Chapter 9: Infrastructure systems – A determining factor in society-nature relations

Overview

In this chapter, you will find out about how infrastructure systems are created and how they shape society-nature relations in the long term. You will learn about their central characteristics which make them highly resistant to change. We will demonstrate how attempts to reshape our systems of mobility, food or energy supply bring about conflicts, are based on visions of desirable futures, and must contend with path dependencies.

Infrastructures are supply systems, social institutions and technical facilities that are intended for collective use and, as socio-technical foundations, predetermine the social, economic and ecological living conditions in a spatially specific manner. Infrastructure systems consist of (material) technical networks such as roads, railways and waterways, electricity lines, and supply and disposal facilities, as well as (immaterial) social institutions such as educational, health and other welfare institutions, as well as an institutionalised, politically negotiated operational organisation with a high level of legal regulation and a special financial framework (e.g., taxes or levies that are incurred independently of usage fees). As the foundation of modern welfare states, infrastructure systems also encompass norms and standards that influence their patterns of development (keyword: path dependencies) as well as place-specific "utilisation knowledge", for example about what can be expected from the healthcare system and how to behave on public transport. They are often summarised by the term "*public services*". Without their existence and the socio-technical conditions they provide, individual households could hardly survive, nor would private sector activities be competitive or modern societies be able to function politically: Infrastructures enable the functioning of modern societies. Tangible material infrastructure systems contain economic capital, many years of investment, technical devices and expertise, industry standards, and a multitude of material resources. The intangible components include institutions and services, as well as the legal, technical and political knowledge required to operate and maintain them. With their high capital requirements and long service life, infrastructures outlast political and technological change, are unquestionably assumed to be a public good for all kinds of activities, and yet are constantly being remodelled and expanded. They are omnipresent yet mostly invisible, collective yet not free of charge. Infrastructure policy is typically legitimised by the creation of modern living conditions (Edwards 2003) and social justice. Since the 1990s, ecological issues relating to the unsustainable external effects of infrastructure development have also become increasingly important. Until that point, infrastructure development had been viewed as an economic growth policy. It is becoming increasingly clear that infrastructure conditions must be viewed as a key factor in terms of climate impact and the specification of ecological material flows (Monstadt 2009).

Infrastructure systems are significant, not only ecologically, but also because they are spatially and temporally expansive and extend across multiple sectors. Despite this, they were not addressed in environmental sociology for a long time. The question of why modern societies jeopardise their environment and transform it in ways that threaten their existence has tended to focus on people's lack of environmental awareness or knowledge, or on incorrect individual behaviour, counterproductive incentive systems and cultural orientations that stand in the way of sustainable behaviour (→ chap. 4 on environmental attitudes and action, and chap. 7 on sustainable consumption). Reference is also made to the compartmentalised internal rationalities of societies that are functionally highly differentiated, follow imperialist traditions, and are characterised by capitalist growth imperatives (Brand & Wissen 2018). The technologies and system complexes perceived as particularly problematic, such as those involved in food and energy supply or transport, are the focus of many studies due to their direct and indirect environmental impacts. However, the fundamental role played by long-lasting infrastructure systems as both an expression of society-nature relations and a determining factor of those relations and the practices they enable has not been systematically analysed for a long time. This requires greater sociological attention, particularly in view of the politically initiated "transitions" in the energy, mobility, and agricultural sectors.

Against this background, we will first discuss the characteristic features of infrastructures. We will subsequently present the challenges of redesigning infrastructures in the context of socio-ecological transformation processes and then look at the social conflicts that the redesigning of infrastructures entails.

1. Characteristics of infrastructures

Unlike the concepts of "network" or "system", which also refer to the connections and interdependencies between different elements, the concept of infrastructure is not well established in sociology. This may be related to the fact that the discussion of infrastructures is generally regarded as a technical matter whose social character only becomes apparent at second glance. Another reason may be that infrastructures are perceived as rather "boring" and often remain "invisible", as emphasised by the American sociologist Susan Leigh Star, who has dealt extensively with infrastructures and their social effects (Star 1999; Bowker & Star 2000). The term infrastructure is a French neologism, a collective term that firstly always denotes a plurality of integrated components and secondly refers to an "underlying", heterogeneous structure that makes superordinate projects possible: *infra* is the Latin word for below / under / underneath (as opposed to *ultra*). "Infrastructure" differs from the terms network or system due to this focus on a heterogeneous socio-technical foundation, which consists of both technical and social components. The term was adapted in English in the context of railway construction to refer to the necessary organisational and preparatory work that precedes the actual rail construction, i.e., decisions about routes, tunnels, stations, bridges and the material foundation of the rail bed (Carse 2017: 27). It has always been a relational term that refers to the interdependence of social, technical, physical and financial dynamics and focuses on their necessary linkage and practical maintenance for the economy and society (Star & Ruhleder 1996: 113).

The most widespread perspective on infrastructure in sociology comes from Susan Leigh Star: "People commonly envision infrastructure as a system of substrates – railroad lines, pipes and plumbing, electrical power plants, and wires. It is by definition invisible, part of the background for other kinds of work. It is ready-to-hand. … [But given the bottlenecks and constraints that infrastructures create] We were forced to develop a more relational definition of infrastructure, and at the same time, challenge received views of good use of ethnography in systems development. We began to see infrastructure as part of human organization, and as problematic as any other" (Star 1999: 380). Accordingly, infrastructures are understood as socio-technical arrangements whose readiness for use is the precondition for social practices, which usually remain inconspicuously in the background, but organize standards and practices. This means that they represent structures that, in the etymological sense of the prefix *infra* described above, lie beneath social practices and form their foundation, but unlike technical devices such as cars or mobile phones, are rarely the subject of direct interaction (Larkin 2013: 329; Shove 2017; Shove & Trentmann 2019). Nevertheless, infrastructures have far-reaching effects as determining factors behind social and environmentally relevant practices. For example, the practice of showering is based on a socio-technical arrangement of water pipes, heating systems, wastewater disposal and recycling facilities, forms of organisation, expectations about cleanliness, and financing models (Bell 2015), the existence of which is perceived as predetermined and ignored in everyday showering, but which "pre-structures" the practice of showering. In this respect, infrastructures set standards and shape conventions that narrow the scope for further decision-making on several levels: a) As a background condition, they only allow certain technical and organisational linkages, so that, for example, fuel cell vehicles cannot become widespread without petrol stations that sell hydrogen. b) They create horizons of expectation that, like conventions, invisibly standardise social practices in the background. c) They are linked to cultural horizons of interpretation, for example by setting and maintaining standards for differentiating and classifying things, and such standards are also nested within one another and therefore difficult to dismantle (Star & Lampland 2009).

Due to its barely perceived impact and the multidimensionality outlined above, it is not surprising that the concept of infrastructure has remained vague in sociology and that it is difficult to draw boundaries around it (Larkin 2013: 329). For example, what is transport infrastructure? Is it primarily roads, traffic lights and railway lines? Or do maintenance systems, road traffic regulations and technical inspection agencies also need to be conceptually included? What about modern poetics of mobility? What significance do national borders and regional differences have for transnational infrastructures and what conventions are typical for different countries? It is neither meaningful nor possible to determine definitive answers to such questions. In infrastructure research, it is the specific object of investigation and the respective research interests that determine where boundaries are drawn and which aspects are taken into account.

However, in recent decades a consensus has emerged in social science infrastructure research regarding a number of defining characteristics that should generally be taken into account. Depending on the research perspective, other aspects may also become more important (Hughes 1983; Star & Ruhleder 1996; Star 1999; Shove et al. 2015).

Socio-technical hybridity: The main defining characteristic of infrastructures is their hybridity. Infrastructures are inevitably heterogeneous hybrids that are the result of both material and social components. In his study "Networks of Power: Electrification in Western Society", which is fundamental to infrastructure research, the technology historian Thomas P. Hughes (1983) showed how the construction, conversion and dismantling of infrastructures depend on the art of forging stable networks from heterogeneous material, technical, financial and symbolic components. Hughes analysed electrification in Chicago, New York, London and Berlin historically and comparatively in order to reconstruct how access to electricity was implemented as a large-scale socio-technical supply system. The study shows that electrification was only able to replace gas as a source of energy because technical artefacts and social conditions became related to one another and mutually adapted; in other words, the power lines, markets and processes of coal-fired power generation became networked with important actors, expectations and organisations in a way that was typical for each nation. In the process, socio-technical systems emerged in North America, the UK and Germany that each produced different standards, financing and organisational structures as well as power structures – just as Hughes' ambiguous book title "Networks of Power" suggests. Hughes emphasises the organisational skills of Thomas Edison, one of the inventors of the lightbulb, who succeeded as a "system builder" in successfully linking social, material and technical resources to create a seamless web that facilitated the creation of complex infrastructure systems. His research led him to establish the "system approach", according to which infrastructures and their transformation should always be viewed as the temporary result of the integration of heterogeneous material and social components into a system.

Invisibility: Another central feature is the aforementioned *transparency* or invisibility of infrastructures. This refers to the way that infrastructures disappear into the background of the utilisation practices that they make possible. In general, for example, users do not ask themselves whether and how the transport network, the water supply or the internet will still be available tomorrow and what conditions are necessary for them to function. As Susan Leigh Star and Geoffrey Bowker put it: "The easier they are to use, the harder they are to see" (Bowker & Star 2000: 33). In fact, infrastructures are not present in individual and social consciousness as long as their functionality can be assumed – even if they are accompanied by ecological and social upheavals. They only become visible as a prerequisite of social life when they break down. Then it becomes clear how dependent modern people in particular are on these collective socio-technical foundations. Dirk van Laak (2023) accordingly describes infrastructure failures as activating unconscious fears because they make hidden vulnerabilities and dependencies tangible and often produce forms of impotent rage. When transport systems fail, it not only affects people's mobility – the economy also comes to a standstill. Power failures fundamentally jeopardise society's ability to function and are capable of triggering cascading disasters in almost all areas.

Relational mediation agencies: On the one hand, infrastructures form the basis of almost all actions and, on the other hand, are only relevant as long as they function and are used. A few decades ago, telegrams were used to communicate the most important messages, but today teleprinters and telegraphic infrastructure have long been forgotten. It is true that infrastructure systems shape social practices, such as mobility or consumption, by structuring how they are regularly carried out in socio-technical terms. But they collapse when their functions fail or social practices turn to other infrastructure systems, as is the case today with the shift towards renewable energy sources (Gross & Mautz 2014; Watson & Shove 2023). They therefore mediate between structure and practice, and do so in a reciprocal and interrelated manner. What is relevant here is their interconnectedness with a variety of different practices, so for example, the water supply is used equally for showering, cooking, the provision of drinking water and garden irrigation. A reorganisation of infrastructure or a symbolic reinterpretation of its central elements therefore entails far-reaching, systemic changes, affects a large number of people, and brings forces of inertia to light.

As infrastructures always enable certain practices and exclude others, they must also be viewed as political projects that are also linked to distribution issues. Their study is interesting because infrastructures reveal "technopolitics" (Larkin 2013), as well as geo-spatial politics and political decisions underlying the socio-technical foundations of society (Coutard & Florentin 2024). They define social participation and opportunities for participation, open up certain development corridors and close others, determine environmental consumption and channel both supply and demand structures as well as the social expectations, standards, and identities associated with them. Therefore, infrastructures not only materialise expectations about the future; they themselves also have an impact on the future and are at least temporarily irreversible (Barlösius et al. 2011: 164). They can even be regarded as political instruments: Infrastructures are instruments of political control, but they are often presented as politically neutral or apolitical because their design and implementation can be presented as purely technically justified, even though they are based on political ideas and intentions and have corresponding consequences (ibid. p. 166). Infrastructure projects are therefore an integral part of nation-building, they are never finalised and are integrated into complicated processes of coordination and the balance of power. The design of infrastructures is not only orientated towards technical feasibility and dominant social practices, needs or expectations, but is also influenced by the implicit and explicit visions, conventions and interests of planners, designers, and decision-makers (Shove et al. 2015: 284), what the term "infrastructuring" emphasises (Coutard & Shove 2024).

Obduracy: Infrastructures are built up over long periods of time, can only change slowly, encode spaces and create path dependencies. They materialise social standards and ideas about normality and allow certain connections, while complicating or interrupting others. As a result, infrastructure systems cannot easily be changed and adapted to new goals, but are instead resistant, obdurate and "hardened" in technical, social and institutional terms (Hommels 2005). That is why ecologically necessary reforms and renewals such as energy and mobility transitions are so difficult. For example, automobility is stabilised as the predominant form of mobility by the underlying infrastructure of built transport routes, social norms about spatial flexibility, technical standards of motorisation and spatial development, and institutional regulations that stipulate how many parking spaces must be provided on or near new buildings which turn public spaces into car parks. Abandoning such an established infrastructural path is associated with high costs. At the same time, research also shows the influence of collective shifts in meaning and (aggregated) practices on infrastructure development, suggesting a potential for infrastructure plasticity (Watson & Shove 2023).

Infrastructure development, its path dependencies and forces of inertia are a central issue for socio-ecological transformations due to infrastructure's socio-technical interconnectedness, its invisibility, its mediating effects on social practices, and its resistance to rapid change. We will take a closer look at this in the next section.

2. Infrastructures and their forces of inertia

The often promised and hoped-for "decoupling" of economic growth and prosperity on the one hand, and resource consumption and environmental damage on the other, has not yet been sufficiently achieved. The inertia of the existing supply systems and the norms that are built into them privilege the status quo, so that even dedicated sustainability innovations fail to achieve their goals of a) making societal development sustainable through novel solutions to problems and b) bringing about intra- and intergenerationally sustainable modes of living and production. Electric vehicles, heat pumps, photovoltaic systems or car sharing do have the potential to reduce problematic resource consumption and climate-relevant emissions. However, the current infrastructure conditions stabilise unsustainable "normalities" and routines at an underlying level, for example with regard to the focus on single-family homes and private motorised transport. As a consequence, individual sustainability innovations often tend to lead to substitution, rebound, and addition effects (Sonnberger & Gross 2018) (→ chap. 4 on environmental attitudes and action, chap. 7 on sustainable consumption and chap. 8 on sustainable innovations). Reductions in consumption facilitated by new technologies are then partially cancelled out or even overcompensated by additional or alternative consumption. Infrastructures can therefore be regarded as "socio-technical systems" or "technostructures" whose stability and obduracy stand in the way of socio-ecological transformations.

The concept of "socio-technical systems" is helpful for understanding how and why large-scale technical infrastructures, which feature multiple linkages, are resistant to change (Edwards 2003). A socio-technical system is defined as a tightly linked ensemble of technical, institutional, organisational and social arrangements, practices and relationships that are held together by their interdependence. Transition research also describes the interplay between technical conditions, socially anchored usage norms, and the associated knowledge, organisational and usage cultures as a "socio-technical regime". Overcoming such regimes requires external windows of opportunity and alternatives that have been tested in protected niches (Geels & Kemp 2007) (→ chap. 8 on sustainable innovations). The socio-technical regimes at the core of infrastructures attain their stability through their historically developed and constantly rebalanced social and technical linkages. On the one hand, these linkages enable infrastructures to operate continuously without further thought or reflection, and on the other hand, are robustly opposed to socio-ecological transformation attempts.

Large-scale technological systems with structures that extend across space and time are contributing to the fact that resource consumption and emissions are falling too little and too slowly in relevant fields such as mobility, energy, housing and food to avert the catastrophic effects of climate change or even meet politically defined targets – despite increased environmental awareness and numerous sustainability innovations. Their forces of inertia play a decisive role in determining the form and depth of intervention in society-nature relations (Monstadt 2009). As the basis of social and economic life, particularly in cities, infrastructures not only "channel" resource flows, but also shape ecologically relevant structures of expectation and everyday practices, and determine the design of technologies and innovation processes. Infrastructural resistance is encountered wherever there are attempts to introduce sustainable economic and consumption options: Although it may be ecologically better to walk, cycle or use public transport instead of cars, socialised expectations regarding motorised individual transport stand in the way. Renewable energy sources could be utilised in a variety of ways, but their integration into existing supply arrangements poses numerous reconfiguration problems. Even the partial replacement of individual components in existing infrastructure systems collides with "hard" system constraints and leads to opportunity costs and interface problems, as demonstrated by the sluggish spread of heat pumps or the difficulties of taking bicycles on trains.

Due to this hardening or *obduracy* (Hommels 2005), infrastructures block isolated changes that only take effect at one level – for example, at the level of consumer practices, technologies, usage rules, connections or interfaces. As such, infrastructures require complex system transformations (Hughes 1983). Any redesign of infrastructures in line with environmental goals therefore faces the multifaceted task of having to make changes in a system with multiple linkages that is held together by underlying guiding principles and norms as well as by technical instruments and compatibilities, associated technical knowledge, the natural environment, and culturally determined user behaviour (Grin et al. 2010). A targeted transformation of infrastructures therefore faces the challenge of having to reconfigure self-evident factors that have been stabilised in many ways. In recent decades this has been confirmed by the ongoing energy transition in many Western countries, which was desired by citizens and driven forward by politicians. The implementation of renewable energy sources is taking longer than hoped, causing technical and social adjustment problems and raising opposition at various levels. All of this must be considered in relation to the interplay between the various components: Electricity supply and billing modalities must be redefined, past investments in technologies such as coal-fired power plants and heating systems become "sunk costs", new manufacturing and operating expertise is required, new networks and supply lines must be established across borders, and old sensitivities and balanced conflicts of interest must be taken into account. Entire sectors are being restructured, ministries are taking on new responsibilities – but from the consumer's perspective, the depth and breadth of the necessary changes are at best only marginally visible.

Despite the many linkages, the continued existence of infrastructures also hangs by a thread in terms of their usage or the ways in which they are used (Star 1999: 380). As described above, infrastructures have a strong practical relevance, as they serve as the basis for different practices, often interlinked with further infrastructures. However, if those practices are no longer carried out, the underlying infrastructure systems decay and are forgotten. For example, if certain energy sources are abandoned, entire infrastructure systems become superfluous. The cessation of brown coal mining leads to the abandonment of open-cast mining sites, the respective business locations and the associated jobs, and has a profound impact on the regional environment and living conditions – from the development of new recreational areas to emigration and economic decline in the affected communities. A significant change in the number of vehicles or the demand for heating would inevitably result in similarly far-reaching and climate-relevant changes to existing (currently unsustainable) infrastructures. To a certain extent, infrastructures could be dissolved virtually overnight through a lack of usage, as the telegram example illustrates. However, there are only a few examples where the radical dismantling of infrastructure has led to fewer supply requirements, resources, emissions, and impacts rather than more. Infrastructure systems are much more frequently expanded, upgraded or at best reorganised.

It is also relevant that there are virtually no persons or parties in charge of infrastructure development, precisely because of its overarching importance and its many components ("nobody is really in charge of infrastructure"; Star 1999: 382), and that only disruptions to infrastructure "draw attention to problems that are important for the context of functioning" (Luhmann 2012 [1984]: 318). As Niklas Luhmann emphasised, the dependencies that develop in the shadow of infrastructure networks mean that "any breakdown of technology (especially energy supplies) would also lead to the breakdown of our familiar society. In other words, technological development has led to innumerable *nonnatural self-evidences*. We take it for granted that the cistern will refill when we flush the toilet" (Luhmann 2012 [1984]: 321f.). Once infrastructure systems have been established, they lead a life of their own that eludes social attempts to organise or design them, even though they are permanently subject to repair and maintenance.

In the engineering sciences, it is often assumed that questions of infrastructure design are solved technically and that society must then be familiarised with the new solutions. Meanwhile in the social sciences, numerous case studies in Science and Technology Studies (STS) have shown the extent to which social forces determine infrastructure development. Central to this are perceived possibilities and imagined futures that enable coordination across different areas of action (Jasanoff & Kim 2015). Shared ideas about desirable futures bring actors together and they align their activities towards a common goal (Wentland 2016). Infrastructures are always both existing and inadequate at the same time; their reorganisation is geared towards the future and anticipated future demands (Edwards 2003; Shove 2016). Infrastructure development projects are thus embedded in a narrative of progress in the future perfect tense (the completed future) (Hetherington 2017: 40). As proof of the state's ability to act (van Laak 2023: 17-19), they articulate a welfare promise for the future: When this infrastructure project is completed, it will improve the conditions for more successful technologies, actions, opportunities for participation, and sustainability. Future infrastructure promises are also used as arguments in the context of spatially and socially unequal development, in which nations and cities compete as business locations by promising better facilities, supply networks, etc.

Rather than viewing infrastructure in terms of its supposed stability and inherent necessity, the term "infrastructuring" captures the assembling, maintaining and stabilising efforts that infrastructure requires. In contrast to the static concept of infrastructure, the term "infrastructuring" is intended to emphasise the processual nature of the construction and ongoing maintenance of infrastructure systems and thus point out that they are not simply "there", but are always "in flux". For example, the road transport network is constantly being maintained, expanded and, in a few cases, dismantled or reverted back into space for public interactions. Considering the variety of processes, strategies and interests involved, it is not surprising that infrastructuring is often characterised by conflict and fierce design controversies, during both the design and construction phase as well as the continuous maintenance and adaptation phase (Coutard & Shove 2024). Only from a long-term perspective do the processes of infrastructuring lead to stabilised socio-technical systems with corresponding socio-economic path dependencies. We would like to conclude our discussion about the obduracy of infrastructures by highlighting three stabilising factors (Hommels 2005).

Firstly, these are collective orientation schemes which, depending on the sociological perspective, shape infrastructuring either as dominant patterns of thought or interpretation, guiding principles, institutionalised structures of action and expectation, or systems of rules. They manifest themselves as culturally anchored, shared ideas (*imaginaries;* Jasanoff & Kim 2015) about goals, problems and conditions for action that transcend actor groups and only allow certain changes to appear legitimate and sensible, while other options are ignored. With regard to the emergence of car-friendly cities, Cliff Ellis (1996), for example, examined how American road engineers were able to assert their "professional worldviews" (which they formed in relation to the development of rural areas) in the planning of urban motorways for inner cities over the opinions of critics from architecture and urban planning, who had less legitimacy. Firstly, they benefited from the ability to use computer models and statistics to establish simple and coherent rules and define them as standards. "Their texts dryly catalogued the rules for successful technical performance, purged of ambiguities" (Ellis 1996: 273). Later on, even though these standards were widely criticised, they could no longer be revised due to fragmented responsibilities, complicated conflicts about objectives and controversial detailed proposals. As Ellis states: "Professional worldviews are not transparent lenses, but refracting prisms. They enable people to act, but also prevent them from seeing avenues for action" (1996: 278). Established ways of thinking structure the energy transition in many countries in such ways that socio-technical solutions are selected according to traditional planning and legitimacy concepts and aligned with the dominant model of a centralised energy supply. For an example, the same applies to the principle of centralised energy supply enforced in Germany, which resisted alternative proposals despite all the conflicts surrounding grid expansion and decentralisation – even though decentralisation could be implemented in a technically and ecologically sensible way, particularly in the electricity sector (Gross & Mautz 2014).

Secondly, regimes play a key role as an expression of the multiple linkages of infrastructure development and their embedding in interdependent complexes (Grin et al. 2010, see also chap. 8 on sustainable innovations). Once stabilised, the linkages connecting different components in socio-technical systems make it difficult to change prevailing supply solutions through the use of alternative solutions. Thomas P. Hughes in particular emphasised this effect of the systematic links between "people, ideas and institutions, technical and non-technical", which led to a "super-system" (Hughes 1983: 140). The spatial and temporal expansion of infrastructures with their ever-increasing number of linkages reinforces the *momentum* of the powerful complexes of mutually stabilised properties, rules, interests, and interfaces. In order to renew infrastructures so that they are more environmentally friendly, various components in various subsystems must be re-configured simultaneously – and alternative proposals generally lack the power, competences and resources to do this. Frank Geels (2014) describes how the coal industry's established alliances and the coal-oriented policies that lie at the heart of such a regime in the UK were able to prevent the transition to low-emission technologies, even though there were alternatives available that were assessed as more ecological. These alliances were able to evade the pressure to respond to climate change by strategically influencing the discourse surrounding the problem, materially prioritising certain technology development options over others (such as carbon capture and storage as a "bridging technology"), and institutionally committing policymakers to certain governance styles. In light of these forces of inertia, sustainability researchers widely believe that exogenous forces (so-called niche players) can, at best, implement the sustainability innovations developed by innovative outsiders with sophisticated strategies by establishing their own networks and development milieus (Grin et al. 2010) (→ chap. 8 on sustainable innovations).

Finally, there are the notorious path dependencies (Unruh 2000, 2002; Seto et al. 2016). They only partly involve technical and social restrictions, are partly found in various forms of capital commitment, and are regarded as forms of material resistance. In evolutionary economics, which is inspired by evolutionary biology and attempts to explain economic change through the interactions between different actors, path dependencies have been described as unintentional commitments made in early phases that limit change caused by factors within the economic system (i.e., endogenous change), and thus also limit the diversity of later development processes. Such path dependencies result from past decisions that are difficult to revise and their impact on capital commitment and debt, investments, network and scale effects, critical mass phenomena and routine-forming learning effects, all of which favour adherence to technological development paths and the expansion of existing structures over the possibilities of creating new paths. An infrastructure industry that makes good profits with climate-damaging technologies in a growing global market is unlikely to change. At worst, such path dependencies contribute to a "lock-in" of established infrastructure and behavioural paths, because subjects acting rationally (keyword: "homo oeconomicus") decide to continue with the status quo regardless of alternative models, even if this turns out to be the wrong decision (Unruh 2000).

Given that infrastructures function outside of our conscious awareness and are only problematised when our expectations regarding their flawless functioning are not met, it is difficult to mobilise forces for their restructuring. For this reason, decisions relevant to infrastructure often remain hidden and only seem to concern a small group of experts, even if they place dispositions that favour certain regimes over other, possibly more sustainable options in the long term. Infrastructure failures and resource-related disruptions, such as the oil crises of 1973 and 1979/1980 or foreseeable cost increases, bring the far-reaching dependencies to light and lead to severe and often antagonistic reactions among those affected. A more recent example of this is the Yellow Vest protests that took place in France in response to the higher taxation of fuels, which was part of the government's attempt to finance and implement the energy transition.

3. Conflicts related to infrastructuring

There is no shortage of attempts to reorganise or replace existing infrastructure systems. The politically initiated "transitions" (e.g., in the energy, mobility and agricultural sectors) are large-scale examples of this, which are accompanied by a multitude of smaller-scale efforts (e.g., more bicycle-friendly infrastructures). These reorganisation efforts make infrastructures "visible" and the subject of public controversies. Conflicts arise over the selection of the right design, the appropriate components and their contested assessments. The conflicts are based on mutually contradictory proposals regarding the best possible arrangements as well as on very different concerns. They are also characterised by the inertia described above, in which unequal interests and power relations are embedded. Added to this is the fact that industrial growth targets in infrastructure development have largely lost their legitimacy, but new binding norms have not yet taken their place (Kropp 2018a). In this institutional vacuum of culturally binding rules and in light of the organisational fragmentation of responsibilities in liberalised markets that has become typical of infrastructure projects, either the status quo prevails or major conflicts break out over the aims and implementation of infrastructure restructuring and demolitions. A fundamental reconfiguration is made even more difficult because there is a lack of clear decision-making structures or shared decision-making norms (Wolsink 2018) upon which the transition can be built. Rather, the multitude of perspectives, their heterogeneous references and the "indivisibility" of the objects of conflict create conflict configurations in which conflicts cannot be resolved simply by reconciling two different perspectives – instead, they give rise to a multidimensional conflict structure. The disputes revolve around the underlying definitions of the problem and the models for solving it, as well as the distribution of scarce goods, opposing interests (related to usage and avoidance), irreconcilable values, disputed understandings of roles, recognition, power, identity, and legitimation. Thus, disputes about infrastructure transitions exhibit all the causes of conflict known in the social sciences (→ chap. 6 on environmental conflicts). Conflicts of interpretation, interest and legitimation are particularly prominent in infrastructure conflicts, alongside conflicts about knowledge, values, and justifications. The three main types of conflict in infrastructure debates are outlined below:

a) **Conflicts of interpretation** are sparked by controversial problem diagnoses and involve divergent imaginaries and judgements about desirable objectives. For a long time, the mobility transition was dominated by conflicts over drive technologies, political incentives and competition between the various modes of transport. Behind this lay fundamental conflicts of interpretation regarding the problems of private motorised transport and the appraisal of its consequences. More recently, (primarily) economic actors have proclaimed the end of the combustion engine. This has far-reaching consequences for mobility infrastructure (e.g., charging stations for electric vehicles instead of petrol stations) and has eased debates about the various drive technologies. In terms of energy supply, conflicts about restructuring existing infrastructure continue to be fed on several levels by the deep conflict between proponents of decentralised supply solutions (with governance that is more fragmented and more strongly oriented towards supply autonomy) versus those who cling to centralised supply structures (with a necessary grid expansion). At the same time, the assessment standards are shifting as a result of the European climate measures and the restructuring taking place in the respective countries.

It goes without saying that path dependencies play a key role in these conflicts: previous investments justify the effort required to adapt; established technologies, from radiators to cars, enforce compatibility. There is also fundamental disagreement as to whether environmental problems can be overcome at all through better technology (in other words, a technologically optimised "business as usual" approach), or whether they require a fundamental change in awareness with a radically reduced need for resources. Even if there is consensus regarding the need for change, conflicts still arise about which new infrastructures are more sustainable, better suited to existing business models, and how the transition should be structured. Some interpret energy transitions as a fundamental change in infrastructure and a revolutionary shift towards a "regenerative society", while others see it as a new business area with unchanged framework conditions. The associated allocation of responsibility is also controversial. Should the case be made for a decentralised energy transition at the community level with hopes of self-sufficiency, or should there be supra-regional and state supply guarantees? Are global environmental and economic changes a reason for building local resilience and decision-making autonomy, or are vulnerabilities, especially in peripheral locations, a reason for improving nationwide and international cooperation? In view of the opposing viewpoints, the normative conflicts over local infrastructure projects are often highly emotive – what some see as proof of the credibility and sincerity of particular claims, others see as dubious. Conflicts of interpretation can ignite over technical, economic, social and ecological issues and usually make emotions run high, because it is almost impossible to negotiate between the various parties due to fundamentally different understandings of reality and situations.

b) But **conflicts of interest** also mean that infrastructure restructuring is fraught with conflict: In many cases disputes centre on whose interests should be prioritised (e.g., user, operator or investor interests). Is it necessary to protect vested interests, for example with regard to long-lasting consumer goods such as heating systems and private vehicles, and if not, how can the individual conversion costs be absorbed in a socially just and politically acceptable way? How should the costs of infrastructure restructuring be distributed, who should bear certain burdens and who should receive relief? And how much should current generations pay for infrastructures that will only be profitably used in the future (such as the 5G mobile communications standard, which will primarily benefit cyber-physical forms of production)? Conflicts between ecological and economic interests and between more ambitious and often more expensive modernisation approaches compared to smaller end-of-the-pipe solutions (e.g., filter systems) are of course particularly relevant for environmental sociology. In addition, there are controversies about infrastructure changes that favour technologies which contain lucrative business prospects for some, but disadvantages for others (wind power, hydrogen, passive houses). Conflicts related to usage are also highly significant, especially when it comes to visible infrastructures in public spaces. For decades, there have been disputes in city centres about the fair distribution of street space, i.e., about the proportionality of the different space requirements in transport infrastructure, including between pedestrian and bicycle traffic, stationary and moving traffic, as well as about possible uses of inner-city areas as public space, for example as spaces for retail, gastronomy, social interaction, playgrounds or parks (Carmona 2010).

Conflicts of interest result from the need to select technical, financial, social, and organisational options, each of which have different implications and can also have indirect consequences in other areas. Conflicts of interest lead to debates about suitable incentive schemes and implementation steps and about strategies for containing any undesirable interactions and consequences. The debate centres on whether or not economic windfall gains are intended, how urgent climate protection and climate adaptation measures are in comparison to other infrastructure projects (for example in the education and health sectors), as well as how to assess the progress that has been achieved so far. The greater the potential threat posed by the consequences of climate change, the more critically the suitability, planning and implementation of previous measures is assessed. In the battle to reduce carbon dioxide emissions, most people consider a renewable energy supply to be the most important building block, but at the same time there is debate about which areas of action are most likely to reduce emissions first. The experimental and not yet fail-safe nature of many approaches to infrastructure restructuring makes it difficult to reach agreement on possible approaches and tends to support their postponement over the known tasks of ensuring long-term public services. Conflicts of interest often translate into conflicts about resources and are therefore an expression of the controversial negotiations involved in socio-technical arrangements, the choice of components, their composition and the associated organisational issues of management, financing, and legal regulation. They follow the lines of power of well-established regime configurations as opposed to those of challengers with novel approaches to solutions. And these gruelling conflicts can erupt in relation to each individual element that needs to be changed in the supply arrangements.

c) Finally, infrastructuring processes can also trigger **conflicts of legitimacy –** this is where unresolved conflicts of interpretation and interests come to a head. These conflicts over the fundamental legitimacy and acceptability of infrastructure changes are well known from research on new technologies and technology impact assessments. They primarily erupt when decisions need to be made or when new infrastructures are implemented, but smoulder from the start of development projects until well after those projects are up and running. They always involve questions about a) what constitutes an acceptable justification, b) specific measures and their justification in relation to alternatives and other necessities, as well as c) the underlying principles guiding the path to the future. Should uncertainties be seen as a justification for postponing system reconfiguration or as a reason for its experimental, participation-orientated design? How are reconfigurations to be legitimised in relation to the status quo: with knowledge or technical ability, qua expertise or with reference to majorities and political/administrative mandates? The conflicts are further fuelled by the need to deal with uncertainty, a lack of empirical data, the dilemma of expertise and counter-expertise and the profound realisation that earlier problem-solving patterns are partly responsible for today's problems. This leads to widespread complaints about a lack of clear objectives, reliable planning standards and continuity in terms of the implementation measures (e.g., for the energy transition). Many parties to the conflict therefore wish to re-establish clear frameworks that guide action and create overarching standards – ideally through public consensus rather than legislation. Faced with an uncertain future, conflicts are generated and promoted by the lack of regulatory guidelines, the erosion of culturally self-evident values and their corresponding knowledge and training structures, as well as the normative questioning of the old consensus on growth and progress.

The perspectives articulated about how to solve infrastructure problems are often unconnected from one another, right down to the smallest details (Kropp 2018b: 196ff.): Overarching coordination is required, but this is not possible due to a lack of shared assessment criteria and comparative evaluations of the proposed measures that would allow the ecological, economic and social effects of different infrastructure systems to be weighed up against each other. Another complicating factor is that infrastructure change requires cooperative processes between public and private actors, but there is often a lack of mutual clarity about the possibilities for and constraints on action. The various parties involved address a large number of different aspects and infrastructure-related issues, but they lose sight of the environmental and climate problem as a multi-sector issue with special challenges: Fragmented into departmental responsibilities, the significance of these challenges across time, space and different sectors takes a back seat to perspectives that are specific to particular sub-systems and sectors. In the heterogeneous infrastructuring carried out by actors from politics, business and civil society, these sector-specific perspectives mean that – regardless of a fundamental willingness to overcome conflicts of interest – cooperation primarily consists of sealing off one's own sphere of action from the demands of others. Without cross-sector legitimacy, the announced infrastructural changes disintegrate into small blockade conflicts of negative coordination that are designed to minimise mutual interdependencies and disruptions to one's own process. In this way, the inertia of the status quo (which is also determined by the balanced forms of resource distribution and the associated interpretive authority) leads to cross-system challenges ultimately being dealt with in the existing frameworks that guide action and determine the division of labour. By categorising the conflicts according to established assessment and justification criteria, they are resolved using the same legitimation strategies that contributed to their emergence.

The design conflicts make it clear that infrastructure projects in the Anthropocene are to be regarded as "wicked problems" (Rittel & Webber 1973). Neither the problems, objectives and solutions nor their evaluation can be clearly characterised as right or wrong. Conflicts about how to legitimately determine the causes of problems and find suitable solutions, as well as about the implications, interactions and path dependencies that need to be taken into account, mean that those involved do not pursue overarching strategies that are capable of consensus. Instead, the conflicting parties pursue various different strategies that are often incompatible. However, if the adopted approaches are increasingly questioned and incompatible approaches are pursued instead (so-called "technological openness"), then we can assume that conflicts about infrastructure projects are not likely to decrease. Instead, they will become more intense and polarised, especially as the need for a solution becomes more urgent.

4. Outlook

Due to the forces of inertia and conflicts described above, infrastructure changes rarely develop as the result of long-term and consistent transformation strategies. Mostly, changes are the small-scale, fragmented and heterogeneous results of necessary, but sometimes unwanted, sometimes cancelled and sometimes undetermined restructuring processes in large-scale technical systems. Even where radical infrastructure changes have been implemented, such as the cessation of nuclear energy production, decommissioning measures have been and will be postponed for a long time into the future (phase-out models, nuclear waste storage issues, etc.). The diversity of conflicts described above expresses this complexity; path dependencies favour the strengthening of economically motivated ways of thinking about efficiency. As a result, the diversity of socio-technical linkages and arrangements is growing – as is the selective influence of economic constraints on them, which tends to stand in the way of sensitivity towards the climate change issues and potential side effects. As a consequence, sustainability-oriented infrastructuring suffers from a lack of addressable governance subjects and standardised design norms. In addition, it is confronted with the paradox of having to deal with considerably increased complexity and its own internal dynamics, as well as an ever-more extreme socio-economic narrowing of options that cannot do justice to the diverse, long-term and threatening interactions and side effects associated with the Anthropocene.

The considerations in this chapter make it clear that infrastructure systems are not monolithic blocks. They are diverse and heterogeneous, full of fractures and contradictions, and these frictions and pluralities also provide starting points for change. For example, car-centric infrastructures give rise to the use of cars for everyday mobility. However, the more these infrastructure systems are used, the less they are able to fulfil private motorised transport's value proposition of freedom and flexibility, as this can no longer be provided in urban congestion. As a result, dissatisfaction with car-centric infrastructures is growing among parts of the population, thereby opening up opportunities for change. Civil society and economic niche players are addressing these fractures and contradictions in infrastructure systems with the aim of changing them. This gives rise to horizontal actor networks and multilateral arrangements that are being investigated by parts of academia in the form of transformative real-world laboratory research (→ chap. 10 on transdisciplinarity). Within these real-world laboratories, the infrastructure conflicts that inevitably arise in the course of socio-ecological transformations can be observed and dealt with in a co-constructive manner. All in all, infrastructure conflicts provide environmental sociology with an interesting area of investigation that will enable us to better understand processes of change in the relationship between technology, society, and nature. However, they also require critical sociological monitoring so that social inclusions and exclusions, contradictions and possibly unintended side effects arising from infrastructuring processes can be taken into account at an early stage.

What students can take away from this chapter:

- Knowledge about what is meant by infrastructure systems and infrastructuring
- Knowledge about the complex relationship between infrastructures and society
- An understanding of infrastructures' resistance to change
- An understanding of the controversial nature of infrastructure change

Recommended reading

Bell, S., 2015: Renegotiating urban water. *A multifaceted examination of urban water supply and the socio-technical difficulties involved in its sustainable transformation.*
Coutard, O. & E. Florentin, 2024: Researching infrastructures and cities: Origins, debates, openings. *Provides a comprehensive introduction to the study of infrastructures and the various traditions and concepts.*
Hughes, T.P., 1983: Networks of power: Electrification in Western Society, 1880-1930. *A classic of social science infrastructure research and environmental and technological sociology as a whole.*
Star, S.L., 1999: The ethnography of infrastructure. *A much-cited article on the characteristics of infrastructures and their power to shape society.*
van Laak, D., 2023: Lifelines of society. A global history of infrastructure. *An easy-to-read introduction to infrastructures and their national and cultural significance.*

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