair across interconnected infrastructures under not-in-transition conditions, we provide a better understanding of how these periods are (re)produced. Our in-depth case study of the Norwegian offshore oil and gas (O&G) drilling industry shows how stability can be ensured by means of *inter-infrastructural governance* carried on by specific power constellations, i.e. *action nodes*. The way they mould infrastructural components is revealed when normal operations are endangered by adverse events, such as accidents or economic crises.

Keywords: infrastructure, governance, oil and gas, power, repair, not in transition

1. Introduction

This paper brings attention back to the socio-technical dynamics at work in industries that are seemingly not in transition. Urgent quests for climate change, energy security, and energy justice solutions have magnified the analytical importance of transitional processes [1]. Studies of transitions have attributed a crucial role to infrastructures by including them in the wider socio-technical landscape that favours the sturdiness of existing technologies [2]. Effective transitions are then possible by means of heavy infrastructural changes or by designing new ones. Examples in the literature range from electric car grids to efficient buildings, sustainable food processing, and packaging [3–8]. In this respect, infrastructural governance plays a key role in enabling and disrupting industries by interleaving moments of stability with others of radical transition [5]. From a methodological perspective, recent research has shown that *infrastructural interlinks* should be taken as the unit of analysis to unpack both the challenges and the opportunities for governing socio-technical transitions instead of providing in-depth insights into individual infrastructures [9,10]. However, studies of *inter-infrastructural governance* [11] – that is, the practices of decision making at the intersection of different infrastructures – have remained within the realm of emerging or transitioning systems, thus tacitly downplaying inter-infrastructural governance during not-in-transition (or "stable" or "normal") periods.

We find this problematic and argue that the practices of repair and maintenance that are performed during not-in-transition periods still warrant further examination. In particular, we investigate and categorize different repair practices enacted by means of inter-infrastructural governance. Our analysis shows how governance and repair evolve in relation to temporal, spatial, political and organizational factors. In line with Star and Ruhleder [12][1] and subsequent works by Shove et al. [11,13], we conceive an infrastructure as a relational concept. It is an organizational and social arrangement composed of heterogeneous elements – such as standards, norms, technologies, people, and systems – "that emerges for people in practice, connected to activities and structures" ([12]: 112). Infrastructures are constantly in the making, unfolding *via* dynamic and distributed relations and adaptations enacted at their intersections [14]. Empirically, we examine the Norwegian offshore oil and gas (O&G) drilling industry and the efforts to restabilize it after (or in prevision of) adverse events. This industry is under increasing pressure because of ongoing decarbonisation pushes, but it has proved to be very resilient in time, even when endangered by major accidents and global economic crises. The O&G sector is interesting because of its profound role in energy transition pathways: the so called "carbon lock-in" has been analysed in sectors such as energy, transport, and agriculture [3,15–19].

This paper makes two contributions. First, it provides an empirical industry-wide account of *inter-infrastructural governance* aimed at industrial stability. We theoretically characterize inter-infrastructural governance as an orchestrated endeavour, and we adopt infrastructural interlinks [11] as a unit of analysis to identify the loci where this orchestration is enacted. Neither entirely bottom-up nor top-down, the governance of the O&G drilling industry emerges from the coordination and alignment of particularly powerful constellations of actors, which we name *action nodes*. By controlling multiple infrastructures at the same time, action nodes carry out the delicate repair work of restabilising the industry. With this concept we emphasize "the mobilisation of power resources operat[ing] across complex networks of power relations" [[20]: 8] (i.e. at the infrastructural interlinks).

Second, this paper provides an analysis of the politics of inter-infrastructural governance during not-in-transition periods. Governance qua repair work demonstrates that maintaining overall industry functionality (i.e. finding and extracting O&G) and its operational continuity and profitability is a political exercise largely serving the interests of few. Transition studies have already explored the role of "incumbents" in resisting [21–24] or supporting transitions [20]. Here we take a step back and study how action nodes normally carry out repair work.

2. Governance during not-in-transition periods

In this paper, we study *not-in-transition periods,* in which no revolutionary change occurs in the way the functionality of a system is fulfilled (usually expressed as a bundle of specific technologies and related practices). In studying an industry such as the one driving the drilling

[1]Star and Ruhleder [12] define infrastructure as being (1) embedded in other structures, social arrangements, and technologies; (2) transparent (and largely invisible) once established, reappearing upon breakdowns; (3) beyond a single event or location; (4) learned as a part of membership; (5) linked with conventions of practice; (6) built on and constrained by an installed base; and (7) fixed and changed in modular increments

of O&G[2], we expand this almost technical-functional definition to also include the capacity of the system to maintain its operational and economic identity in the face of changing external conditions [25,26]. Maintaining a not-in-transition period is tightly connected to the governance of those infrastructures allowing the industry activities to flow. To understand this point, we first explore the literature on infrastructures before elaborating on infrastructural governance. The study of infrastructures somehow bifurcates in two directions. One strand assumes that infrastructures evolve in a cumulative and bounded way, thus conveying stability to the industry. The propensity for this view among studies of socio-technical change has largely contributed to a lack of interest in questions related to the making and maintaining of not-in-transition periods. The other strand focuses on infrastructures as fragile and political compromises, constantly redacted and modified.

The first view of infrastructure adopts a cyclical model of infrastructure evolution [6]. Starting from technological solutions designed to satisfy targeted societal problems or to act as scaffolds for other activities, infrastructures evolve into internally coherent and heterogeneous networks [27–31]. Their obduracy emerges from the interrelations of elements, constrained and kept together by shared frameworks [32,33]. The considerable degree of infrastructures' systemness and sunk investments run counter to exceptional changes. "Infrastructures evolve through incremental changes along established paths", aimed at optimizing their efficiency ([7]: 115; see also [11,34]). Irreversibility and resistance to change seem to act beyond the control of individuals, with the exception of a few experts responsible for the infrastructures' inertial reproduction [35–39]. This approach of treating infrastructures as neutral/apolitical and at the same time as a massive and reliable presence has been explored in areas such as energy, mobility, health care and food provision [5,27,40]. Their "reassuring stability" [41] is such that "in economic development analyses [they are often treated] (…) as a constant factor for the relevant forecasting or planning period" [42: 800]. In line with this understanding, scholars such as Frantzeskaki and Loorbach [5] have studied the governance of infrastructural changes "to accelerate or direct ongoing societal transition dynamics" (p. 1294; see also [39,43,44]). However, a discussion on power and politics is rather limited in terms of who is carrying out infrastructural changes and which kind of socio-technical order is then produced [45].

From a different view, scholars such as Susan Leigh Star have challenged the apparent orderly and progressively changing appearance of infrastructures, arguing that their evolution is hardly cyclical and sequential. Rather, they are fluid, always in-the-making, intersecting among each other, and embedding the interests and agendas of different actors [12,46–48]. Talking about "infrastructuring" is then an analytical shift emphasising the work necessary to prevent unpredictable changes [49]. These practices are not meant to favour the technical over the social [38], but to combine heterogeneous elements – such as users, systems, practices, agendas, strategies, and regulations – that together fulfil certain infrastructural functions that depend on

[2] An industry is here considered as a heterogeneous socio-technical system fulfilling characterized by one or more core functionalities, and centred on selected socio-technical solutions [27, 101–103].

an actor's perspective and purpose. Here, maintenance and repair workers come to the fore as those who do not see infrastructures as invisible wholes, but as naturally fragile heterogeneous assemblages. They "are immersed in a malleable material flux" ([50]: 352), and their role is to find ways to keep infrastructural invisibility constant for those making use of it. We can somehow distinguish between two forms of infrastructure repair: one is a "mere" substitution or restoration of what got broken. The other is about generating innovative connections between the new and the old [51–55]. Following this latter view, repair activities should be seen as temporal moments and spatial sites from where to question the form and the ordering principles of infrastructures [51,56]. Undoubtedly, repair and maintenance are political: choices of whether and how to repair perpetuate existing power relations or perform new orderings [57–60]. Infrastructures emerge out of the interactions between a plurality of subjectivities, not always in line with their initial design [31,41]. This instability and openness produce "diverse and contradictory dynamics, which manifest different objectives, rhythms and patterns of circulation" ([61]: 760; see also [62,63]).

In practice, handling and harnessing the complexity of industrial dynamics – with the aim of maintaining its operational identity and profitability – is a matter of combining emergent and distributed control strategies [35]. This necessarily implies considerations over the infrastructures supporting these practices. Understanding infrastructures as relational and processual entities demands a particular attention to issues of governance (i.e. those processes through which economic, social and political authority is exercised) [64]. Infrastructural governance has been described as top-down [65], bottom-up collective action [14], or an amalgam of local practices and top-down policies [66]. It often lacks unique control points (i.e. centralized management), instead relying on a blend of top-down design and bottom-up generative mechanisms [67]. Importantly, this kind of governance cannot be limited to one infrastructure: operational practices in an industry normally rely on more than one infrastructure. Therefore, *inter-infrastructural governance* plays a key role in enabling and disrupting industries by interleaving moments of stability with others of radical transition [5,11].

In summary, studying industrial stability means to uncover infrastructural intersections and interdependencies and "conceptualise forms of 'co-evolution' (…) between co-existing and sequentially ordered forms of infrastructural arrangements with the (…) complexes of practice to which they relate and through which they are defined" ([11]: 162). In this way, it is possible to bring to the fore the politics of industrial maintenance, also operating through inter-infrastructural governance. Our in-depth case study of the Norwegian offshore drilling industry exposes *action nodes* as the actor constellations having the means to strategically disassemble and recombine infrastructural components for purposes of repair. To them, infrastructures are unpredictable and messy and, at the same time, flexible and visible [12,35,53,68]. Identifying and following these constellations help to characterize different forms of not-in-transition repair practices.

3. Case selection and methodology

3.1 The Norwegian offshore drilling industry

This paper presents a study of how the Norwegian O&G offshore drilling industry is governed. This socio-technical system that we generically call "industry" is aimed at accessing offshore underground oil reservoirs. The techniques and equipment employed offshore and onshore are somehow similar; some of the differences relate to their adaptations to more extreme conditions offshore, leading to additional costs and risks. In the offshore environment, drilling has been conventionally done by means of rotary drilling methods [69,70]. This does not mean that technological developments have not occurred. A technological leap came in the 1980s, with the design of downhole drilling motors and downhole telemetry equipment [71,72], where the drill bit is connected to the bottom of the drill string by means of a motor (instead of having the drilling rig rotating the drilling string). In the 1990s, the Norwegian continental shelf was thought to have reached a maturity stage, as the large oil fields were discovered and oil companies were left with small independent fields sometimes difficult to access ("tail production") or located in deeper waters. This on one side pushed for an overall cost reduction in operations and on the other side for the creation of faster and cheaper drilling technologies [73]. Horizontal drilling proved particularly useful (and economically efficient) to reach extensive, but not thick reservoirs. On the contrary, vertical drilling would have provided access only to a small part of the oil reservoir, thus making the well itself not profitable. Horizontal drilling allowed extending the life of existing fixed platforms, as underground cables can extend for kilometres (multi-branch wells). Among the complementary innovations that augmented the drilling success, one should mention advanced seismic surveys, improved data analysis techniques, and new subsea technologies. From a system maintenance perspective, these advancements have been crucial to guaranteeing the stability of the industry; that is, to maintain an economical and safe recovery of O&G from reservoirs.

Searching for and extracting O&G is normally defined as the upstream phase of the whole petroleum industry (followed by the midstream and downstream phases). This phase is composed of the exploration, drilling, field development and production sub phases. The main actors in the Norwegian O&G drilling value chain are the oil companies and their suppliers: licensees/operators (e.g. oil companies) have the licence to explore and drill in the Norwegian continental shelf. O&G suppliers provide vessels and installations, operations support services, drilling and well operations and equipment, exploration and underwater drilling technologies, computer-assisted reservoir modelling and data processing. In time, oil companies have become more and more dependent on a few top suppliers who own drilling (and other) technologies and related expertise. After the 2000s, the Norwegian industry has gone through an organizational transformation process, with small independent oil companies emerging, suppliers specializing in niches, and some service and technology suppliers attempting to enlarge their activities to cover a larger portion of the value chain [74,75]. Of course, in this picture we should mention other important actors, such as the government and its different branches somehow implicated in O&G activities: the Ministry of Finance, the Ministry of Fisheries and Coastal Affairs, the

Ministry of Environment, the Ministry of Petroleum and Energy together with organizations such as the Norwegian Petroleum Directorate, and the Ministry of Labour. Also, unions, industrial associations, and environmental organizations maintain considerable impact.

By placing the drilling industry at the centre of the analysis, we shift the focus away from single technologies and infrastructures. Moreover, it allows an enlargement of the geographical and temporal location of action and therefore a synthetic perspective ([76]: 330). Because infrastructures and their role for industrial maintenance are often taken for granted, we selected specific events of crises to uncover the politics of repair. From a methodological perspective, these are spatial and temporal sites that can reveal both the infrastructural fragility, as well as the social conditions and practices in which infrastructures were situated [77,78]. When it comes to the O&G drilling industry, breakdowns – such as accidents – are indeed useful entry points to question "the social nature of "normal technology" ([79]: 149). As with other kinds of shocks, they might enable "learnings and trigger critical evaluations of the existing principles" ([33]: 187–188; see also [80]). These are not the sole occasions for system maintenance: repair processes happen every day as part of conscious routines or stabilizing reactions and of unconscious acts [51,81,82]. Given the scale of our study, we have sampled two types of breakdown: 1) accidents and quasi-accidents in offshore rigs – as they deal with human and environmental safety concerns, but also with material disruptions and infrastructural changes; and 2) the 2014 oil price crisis – which shook the system's values and reframed the "rules of the game", thus influencing the repair terms and conditions.

3.2 Data sources

This paper draws on a qualitative exploratory case study [83,84] designed to obtain an in-depth understanding of the governance dynamics orchestrated to respond to the selected moments of breakdown. Case studies allow us to understand complex social dynamics of change and maintenance. Our work includes multiple perspectives that are gained by triangulating semi-structured interviews and extensive document analyses [85]. A total of 37 interviews with people from more than 30 organizations were conducted between 2016 and 2017. The interviewed organizations relate to the drilling functionality: public institutions (e.g. unions, safety organizations, ministerial departments and agencies), industrial associations, research centres, oil companies, international certification bodies, rig owners, organizations belonging to the supply chain holding different types of expertise (e.g. robotics, automation, mechanics and hydraulics, engineering, and equipment maintenance), and safety consultants.

Table 1: Summary of interviews and interviewees organizational roles

Organization	Role	Organization	Role
Firm 1 – supply chain	CEO	Firm 16 – safety consulting agency	Department Manager/Specialist adviser
Firm 2 – supply chain	CFO	Firm 17 – supply chain	General Manager
Firm 3 – supply chain	CTO	Firm 18 – supply chain	CEO
Firm 3 – supply chain	1) Vice President Corporate R&D; 2) engineer at corporate R&D; 3) engineer at corporate R&D	Firm 19 – supply chain	CEO

Firm 4 – supply chain	CEO	Firm 20 – supply chain	CTO
Firm 5 – supply chain	CEO	Industrial Association 1	Managing Director
Firm 5 – supply chain	CSO	Industrial Association 2	Project Manager
Firm 6 – supply chain	Senior researcher	Industrial Association 3	O&G director
Firm 7 – supply chain	Vice President	Industrial Association 4	Chief Advisor in the offshore safety area
Firm 8 – oil company	VP Efficiency and Rig Management	International certification body	Consultant, safety and risk assessment
Firm 8 – oil company	1) Leader Drilling and Well Solution; 2) Patent Division responsible	International certification body	Vice President and head of the O&G research unit
Firm 9 – supply chain	Vice President Operational Excellence & HSE	Labour Union	Deputy Leader
Firm 10 – rig owner	QHSSE Director	Public Institution focused on Innovation 1	Department Leader
Firm 11 – oil company	HSEQ Manager	Public Institution focused on Innovation 2	Department Director
Firm 11 – oil company	Senior Drilling and Well control	Public Institution focused on O&G	General Director
Firm 12 – oil company	Head of HSEQ	Public Institution focused on O&G technology policies	Director
Firm 13 – rig owner	Supply chain manager	Public Institution focused on O&G technology policies	Director
Firm 14 – rig owner	Managing Director and Operations Manager	Public Institution focused on safety in O&G	HSE Manager
Firm 15 – oil company	1) Procurement Manager; 2) Technical Manager		

Interview respondents were selected for their expertise and organizational positions within the O&G sector [86], as well as for their diverse set of insights on the subject. The interviews lasted on average around 60 minutes and were recorded and transcribed.

To achieve our research goals, we first conducted in-depth landscape interviews informed by documents analyses (e.g. company press reports, laws and regulations, standards, and academic books and articles). A broad interview scheme with open-ended questions was designed to encourage unanticipated stories. The data analysis was iterative and overlapped with data collection, thus allowing us to identify the emergent themes. It followed the principles of constructivist grounded theory [86,87] and systematic combining [88]. The first phase was aimed at unveiling moments of disruption in the industry, as well as attaining an understanding of how power is distributed (i.e. which entities initiated and enacted practices of industrial repair and how). Successive interview rounds aimed to (1) understand which infrastructures were disrupted or mobilized in relation to the selected events typologies, which heterogeneous elements compose them, and how they relate with each other; (2) explore which infrastructural elements were proactively changed in attempts to repair the industry and guarantee its resilience; and (3) trace which entities carried out these infrastructural changes and how these processes played out.

Crucial for our study is the definitional starting point of infrastructures as heterogeneous systems allowing industry activities to flow. Infrastructures comprise the practices carried on in the drilling O&G industry. However, it is important to understand that "there are no hard-and-fast rules about what to count as necessary background" ([13]: 158). Because of the situational specificity of this concept, we have identified important infrastructures for drilling maintenance *ex post*; that is, during the analysis of the information collected through interviews and documents (see Section 5). Indeed, defining an infrastructure is a "categorizing moment" for both the respondents and the analysts [76]. What helped us in distinguishing one infrastructure from another was the focus on (1) the infrastructures' goals or functionalities; (2) the group of agents involved; (3) the elements cited by interviewees when narrating their reactions (or those of others in the industry) to potentially endangering breakdowns (i.e. safety accidents) (section 4.1); and the 2014 oil price crisis (section 4.2). These events somehow disrupt the normal industrial practices, and they need somehow to be fixed to bring things back to "normal". The elements standing in an "infrastructural" relation [11] with the drilling industry practices are not only physical components – such as oil pipes, drilling rigs, sensors, and electrical cables – but also organizations, individuals, regulations, and so forth. Once again, infrastructures are heterogeneous in nature.

As will be discussed more thoroughly in Section 5, the infrastructures that emerged as having an important role in matters of drilling industry repair are as follows: a) The safety infrastructure - which involves all the calculations and surveillance issues related to it - is one of the socio-technical dimensions upon which the drilling industry is meant to progress (see the notion of technical code in [89]). This includes the practices of technological risk assessment but also the development of organizational routines and procedures to produce safety. b) The infrastructure for developing knowledge and manufacturing technologies and services. c) The R&D funding infrastructure (private and public). d) The infrastructure related to the making of formal laws and standards. These latter infrastructures, for the sake of clarity, can consist of legislative texts, threshold measures, research institutions, industry experts, surveilling agencies, courts, governments, industrial associations, and labour unions. To study repair and maintenance dynamics as acts of inter-infrastructural governance, we identified those elements belonging to more than one infrastructure [5,11,43,90], as well as those entities carrying on such acts. Also, we studied repair practices and strategies by referring to the following dimensions: temporal (i.e. which transformations are deemed workable with the aim of maintaining the industry in the future), spatial (i.e. where repair practices do happen at a localized or industry-wide level), political (i.e. who is allowed to carry on repair processes), and organizational (i.e. which organizing strategies are activated during repair). In this regard, during the empirical analyses, the concept of *action node* emerged as an important analytical category to capture the dynamic nature of not-in-transition periods.

4. Case analysis: maintaining the Norwegian drilling industry

In the following two subsections, we present our empirical findings rearranged to reconstruct inter-infrastructural repair dynamics in the O&G drilling industry. Section 4.1 offers an explanation about how "safety" is constructed and maintained and which kinds of measures are employed when it is in danger or it has been violated. Section 4.2 is about some of the endeavours carried out to save the industry from the economic crisis of 2014. We will show how not-in-transition periods are always periods of maintenance and change, obtained by means of inter-infrastructural governance in the hands of a few actor constellations. Infrastructures are fundamentally "open" and connected to other infrastructures.

4.1 Inter-infrastructural governance to ensure safety

From our analyses, safety emerged as a central social and technical value characterizing the offshore drilling industry governance. A rig is considered a dangerous place to work: not only is it physically difficult to reach if something irrupts, but the consequences of an incident might be catastrophic from a human, environmental, and capital-loss perspective. Containing an accident in the middle of the sea is far from easy [91]; therefore, operating "safely" is a conditio sine qua non to be part of the O&G industry. While it is certainly true that those organizations deemed responsible for an accident might risk exclusion from the industry or considerable reputational damage, it is generally believed that big accidents typically constitute a loss for the whole industry. According to our respondents, our (Global North) society is sensitive to the O&G industry such that even small operational errors catch the media's attention. Aware of this, actors such as oil companies, industrial associations, and dedicated regulatory bodies have taken on roles of building, surveilling, and repairing safety. This includes laws and standards, supervisors and third-party certifiers, criteria and models for discriminating what is safe, risk-assessment calculations, and technological safety barriers.

When it comes to the making of safety regulations, it is important to note that while National Framework rules and standards de facto materialize definitions and accumulated knowledge to avoid accidents, they are intrinsically unable to forecast event typologies that have never happened before. Therefore, they are consistently revised after severe incidents. This awareness about what regulations can and cannot be actually emerged after the Alexander L. Kjelland (1980) and the Ekofisk Bravo (1977) disasters. These events pushed for goal and risk-based regulations in spite of prescriptive and scattered ones (see for example the Petroleum Activities Act of 1985). Under this new paradigm, operators could choose which technical, operational, and organizational solutions to employ to carry on their activities in a safe manner, provided they are also economically efficient. The role of the government and its agencies (e.g. the Petroleum Safety Authority – PSA) became one of surveilling to ensure compliance to regulations, while the operator had to document that the chosen systems delivered prudent and safe operations [92].

The Norwegian formal legislative texts (Regulatory Framework and Guidelines) are modified under the aegis of a tripartite collaboration among unions, the government, and industrial associations. This is meant to engage all parties in issues concerning the petroleum industry, especially those about health, safety, and the environment (forum established in 1986). During regulatory fora, actors' stakes and principles are revealed. At the time of the interviews – to exemplify the process of regulatory and technological questioning in the aftermath of an accident – the "air gap" and "lifeboats" disputes spiced up the discussion among different actors in the drilling industry. The former case relates to an extraordinary high wave hitting a drilling offshore rig in the North Sea and killing an employee. The accident highlighted a possible flaw in the definition of what is an "acceptable air gap between the rig's lowest part and the ocean". The discussion that followed among authorities, technology experts, unions, and industrial associations aimed to settle compensating measures and decide whether they should affect already running or pre-approved rigs. The latter controversy, instead, emerged during maintenance test procedures carried out on an offshore rig's lifeboats. These tests consist of dropping boats loaded with sand bags from the rig as an approximation for escaping personnel. The test showed that most of the people would have died, as the boats were heavily damaged. This led to a debate between the PSA and the unions, against industrial associations. While the former wanted all rigs to substitute lifeboats with new ones, the latter claimed that this would cost the industry a considerable amount of money – challenging the financial sustainability, especially of those offshore platforms at the end of their production activities. Eventually, the controversy was settled with the PSA instructing the industry not to follow up with any change.

Because they are considered by Norwegian authorities to be ultimately responsible for accidents, oil companies have developed manifold strategies to protect themselves against judgements, including suppliers' pre-qualification criteria, routines and programmes to ensure that those working for them will behave according to their safety requirements, procedures to share knowledge between crews when changing shifts, barriers to technological adoption that include severe risks assessment tests, and employee training. These safety systems take on peculiar features for each oil company and concern both the relations between clients and suppliers and the development and selection of technologies and workers to be employed on rigs.

To be able to deliver to an oil company, you have to be pre-approved. Achilles is a database with approved companies according to safety and economic results. The NORSOK standard has a dedicated standard for this. Both are setting criteria for contracts; for example, you have to measure the last time incident or the medical treatments (cit. industrial association).

As one of the biggest risks in the drilling business is to have a blowout during operations, oil companies and rig owners tend to avoid introducing technologies that might lead to a "well-control situation". This has been one of the underlying problems of the Gullfaks C (2010) oil platform in the North Sea, in which the managed pressure drilling was used even though there was a lack of competence, risk assessment, and monitoring of the technology [93]. Arguably, this is one of the ways these organizations influence the *technological infrastructure* that allows reaching the O&G reservoirs. As an interviewee declared:

You should not complicate the business" (...); the worst-case scenario for any oil company is to end up with a Macondo disaster (cit. oil company).

Technological adoption is conditional to the demonstration of absence of risk (or them being as small as possible). Therefore, technology research and development programs can last for decades: the technology needs to be prototyped, tested in laboratories, and then used in wells having different risk levels. Various technology experts are involved in this process. The need for protection from accidents produces a continuous design of measures and models certifying technological safety, along with the emergence of organizations developing and monitoring them, such as safety certification bodies, private or public labs, research centres, and universities. This safety *infrastructure* can actually be perceived as a barrier to technological adoption because the whole endeavour is expensive and often necessitates the innovating company to partner with organizations backing the financial side, such as oil companies or rig owners.

We have to depend on renting some testing facilities, which are run by marketing. If you want to do a test program, you need a lot of empirical data to verify your models and this means that you have to maybe test for half a year. That will cost you enormously (cit. technology supplier).

Oil companies' and rig operators' resistance towards technological adoption also relates to the pursuit of operations efficiency. In connection to this, some interviewed suppliers discussed their failures in introducing technologies that purely tackle workers' or environmental safety. Another option for introducing a new technology would be to modify laws and regulations in such a way that they would nudge the companies towards certain socio-technical transformations (e.g. the introduction of mechanized and automated systems); however, changing regulations is not a straightforward process.

Summing up, safety is continuously produced through a complex network of heterogeneous entities. While this is quite a dispersed system, some entities have greater control over their governance. We point specifically to oil companies, the government, unions, industrial associations, big manufacturers, and rig owners. The goal of maintaining a safe industry affects not only relationships among organizations but also technological development and selection. Drilling technologies are hence co-produced by several agents, resulting from feedback loops of development, assessment, and testing.

4.2 Inter-infrastructural governance when dealing with an economic crisis

Before 2014, the Norwegian O&G industry was referred to by our informants as capacity driven. The aim was to drill as many wells as possible, and every drilling rig and drill ship was in operation. Because the most important thing was to start drilling, oil companies asked suppliers to deliver, in time, safe and working technologies, even if they were not the best ones. The income was generally good for everyone, but especially for those suppliers that started providing complete drilling packages at higher prices.

[These manufacturers] gained a big market power; they could dictate prices for upgrades, maintenance services, and after-sales activities. They also stopped smaller companies to modify technologies because they had to be integrated into their control systems (cit. technology supplier).

Not only was buying all-in solutions more practical for oil companies, but the fact that they were standardized also meant that they were "safety proven", as they had already been applied several times to drilling rigs.

In June 2014, the nominal Brent price of crude oil began to fall, from $112 to $62 in December. The price continued to fall in the following years, reaching a low of $31 in January 2016. This event came in conjunction with the negative cash flows oil companies were already experiencing. Their immediate reactions were, on one side, to decrease or stop investments in new explorations and drilling operations. On the other side, they focused on cost reductions by decreasing the number of employees or by forcing suppliers to lower their prices. There is no denying that an oil company is driven by their income, as represented by O&G prices. If the income lowers, the willingness to spend money in the future is widely affected, and this cascades through the whole value chain. As the oil price had not recovered after some months, the industry started reflecting on how to continue operating and gaining, given the new price level. In particular, the cost structure came under scrutiny.

They [oil companies] have to reduce costs in a sustainable way. Not just by decreasing the costs per contract, but (...) anything reducing the overall costs or improving the operations efficiency (cit. technology supplier).

Indeed, drilling operations are a major cost source, and during this phase, the extraction of O&G is not taking place, and therefore the companies have no revenue. One important target in terms of increasing drilling efficiency was the reduction of so-called non-productive time (NPT). NPT is calculated in terms of daily rig rental (more than 400.000USD before the 2014 crisis), and therefore operations efficiency was translated into "*how long does it take to drill a 'perfect well'*". Practically, this meant avoiding delays caused by equipment breakage, inaccurate geological forecasts, and adverse weather conditions, but it also meant ameliorating planning by reducing the discrepancy between a well construction plan and its actual realization and so forth. From a technological perspective, this efficiency focus triggered by the crisis opened up oil companies and drilling operators to an increased amount of novel solutions, especially coming from companies different from those previously delivering complete drilling packages. The power that these few firms derived from the materiality of relationships with their clients (i.e. through the provision of long-lived standard technologies) was partially redistributed. This has changed not only the client/supplier relationships but also the criteria used to select "interesting technologies".

Oil companies are struggling with becoming more cost-efficient, so they are saying to their suppliers: 'We are willing to abandon all our company requirements; tell us how you can provide solutions that are more efficient'. It is a completely new way of thinking: [it is about] asking for (...) different solutions (cit. public organization).

This quote illustrates a decreasing focus on formal workflows and bureaucracy, in exchange for technical solutions that might help in recovering the new cost problem. Not only did the restructuration of the industry concern future directions and scenarios, but existing technologies were questioned when it came to their "optimality" and "efficiency".

[Oil companies and drilling operators] have to start looking into: 'is it possible to do this operation with more customized equipment?' In the last 15 years, the development has not been big because everyone was interested in buying standard setups (cit. technology supplier).

Notwithstanding an apparent opening to solutions that might repair the industry from the incumbent crisis, oil companies and drilling contractors still imposed their own way of reorganizing the industry.

We are extremely focused on drilling performance (...).Unless suppliers are driving technologies into a direction where it is 'competitive' and sustainable in terms of having a business case to it, then their products are not being requested (cit. oil company).

Also, the governance of infrastructures related to drilling operations has changed, even though power imbalances persisted in favour of oil companies and drilling operators. These have enforced a new management culture throughout the whole supply chain by means of cost-cutting programs at all levels, centred on goals to be reached. However, these new governance measures have increased pressure and delegated more responsibility to the operating personnel, while affecting the balance between pursuing efficiency through lowering costs and preserving safety. For example, when deciding on whether to stop a machine if a safety threat is perceived, a driller would face a rather controversial situation:

You are damned if you do it, damned if you don't. If you don't stop, you can have a serious accident; if you stop, you can get in trouble [with your clients, because of the financial loss caused by the increased NPT] (cit. union representative).

Also, middle managers experienced higher pressure related to budget goals:

That will lead to the avoidance of necessary investments; for example, they will not do (...), competence training, maintenance, redesigning, rebuilding, improving (cit. union representative).

The whole heterogeneous infrastructure meant to provide safety, including normative questions of what safety actually is, has de facto been unevenly reopened, causing controversies and debates on how this value should be concretized into standards, rules, and devices.

This subsection has extensively showed that a few actor constellations were particularly influential in paving the way for the restructuring of the industry during and in the aftermath of the 2014 oil economic crisis. Their necessities in terms of saving money, while pressured by society to keep safety records, cascaded differently throughout the whole supply chain. This led to innovation openings, forging new alliances and network constellations, and reframing the socio-technical criteria normally employed to select technologies.

5. Inter-infrastructural governance in not-in-transition periods

To elaborate further on inter-infrastructural governance, we first single out some of the infrastructural repair actions as emerging from the empirical case. Next, we propose the concept of "action node" to highlight the role of certain actor constellations in manipulating infrastructural interlinks to maintain the industry in a not-in-transition period (section 5.1). Finally, we discuss some characteristics of repair practices, emphasizing the politics of repair, thereby exploring the implications of our findings for the understanding of industrial stability (section 5.2).

Table 2 summarizes the infrastructural repair practices influenced by different actor constellations to maintain both the general industry functionality and their own influence. As previously mentioned, the identified infrastructures emerged out of the interviews and the document analyses and should be considered as belonging to the "system of substrates" [94] allowing the normal flows of industrial activities. Other infrastructures not mentioned are simply not activated for the purpose of contingent maintenance (i.e. in relation to the empirical examples). Indeed, we are aware of the limitations of our methodological approach (see also Section 3.2): each respondent is situated in a complex web of interrelated entities and understands "infrastructures" from his/her own perspective. However, what is important for our study is to analyse how repair dynamics are carried out in such an industry and by whom. Following are the infrastructures worth mentioning. First is the infrastructure that produces formal definitions of "safety" in the form of national rules and regulations (aka. formal *rules and regulations infrastructure*). This is composed of regulatory texts and rectifications, standards, industry experts, courts, related government branches and agencies (e.g. the Norwegian Petroleum Directorate), industrial associations, unions, regulatory fora, and accidents or near-accidents reports. Second is the infrastructure related to the calculation and surveillance of safety (aka. *safety assessment and surveillance infrastructure*): testing labs, statistical models, prototypes, technological risk assessments, consultants, expert groups, testing facilities, supervising roles, specific testing technologies, safety certificates, firms' management systems, pre-approval certificates, firms' competence systems, safety procedures and routines, safety cards, accidents or near-accidents reports, safety tests, and so on. Third is the infrastructure providing funding to target petroleum-related technologies (aka. *R&D funding infrastructure*), including private equity, the Norwegian Research Council and the OG21 R&D public programme, experts' groups deciding on the industry future goals, business cases and other documents to prove the worthiness of a technology, and project evaluations. The final infrastructure consists of the technologies and services allowing drilling to happen, including the production of related knowledge (aka. *technologies/services infrastructure)*. This includes manufacturing and service contracts defining reciprocal roles and expectations on deliveries, the management systems controlling drilling planning and operations, research projects, the delivery of spare parts, the transport of people in and out of rigs, exploration activities before drilling, and drilling licence processes.

As we can see from *Table 2*, the big industry players could manage repair and maintenance actions during the economic downturn without much government influence. Instead, in relation to safety and accidents, we see more of a negotiated maintenance scheme among powerful actors, including the government. Notice how, in this latter case, most of the manufacturing industry actors (besides – at times – selected big manufacturers) were not included in governing these processes. However, the changes provided new opportunities and restrictions and changed the roles of these actors.

Table 2: Reactions to the crises and the affected infrastructures

	Repair practices	affected infrastructures	actor constellations
to oil price crisis	• reduce R&D investments to save on costs related to risks (safety, NPT, sunk investments)	• R&D funding infrastructure (public and private)	• oil companies
	• reformulate safety and efficiency values	• safety assessment and surveillance infrastructure	• oil companies • rig owners
	• decrease in bureaucracy and routines when it comes to invest in interesting technologies • openness towards technologies that might save costs and increase efficiency • reduce NPT-related costs: push for drilling operations efficiency (faster, cheaper, more precise) • new management systems and routines to enforce new values • push for reduction in suppliers contracts' costs • change in contracts' nature: from artefacts to service deliveries, to reduce risks and responsibilities • personnel cut • agglomerations with other firms to deliver technologies, easing the access to testing and funding infrastructures	• technologies/services infrastructure	• oil companies • rig owners • big manufacturers
to safety accidents	• influence public funding direction for research • investment in technologies thought as vital for safety	• R&D funding infrastructure (public and private)	• oil companies • rig owners • government • (big manufacturers)
	• reformulate safety values • change in procedures for safety surveillance • change in framework regulations • discuss the implementation of safety laws changes	• safety assessment and surveillance infrastructure • formal rules and regulations infrastructure	• oil companies • rig owners • government • (big manufacturers)
	• change in how technologies are selected	• safety assessment and surveillance infrastructure	• oil companies • rig owners • (government)
	• resistance towards new technologies • push for new “safety” technologies • contracts breakage with suppliers and rig owners • change in how suppliers are selected	• technologies/services infrastructure	• oil companies • rig owners • (big manufacturers) • (government) • (small suppliers)

5.1 Towards a definition of action nodes

The empirical analysis shows that the identified infrastructures are woven together in mutually dependent ways [12,95,96]. In fact, several elements are common to more than one infrastructure, sometimes contemporarily fulfilling different functionalities. It is also clear that a few actor constellations can manipulate infrastructural elements to induce changes that allow the industrial activities to keep on flowing. For example, a relaxation or tightening of the rules employed to select technologies, which might come from a reframing of the efficiency/safety tradeoff. This is rarely possible by one actor alone, but we see patterns of mutually reinforcing actions among some privileged actors – in our case consisting of oil companies, rig owners, government bodies, and a small number of big manufacturers. In other words, in the drilling O&G industry, major transformations are tentatively designed and enforced by a handful of recurring and influencing entities, acting in concert with one another when perceiving a potential harm to themselves and the whole industry, such as when framework regulations or the direction of public R&D funding are modified. We name these powerful constellations *action nodes* because they proactively orchestrate governance at the infrastructural intersections, by connecting, disconnecting, transforming, and reconnecting infrastructural elements. Action nodes approach infrastructures as modifiable networks: to them, infrastructures are neither boring backgrounds, nor invisible [41,48]. Even material obdurate infrastructures and their components can bend to their will – whether those that will be constructed in the future or the existing ones – by means of retroactive decisions. These acts of governance are possible because certain actors participate in those exclusive spaces where infrastructures and their elements are negotiated and (re-)defined. Examples of these spaces are testing labs where technologies are assessed and meetings where national regulations or directions for R&D public funding are designed. Indeed, these spaces are not open to everyone, and this power structure is reiterated through inter-infrastructural governance acts themselves. When perceiving potential damage, action nodes would try to modify and/or substitute infrastructural elements to compensate for breakdowns – thus temporarily repairing the operational and financial flows of the overall industry. Inter-infrastructural governance pro-stability emerges as a proactively initiated cascade of changes, as opposed to a static and predefined decision-making flow. Nevertheless, single organizations cannot dictate the industry continuity alone: most decisions have to be compromised with what is already there in terms of relations, technologies, regulations, stakes, and with how other entities are reacting to the same events. Governance aimed at repair varies in terms of who is granted the permission to act, what actions are allowed, and how elements can be reassociated when previous connections break. In our case study, we highlighted both some rather top-down changes and others having a more collective scent.

In summary, inter-infrastructural governance and its cascades of consequences are inherently indeterminate, as infrastructures are always in flux and their qualities emergent. Governance is a continuous work of repair *at* and *across* intersections. Putting emphasis on infrastructural governance qua repair practices helps in understanding how power is distributed in terms of who activates cascades of changes. In the next section, we identify and discuss the repair dynamics that emerged from our case analysis.

5.2 The characteristics of inter-infrastructural repair

Our interviews and document analyses allowed us to characterize repair practices and strategies in the drilling industry along four dimensions: temporal, spatial, political, and organizational.

First, temporal concerns emerged between workable compromises in the now and maintaining future agency. When serious accidents happen, a few action nodes are the first to take on the responsibility to analyse the chain of failures or identify loopholes in the rules and surveillance infrastructures. In such processes, repair-oriented governance is a product of compromises between each organization's own stakes and the socio-material constraints of existing infrastructures. In other words, the involved actors imagine viable future transformations that can preserve the industry while maintaining and ameliorating – if possible – their personal influence on it. Ameliorating means reinforcing existing relationships or building new ones but also changing or tweaking the existing elements if they become inconsistent with the actors' strategies. For example, oil companies and rig owners might have to invest a great amount of money to change rig components (as shown in the "lifeboat" and "air gap" examples) or train workers on how to use a newly adopted technology. Inter-infrastructural governance to preserve industry functionality against the occurrence of similar events in the future might require the re-questioning of previously black-boxed entities. Action nodes try to disassemble and reassemble infrastructural elements to their own advantage, guided by their need to grant themselves the right to also change infrastructures in the future.

Second, the spatial dimension of repair practices concerns the handling of situated local action versus industry-wide cascades. In principle, repair dynamics tend to be localized, as the fixes do not typically involve the whole industry: only some elements are singled out and modified to allow ordinary industrial activities to flow again. However, which elements will be selected is not predictable a priori: it depends on which actor constellations are involved, their interests, which solutions are picked as viable, and which capacity they have – together and singularly – to practically modify infrastructural elements. To understand an exemplified cascade repair dynamic, we can employ again the example of a serious accident. This might cause a change in safety definitions (Section 5.1), thus modifying laws and standards, risk assessment models and the way technologies are assessed, organizational routines, and so on. In practice, a legislative modification first affects oil companies (and rig owners), as they are the main entities responsible for O&G operations. Yet, the way they will solve the tradeoff between legislative amendments – which might oblige them to implement "less efficient" and more expensive solutions – and their own financial and operational sustainability is locally achieved and will produce different solutions. As previously recalled (Section 4), the Norwegian legislative framework is performance based, and the government cannot impose a unique way of fixing a problem. It can only advise on what has to be achieved. Policies and practices, lengthily theorized as shared and stable infrastructures for a not-in-transition industry, are indeed quite negotiable and malleable.

Third, repair practices exhibit a political dimension. To compensate for the unscripted displacement that endangers their previously achieved positions in the industry, action nodes leverage on imbalances [80,97] conveyed and replicated through existing infrastructures. Intersecting infrastructures allow the practices of repair and the existing social arrangements so that "past and present infrastructural intersections condition future conjunctions" [[11]:162]. Indeed, maintenance and repair of not-in-transition periods are political acts [55,58,98]. In the case of the oil price crisis (Section 4.2), the acts of repair governance started with oil companies redefining the efficiency tradeoff to preserve their own financial sustainability. Before the crisis, efficiency meant fast deliveries, technological modularization, and manufacturing capacity; after the crisis, the attention switched to cost cuts. This redefinition flowed over to other infrastructures, and it led to new technological and operational solutions that can enhance drilling speed and precision (e.g. use of sensors and other downhole instruments to transmit information to the operators, providing the position and inclination of the drilling bit).

Fourth and closely related to the above-mentioned politics, the studied events triggered different organizing strategies, from centralizing control to decentralizing agency to participate in repair work. If no repair actions had been carried out, the whole drilling system might have dissolved, either because of hard societal judgments on environmental and employees' health concerns (safety case) or because of a systemic financial and operational breakdown (oil price crisis case).[3] While from the outside it might seem that the industry is intact and predictably progressing, a closer look reveals continuous and widespread changes and struggles. Action nodes do not have absolute freedom in their work of maintaining or transforming the industry. We therefore distinguish between two organizational types of repair dynamics. Whereas the strategy to centralize control among a few privileged action nodes led to *conservative* measures, the strategy to decentralize agency allowed a wider set of firms to engage in *distributed* actions. In the safety case, action nodes worked to keep centralized control by carrying out conservative reparative measures (e.g. reinterpreting this social value for the whole industry). The empirics show that other systems' entities remained somewhat silent (even if "formally" represented by industrial associations and unions), while the wheel of repair is obdurately kept in the hands of a fistful of action nodes. Indeed, in this industry there seem to be few spaces where suppliers can directly express their own safety definitions (e.g. sometimes participating in discussion fora where regulations are defined or being invited as experts to assess new technologies). Moreover, their possibility of exercising control over infrastructures is limited. From their perspective, existing infrastructures are (and remain, after repair) barriers discouraging actions – if not completely blocking them. In the oil price crisis case, reparative measures were more distributed, involving more actors. Oil companies and rig owners called for collective remedies,

[3] Still, it must be noticed that these repair actions are the product of entities' events interpretations, which does not mean that those events would have brought to the system's collapse at all.

and more suppliers were somehow empowered to take action. In the new scenario, some barriers to the industry repair were unlocked by the powerful action nodes, prompting a decentralization of responsibilities and opening up to alternative solutions. This solicitation was indeed full of limitations, as the proposed fixes must be coherent with the new efficiency value(s) defined by oil companies and rig operators. The search for "renewed" drilling efficiency led to the dissolution of some power balances made durable thanks to the existing infrastructures. Prior to the crisis, a few manufacturing organizations were entitled to provide standard drilling technologies and services – thus requiring others to interface with them when introducing new components – or to undergo their package prices. These organizations acted as partial barriers to the re-questioning of the technologies and services infrastructure. However, the oil price crisis gave the possibility of questioning these technologies' rationales to previously silenced agents.

Overall, our case study highlights the multifaceted nature of repair practices and strategies in the drilling O&G industry. Governance aimed at stability can be of the first or second order. *First-order repair* quickly fixes infrastructure disruptions, for example by making identical/similar technological substitutions, organizational routine revisions, and supplier changes in the delivery of a service/technology. These actions happen at a local level, not necessarily involving the most powerful action nodes. In some ways, they could be associated with ordinary maintenance. *Second-order repair* is triggered by the breakdown of critical infrastructural elements. This calls for the involvement of major action nodes, which might have diverging ways of understanding repair, tightly related to their own stakes. Second-order repair dynamics might take a long time to unfold as they might require the development of completely new solutions and technological changes, including transformations in the market and institutional conditions (e.g. new regulations, new standards), in the business networks (e.g. a different way of dealing with suppliers, different requirements and changes in supplier hierarchies), and in the socio-technical codes upon which the industry is rooted (safety, efficiency). Concerning this latter point, interesting differences emerged from the analyses in the use of centralized and *conservative* measures on the one hand or more *distributed* reparative measures on the other. Changes in the definition of safety resembled a conservative act of maintenance where the main action nodes took the responsibility for redefining what is safe. Changes in efficiency led to a more creative strategy in that major action nodes enlarged this responsibility to include others (while still maintaining control of certain parameters). This distinction does not refer to the characteristics of the solution in terms of innovativeness, but to the actors allowed to have a say. These changes would then open up new controversies, such as whether to introduce new technological components, break existing contracts or change their terms, and modify surveillance procedures and accounting systems. Indeed, while Little [43] argued that interdependence is a potential cause of failure, what we argue here is that it can also be a source of stability.

6. Concluding remarks

This study sought to uncover the socio-technical nature of repair dynamics in a not-in-transition industry and the role of action nodes in leveraging inter-infrastructural governance to maintain stability. In particular, we studied how certain actor constellations dealt with threatening breakdowns and maintained themselves in power by undoing their destroying or deviating effects. Different values, practices, regulations, and technologies are interwoven and added over time. The maintenance of such settlements requires the continuous work of repair, inevitably leading to innovation and change. Infrastructures appear to be fragile and manipulable in the careful (powerful) hands of a few mutually related actor constellations – that is, action nodes. From the outside, including from the perspectives of less powerful industry actors (such as smaller companies, single workers, and safety activists), these dynamics are experienced as conservative, rigid, and sometimes oppressive regimes.

Digging more into not-in-transition periods should not be taken as a pure theoretical exercise, but – as we have done in the case of the offshore O&G drilling industry – as a way to deepen our understanding of the existing systems we are acting in, whether with the goal of ameliorating them or not. The boundary conditions [99] of this study are empirical, as we primarily drew on a study in the O&G sector. However, we believe that our findings are applicable to several industrial settings characterized by heavy investments in interdependent resources, transnational operations, and where the control is to a large extent distributed across several action nodes, with powers stemming from partial control over multiple infrastructures and their interlinks.

The findings can be summarized as follows. First, infrastructures and their components are both tools for repair practices and the consequences of orchestrated governance (*infrastructuring* as emerging from repairing practices). The O&G drilling industry comprises several interlocking infrastructures. Steered by their perception of potential harm, action nodes partially modify infrastructural elements to arrive at new stabilities in the way the industry functionality is fulfilled. While at an analytical distance these actions might be perceived as mere system reproduction, they are in fact highly political repair practices, which can be characterized along temporal, spatial, political, and organizational dimensions. These dynamics might concern few entities and have quite localized consequences (first-order repair) or require more complex and controversial adjustments (second-order repair). When pursuing repair, action nodes may create or destroy the connections among infrastructural elements and thus activate cascades of changes. While never completely in power of such unfolding dynamics, these actors have enough room for action to frame their design by leveraging on infrastructures. Whilst complex and interlocking systems have been described as potential causes of failure [43,90,100], here the interconnections between different infrastructures actually grant the system repair. Inter-infrastructural governance brings stability through *conservative* and *distributed* repair dynamics, which inevitably change the infrastructures and the industry itself.

Second, infrastructures are both visible and invisible. Infrastructures have been defined as an invisible background for other kinds of work. Visibility emerges when a sudden absence occurs or when its natural decadence asks for maintenance [12,31,46,51,52]. In this paper, infrastructures emerged as partially malleable and not invisible to certain actors: their re-surfacing, re-exposure, modification, and subsequent "silencing" do not happen only at breakdown but can also be consciously performed during maintenance activities. The reopening of the infrastructural elements' interpretative flexibilities reflects the existing power dynamics and the ability of certain actor constellations to enforce changes coherent with their own and collective strategies. From the action nodes' perspective, infrastructures are more often visible, manipulable, and unstable: they hold the "keys" for the infrastructures' transformation. Infrastructures represent the action nodes' possibility of granting themselves a future – tools for enforcing their ways of understanding and ordering the industry. These actor constellations disassemble and reframe some infrastructural components according to their own interests and logics of repair. This is not happening just during extraordinary events: infrastructures can be proactively un-black-boxed by action nodes at any time.

Finally, we have shown that being aware of infrastructures is not an exclusive privilege of action nodes. Entities silenced by uneven controversy closures over an infrastructure's form and functionality perceive them as a constant barrier to action (therefore, they are indeed visible). These tensions might be ordinarily and individually dealt with through strategies and practices that have a local impact most of the time: continuous micro repair and tweaking activities help constructing stability within an industry. However, tensions might occasionally be released for the whole industry at once, for example when events such as the oil price crisis affect the system. Cases like this lead to distributed repair activities as opposed to safety accidents, leading to conservative and unilateral transformations. In both, dominant nodes may persist and impose their strategies differently from what would happen in the case of a system transition where different ordering logics and action nodes emerge.

Methodologically, focusing on manifold infrastructures has been a key approach to understanding the extent to which they are used to sustain, ameliorate, or damage each entity's role, while at the same time restabilizing the industry after potentially destructive events. Infrastructures can tell us something about governance practices, not only about their consequences on society but also more about how and why they are conceptualized in a certain way and to what extent their conceptualization is invisible to most actors. Further research is needed to reveal the dynamics of inter-infrastructural governance or by what means action nodes are producing and maintaining infrastructures. From our study, three ingredients seem important: the heterogeneity of infrastructural elements, the techniques and positions for oversight and monitoring, and the power relations emerging from overlapping infrastructures and alliances, which allow the actors to enact biased repair practices. Analysing and understanding where these action nodes are located and how maintenance is produced in practice call for more democratic interventions that can reveal the capacities to act and how actions affect the continuous remaking and stabilizing of the system.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.