3

Methodology

While Chapters 1 and 2 discussed the book's rationale, novelty, scope, and conceptual approach, this chapter addresses methodological challenges and operational issues.

Section 3.1 engages with broader methodological issues for research of longitudinal large-scale change processes. Drawing on the wider social sciences, it argues for a particular explanatory style since mainstream methods have limitations for this research topic. Section 3.2 justifies the analytical demarcation choices (e.g., selection rationales, system boundaries), describes how we operationalise the conceptual framework and underlying categories, and discusses data sources. Section 3.3 addresses the evaluation of system reconfiguration patterns across various dimensions.

3.1 Broader Methodological Issues

Before addressing operational issues, we discuss some broader methodological challenges that relate to special characteristics of the research topic (Geels and Schot, 2010; Köhler et al., 2019). First, socio-technical system transitions are longitudinal processes that unfold over time, often involving non-linear and complex interactions. Second, socio-technical systems are large-scale, heterogeneous entities with multiple co-evolving elements. Third, constitutive elements (like actor properties, techno-economic elements, and rules) are themselves transformed as the transition process unfolds.

These characteristics pose challenges for mainstream explanatory formats since 'contemporary social scientists are strongly predisposed to focus on aspects of causal processes and outcomes that unfold very rapidly' (Pierson, 2004: 13). Mainstream analytical formats (such as regression analysis or structural equation modelling) approach the world as consisting of variables or factors, with

https://doi.org/10.1017/9781009198233.004 Published online by Cambridge University Press

independent variables ('causes') having effects on the dependent variable ('outcome'). This *push-type* causality (Mohr, 1982), which has come to dominate many social sciences (Abbott, 2004), assumes that causes 'operate at equal speed and in the same way across all cases. [. . .] Explanations should emphasize immediate causation. [. . .] It is not necessary to know the particular twists and turns of an entity's history to explain it' (van de Ven, 2007: 152–153). While mainstream explanatory formats may be suitable for narrowly defined research topics with *linear causality*, which involves 'a straightforward, direct chain of events that characterizes simple phenomena' (George and Bennett, 2004: 212), they have major limitations for explaining longitudinal transformation processes in heterogeneous macro-entities.

Analysing those kinds of entities, like socio-technical system transitions, requires a different explanatory style, as social scientists with longitudinal processual interests have emphasised. For political science, for instance, Pierson (2004: 1–2) notes that:

> Contemporary social scientists typically take a "snapshot" view of political life, but there is often a strong case to be made for shifting from snapshots to moving pictures. This means systematically situating particular moments (including the present) in a temporal sequence of events and processes stretching over extended periods. . . . The systematic examination of processes unfolding over time warrants a central position in the social sciences.

Hall (2003: 387) similarly observes that:

> Comparative politics has moved away from ontologies that assume causal variables with strong, consistent, and independent effects across space and time toward ones that acknowledge more extensive endogeneity, path dependence and the ubiquity of complex interaction effects. . . . Accordingly, parsimony is no longer seen as a key feature of explanation in political science.

For business and management, Langley et al. (2013: 1) diagnose a similar trend:

> A growing number of management scholars have been researching process questions. . . . Process studies address questions about how and why things emerge, develop, grow, or terminate over time. . . . Process research, thus, focuses empirically on evolving phenomena, and it draws on theorizing that explicitly incorporates progressions of activities as elements of explanation and understanding.

More broadly, Tilly (2008: 9) suggests that: 'In social science as a whole, a substantial intellectual movement has formed to adopt mechanism- and process-based explanations'.

Situating ourselves in this broader epistemological turn, the book's research is oriented by the following guiding principles, which also resonate with the Multi-Level Perspective.

3.1.1 Conjunctural and Configurational Causality and Explanation

Our explanations of socio-technical system transitions are based on conjunctural or configurational causalities, in which outcomes result from multiple interacting processes.

> Heterogeneous entities are composed of disparate components. … complex social happenings are almost invariably composed of multiple causal processes and components rather than existing as unitary systems. The phenomena of a great social whole … should be conceptualised as the sum of a large number of disparate processes with intertwining linkages and often highly dissimilar tempos. (Little, 2016: 8–9)

Conjunctural or configurational causality

> characterizes a specific mode of explanation … in which researchers consider how multiple factors combine to form larger combinations, complexes, and causal packages. One reason this configurational analysis figures so prominently is because the large-scale outcomes … are themselves often aggregated combinations of multiple events and processes. (Thelen and Mahoney, 2015: 7)

This explanatory style is common in qualitative research and suitable for answering 'how' questions: 'Qualitative researchers especially tend to think in terms of combinations and configurations because of their interest in context and in understanding social phenomena holistically. … This interest in combinations of causes dovetails with a focus on 'how' things happen' (Ragin, 2008: 109).

Instead of linear causal chains, longitudinal socio-technical transitions should thus be explained through processual alignments and co-evolution: 'Most historical sociologists reject the notion of a single master process, acknowledging multiple processes that overlap and intersect one another. Explaining a particular outcome or pattern of development thus involves a particular logic of explanation: situating events or outcomes in terms of their location in intersecting trajectories with independent temporalities' (Aminzade, 1992: 466).

3.1.2 Causal Reconstruction and Process Tracing

Our explanations of socio-technical transitions aim to trace and reconstruct the interaction of co-evolving causal processes: 'The majority of macro-phenomena … cannot be explained by applying one particular mechanism model. Instead, the causal reconstruction of macro-phenomena … involves a chain of different mechanisms that jointly generate the outcome' (Mayntz, 2004: 254). Héretier (2008: 75) adds that the causal reconstruction approach 'is appropriate when the number of cases is small, the explanatory factors are highly dependent on each other and … outcomes are the result of complex interaction effects and various forms of multicausality'. Mayntz (2004: 238) further explains that:

Causal reconstruction does not look for statistical relationships among variables but seeks to *explain* a given social phenomenon – a given event, structure, or development – by identifying the processes through which it is generated. Causal reconstruction may lead to a (more or less complex) historical narrative, but in its theoretically more ambitious version, causal reconstruction aims at generalizations – generalizations involving processes, not correlations.

As a general methodological orientation, we use process tracing, which is presented as 'more appropriate than other methods in the study of phenomena characterized by complex causality or multiple causal pathways' (Falleti, 2016: 456). Process tracing studies are concerned with explanations 'that indicate how the process unfolds over time' (Poole et al., 2000: 12). The analytical focus is hence set on understanding *how* and *under which conditions* things change. A process is understood as a developmental event sequence (Langley, 1999; Sminia, 2009), in which processual outcomes (e.g., the occurrence of a particular transition pattern) are explained as the result of sequences of events and related to the identification of underlying generative mechanisms.

There are different types of event-sequences with varying relevance for socio-technical transitions: 1) *self-reinforcing sequences* are 'characterized by the formation and long-term reproduction of [established] patterns' (Mahoney, 2000: 508); they typically stem from cumulative causation and increasing return mechanisms, which may be particularly relevant with regard to techno-economic developments (e.g., cumulative cost reductions or performance improvements), and 2) *reactive sequences* in which each step depends on prior steps and involves reaction and counterreaction mechanisms, that is, 'backlash processes that *transform* and perhaps *reverse* early events' (Mahoney, 2000: 526); this may be particularly relevant with regard to actors (who jockey for position or are involved in struggles) and policies and rules (which may be introduced, removed, or adjusted, depending on effects, learning, and (counter-)lobbies).

3.1.3 Longitudinal Case Studies

A particularly suited methodological strategy for process tracing is the rich longitudinal case study. It involves reconstructing sequences of events, cumulative trends, and evolving contexts with attention to their temporal ordering and the steps along the way.

The temporal delineation of cases is not entirely unproblematic and a usual cause for academic debate. However, a pragmatic approach is to rely on transparent quantitative indicators of the phenomenon at hand, such as the diffusion rates of particular technologies, the economic weight of a particular sector, or the salience of a particular societal problem in the public debate. Major changes in such indicators, observable through inflection points in their general

trends, provide good pointers for where to start and end a particular case or how to periodize if a phase-approach is taken.

George and Bennett (2004) distinguish different kinds of process tracing case studies, including detailed narrative, use of hypotheses, analytic explanation, and more general explanation. The case studies in our book aim for analytic explanation, which 'converts a historical narrative into an *analytical* causal explanation couched in explicitly theoretical forms' (p. 211). The analytical narrative is grounded in a conceptual understanding of the processes and mechanisms at play and structured around theoretically informed categories and dimensions. Such dimensions indicate what kinds of entities, events, and relationships to follow over time, as well what kinds of developments may be indicative of continuity or change. In Section 3.2.2, we explicitly return to the analytical dimensions considered in the empirical chapters of this book by describing how we operationalize the main elements of our conceptual framework.

While historical case studies are fully retrospective accounts that benefit from hindsight, this book is concerned with analysing transitions 'in-the-making'. This has important implications concerning our approach. First, we do not adopt a strict case study methodology but are, rather, focused on evaluating changes over time. In doing so, however, we do adopt a processual approach to explanation and develop a rich narrative approach to make sense of developments over time and mobilise longitudinal data. Second, while we follow historical developments, we do not claim to be historians nor mobilise empirical strategies, such as first-hand archival data, that historians would. Third, we follow reconfiguration processes up to the present, which means that our evaluation remains open-ended: system developments are ongoing, the observed transitions cannot be fully circumscribed and delineated (i.e., they have no end), and are marked by significant uncertainties.

3.1.4 Comparative Research

Most transitions research to date has rested on single case studies, which tend to favour depth, richness, and accuracy over more generic insights. Single case studies remain the privileged method of enquiry in transitions studies, and recent developments have been oriented towards the exploration of non-standard cases (e.g., cases displaying significant variations from ideal-typical patterns), different contexts (e.g., Global South countries), neglected systems (e.g., agri-food, health), different scales (e.g., cities, regions, transnational), or the role of specific actors (e.g., civil society, the State). Cumulatively, this amounts to an extensive collective evidence base of rich and detailed transitions cases (historical and contemporary), which broadly share the same epistemological commitments and often mobilise one of the key transition frameworks.

This extensive collective evidence base now makes it possible to investigate more laterally across cases and develop novel comparative strategies: 'The single-case research design remains prominent in transitions research, also as new regions, new actors, new technologies and new societal domains are explored. In turn, the increasing wealth of case materials creates demands and opportunities for methodological approaches that reach for generic insights across cases' (Köhler et al., 2019: 18).

Recently, researchers have sought to develop comparative approaches to analyse contrasting transition patterns. Such efforts have to date primarily focused on comparing national trajectories within a single sector such as in energy (Geels et al., 2016b; Johnstone and Stirling, 2020), agri-food (Darnhofer et al., 2019), mobility (Mazur et al., 2015; Nykvist and Whitmarsh, 2008) or related policy debates (Lovio and Kivimaa, 2012; Upham et al., 2013). Others have compared cases within the same country and sector but across different time periods, such as gas transitions (Arapostathis et al., 2013; Pearson and Arapostathis, 2017) or transitions away from coal (Turnheim and Geels, 2012). The notion of transition pathway (Rosenbloom, 2017; Turnheim et al., 2015) has been particularly fruitful to support such comparative work, notably through the development of transition typologies (Geels and Schot, 2007; Smith et al., 2005) to make sense of a variety of patterns in case observations, and as means to contrast them. Keeping one dimension constant (e.g., sector or country) simplifies comparability and the identification of key variations.

Other comparative attempts, such as meta-analyses of transition patterns (Martínez Arranz, 2017; Raven et al., 2016, 2008; Sovacool, 2016; Wiseman et al., 2013) are broader in scope, as they are oriented towards the comparison of transitions across sectors, geographical context, and time periods. While the objective is to draw out regularities and deviations across essential features of transitions (e.g., speed, scope, primary drivers and mechanisms), it also implies significant trade-offs, such as oversimplification, losing sight of complex causation, or simply comparing incommensurate phenomena due to inconsistencies in analytical units (Grubler et al., 2016).

So, while there is an 'unmistakable drive towards systematic comparison and theory-building from cases' (Köhler et al., 2019: 19) in transitions studies, such research is only emerging, and is not a substitute for in-depth case studies. A major challenge concerns the importance of maintaining an appropriate degree of richness and attention to local particularism while seeking more generic insights through comparison. For this reason, the book format seems particularly appropriate to minimise ensuing trade-offs involved in comparisons.

In this book, we have privileged intersectoral comparisons within a given national setting (the UK) and a given temporal frame (1990–present), with the aim

of identifying regularities and deviations across the examined sectors. A major advantage of such an approach is that all sectors will share common features at an aggregated level (e.g., national climate policy and decarbonisation frame, approach to industrial policy, or consumer culture) despite important changes over time, which enables us to examine sector-specific variations and explain major differences. The comparative approach put forward in this book rests on 1) the consistent deployment of an analytical grid operationalised at a rather fine level of detail, which enables a systematic comparison, and 2) the deployment of broader categories at the level of pathways, which enables the comparative interpretation of reconfiguration trajectories (e.g., their speed, scope, depth).

3.2 Analysing Longitudinal Socio-Technical Developments

Our core methodological commitment in this book is concerned with documenting, tracing, and analysing longitudinal socio-technical developments in different systems, in a way that enables cross-comparisons. Our comparative aim leads us to consider a systematic and transparent way to map systems and co-evolutionary developments over time, as well as to adopt consistent boundaries across all systems. This section details related choices and operationalisation concerning 1) analytical scope, 2) socio-technical dimensions and levels, and 3) data sources.

3.2.1 Analytical Scope and Selection Rationales

The core focus of this book is to analyse low-carbon reconfigurations in the UK. For this reason, we are concerned with systems characterised by significant GHG emissions, but also for which official emissions inventories are sufficiently detailed and consistent over time. Electricity, heat, and mobility are carbon-intensive sectors that have been the focus of dedicated emission reductions efforts for some time and for which techno-economic assessments of decarbonisation are available. Our system delineation for these sectors deviates nonetheless from climate assessments' conventional focus on power, transport, and buildings.

The empirical analyses in this book cover the period 1990 to the present, because 1990 is a common reference point in climate assessments and related policy discussions, with most emission reduction objectives referring to pre-1990 emissions as a baseline. This also means that detailed longitudinal emissions inventories are available for this period. More substantially, because we are interested in low-carbon transitions, 1990 offers a clear reference point for the mainstreaming of climate considerations as a public issue. From 1990, decarbonisation started to become a major issue for policymaking related to carbon-intensive sectors, with international commitments agreed at the United

Nations Conference on Environment and Development in 1992, followed by the ratification of the Kyoto Protocol in 1997. Of course, climate concerns and emission reductions pre-date the 1990s, so we do not limit ourselves too strictly to this reference point and have included developments pre-dating 1990 when they have significant influence over system trajectories, or when they help explain some of the lock-ins at play that constrain reconfigurations. The most recent years of our evaluation have been marked by significant events with potentially long-lasting implications (Brexit, COVID-19, Recovery packages). These implications are, however, riddled with uncertainties that call for interpretive caution concerning their actual decarbonisation effect and are largely vehiculated by promissory discourse. For this reason, we return to these issues in our conclusion.

The national scale has been the predominant scale at which transitions dynamics have been analysed in the literature. Reasons for this include the importance of national boundaries for technical infrastructure (e.g., roads, gas and electricity grids), institutions and policies (e.g., building regulations), strategic innovation programmes, or user attitudes. There are also pragmatic reasons related to the availability of longitudinal quantitative data (on emissions, sector investments, markets), which are often collected by national agencies. This *de facto* focus on the national scale has been challenged within transitions studies, given that many relevant developments are also constituted at local scales (e.g., local innovation projects and regional industrial dynamics), overflow across national boundaries, and are strongly influenced by transnational dynamics and actors (e.g., global corporations and supply-chains, international policies, social movements, or consumer cultures). Accordingly, transitions studies is increasingly considering multi-scalar processes (Coenen et al., 2012; Raven et al., 2012) and deploying approaches on different spaces. In this book, however, we have privileged the national scale because of our interest in decarbonisation policies and strategies, our dialogue with techno-economic assessments of national decarbonisation strategies, as well as comparative considerations. We nonetheless attend, where relevant, to the influence of supranational policies (notably European standards and regulations) and to local considerations (e.g., London's local transport system). The statistical databases used in this book vary in their national coverage, focusing sometimes on the UK and sometimes on Great Britain (which thus excludes Northern Ireland).

We focus on three carbon-intensive sectors, as justified by their historical contribution to GHG emissions. However, our interest in socio-technical dynamics and production-consumption systems leads us to depart slightly from system delineations as put forward in climate assessments (which distinguish power, buildings, and transport systems) and sectorial policy (which tend to take a supply-side orientation). First, we define socio-technical systems as primarily oriented

towards a societal function (e.g., heat, mobility), which enables us to consider dominant configurations but also alternative or parallel systems contributing to said function. The electricity system differs from the other two systems because it can fulfil multiple societal functions such as lighting, freezing/cooling, hygiene/washing, cooking, and entertainment. Second, because of our interest in whole system reconfigurations, we include production and consumption elements, broadly ascribing to a supply-chain understanding. Furthermore, because we are interested in how production and end users interact in whole systems, we have privileged systems boundaries including private consumers as end-users, which leads us to focus on residential users of electricity and heat and individual passenger mobility, hence excluding commercial and industrial uses. While we adopt a consistent analytical delineation across the three examined systems, sectorial particularisms lead us to also adapt this framework accordingly. For this reason, the first section of each empirical chapter describes and maps the systems considered, and elaborates distinctions between sub-systems and parallel systems, where relevant, according to the aforementioned considerations.

Because our framework is derived from the MLP (see Chapter 2), we analyse existing systems separately from emerging niche-innovations, as well as considering their interactions over time. For the selection of relevant niche-innovations, we focus on the most significant innovations according to our three analytical dimensions (i.e., those with emerging markets, institutional and policy backing, as well as growing actor coalitions), but have also sought variations in types of innovations. We have considered non-technological innovations (e.g., demand-side response, teleworking, and car sharing) and innovations for which technological and market maturity might not be that well developed but for which policy backing and discursive promises are significant (e.g., greening of the gas grid or self-driving cars).

3.2.2 Documenting Socio-Technical Dimensions

Our analysis of socio-technical development follows the adapted MLP framework described in Chapter 2, which rests on a commitment to tracing processes longitudinally, a distinction between different structuration levels (niche, regime, landscape) and an understanding that socio-technical change is the outcome of interaction mechanisms between these levels, and an analytical distinction between three key dimensions (techno-economic, actors, policies and governance). We here describe how we translate these commitments and analytical notions into operational categories to enable the systematic evaluation of low-carbon transitions. Starting with existing systems and established configurations, we explain how the three key dimensions can be deployed to map systems and

longitudinal changes. We then briefly discuss how this can be replicated at the level of emerging niche-innovations. Our empirical analyses do not separately discuss exogenous landscape developments, because this would increase the complexity by adding another analytical layer. Instead, landscape developments, such as oil price spikes, the financial-economic crisis, Brexit, and COVID-19, are discussed when they are immediately relevant for system and niche developments. The conclusions chapter will revisit the role of landscape developments on low-carbon transitions in the various systems.

Techno-Economic Dimensions

Because of our interest in a constructive dialogue with different system assessment approaches and our engagement with climate policy debates, for which techno-economic dimensions tend to be foregrounded (e.g., in carbon-intensive system modelling, in sectorial decarbonisation assessments, in industrial policy), this dimension has a special status in our analysis. The techno-economic dimension allows us to identify and map systems and serves as a distinct analytical dimension.

Each empirical chapter begins with a descriptive mapping of the key techno-economic features and system architecture, following the main material flows, mediating infrastructures, and technical components. To do this, we focus on the dominant techno-economic architecture over the entire period, and schematically depict the connection from production all the way to end uses through a supply-chain logic. This system mapping allows us to identify the main sub-systems involved (for electricity), the orthogonal systems (for heat), and the parallel systems (for passenger mobility), which are then mobilised to structure the analyses of system developments – described in separate sub-sections.

Because of our interest in decarbonisation, these schematic system maps are followed by a description of the main GHG emission reduction trends at play. These emissions reduction patterns provide an overall trend to be explained by our reconfiguration analysis.

For each (sub)system, we then describe techno-economic aspects and developments following a broadly chronological order. The following questions guide our analyses of techno-economic dimensions along material, market, and innovation (especially low-carbon improvements) aspects:

- What are the main technical components, infrastructures, material flows, and transformation activities involved? How are they linked in systems? Where multiple alternatives exist (e.g., fuel inputs, appliances, modes), what is their relative weight and relationship? How have these material components and their linkages changed over time?

https://doi.org/10.1017/9781009198233.004 Published online by Cambridge University Press

- What are the main market developments within the considered systems and subsystems (e.g., input costs, infrastructure and maintenance, accessibility)? How have these changed over time?
- What are the main technical problems addressed through innovation? What are the main low-carbon innovations contributing to improving existing systems? How have these changed over time?

Actors

Several relevant social groups take active part in making systems function the way they do, maintaining them the way they are, framing and regulating their use, using them and deriving a service from them, and engaging in critical debate about relevant issues and desirable priorities for their further development. For each subsystem, we describe actors and their activities over time following a broadly chronological order. For the existing (sub)systems, we mostly discuss operational activities of established actors but also include actors that are not operationally related but nevertheless exert pressure for change, such as wider publics and civil society actors. Because of our analytical scope, we have limited the actors that we include in our analyses to the following, relatively consensual, categories: firms, policymakers, users, and wider publics.[1]

The following questions guide our analyses of actors and networks for each of the categories above:

- For all actor categories: What actors are involved? What actions do they perform with respect to using, maintaining, or altering systems?
- For firms: What are the distinctive features of firms involved in this system (e.g., role, specialisation, market and policy influence, historical presence)? How is the industry structured? What are the main strategies enacted by firms? What are the low-carbon strategies enacted by firms, and how important are these compared to other concerns? Have these strategies changed over time?
- For policymakers: What are the main policy objectives and priorities? What is the importance of climate and decarbonisation relative to other sectorial policy priorities? What are the main policy activities (e.g., debates, negotiations, struggles)? How have they changed over time?
- For users: What are the main users and user practices in this system? What is the level of user engagement with appliances and system choice? What are the main user priorities (e.g., cost, accessibility, comfort, convenience, experience)? What are the main attitudes concerning low-carbon alternatives? How have these changed over time?

[1] Under this label, we include civil society actors and societal issues influencing public opinion.

https://doi.org/10.1017/9781009198233.004 Published online by Cambridge University Press

- For wider publics: What are the main societal issues being discussed and debated relative to this system? What is the relative importance of climate and decarbonisation in public debates? What are the main civil society groups seeking to influence this system?

Policies and Governance

For each (sub)system, we describe the main policies implemented and discuss whether features of a governance style are identifiable. Our interest in low-carbon transitions leads us to give a special status to related decarbonisation policies, but these are considered in the context of broader strategic interventions in the sector, particularly if these are supporting or hindering decarbonisation.

Concerning policies and their implementation, we follow a chronological order and discuss the policy instruments implemented to orient and accelerate the decarbonisation of existing systems, which includes the deployment of low-carbon innovations. These instruments include those typically discussed within environmental policy, such as formal regulatory instruments (e.g., rules, regulations, standards), market-based instruments (e.g., financial (dis-)incentives), and informational instruments (e.g., awareness raising, labelling), as well as additional instruments more specific to innovation and industrial policy (e.g., RD&D programmes, infrastructure investments, supply-chain development, training, and skilling).

For these policies, we document the objectives, degree of ambition, and implementation and seek to explain why particular interventions have led to significant achievements while others have been interpreted as failures or having insignificant positive outcomes. So, we are particularly attentive to the conditions of implementation, that is, understanding not only what works but also why and under which conditions.

Additionally, our interest in the governance of low-carbon system reconfigurations over time led us to pay attention to the interaction of multiple goals and instruments in policy mixes. Accordingly, we have identified three issues as critical to effective policy mix design and implementation in Chapter 2, namely the coherence of goals, the consistency of instruments, and the comprehensiveness of instruments.

Last, we seek to situate the observed succession of policy interventions within broader policy paradigms and related governance styles, which we understand as identifiable approaches to framing and handling policy problems.

Accordingly, the following questions guide our analyses of policy and governance issues:

- For policy instruments: Which policy instruments have been deployed and implemented? What are the objectives and rationales? Have they been successful

https://doi.org/10.1017/9781009198233.004 Published online by Cambridge University Press

in supporting low-carbon changes? Have they been criticised, and if so, why? Have they endured and strengthened over time?

- Concerning policy mixes: Are there multiple interacting policies driving changes in the system? Were their objectives *coherent* or working at cross-purposes? Are their intended and actual effects *consistent* between instruments (e.g., reinforcing or undermining) and over time (e.g., cumulative, interrupted, or reversals)? Are the policy instruments *comprehensive* in their scope, types, and in terms of the balance of targeted dimensions?
- Concerning governance styles: How can the main governance style be characterised? What are the underlying rationales justifying the needs and means of intervention? Is there more emphasis on market-based logics or regulations and standards? Is the governance approach targeting whole system reconfigurations or more limited piecemeal improvements? What is the degree of interventionism and prescription (versus reliance on more voluntary approaches)? What is the degree of government leadership and coordination concerning the steering of long-term changes and/or technological choice prescription? Are certain actors and networks privileged?

3.2.3 Data Sources and Practical Considerations

The intended scope and depth of this book calls for the mobilisation of a wide range of data sources and literatures. Concerning the empirical analyses, we rely on a combination of longitudinal quantitative data and qualitative interpretations of various developments, as well as primary and secondary data sources. The literatures and data sources broadly cover three aspects and related requirements.

Documenting longitudinal system changes requires reliance on descriptive quantitative time-series concerning GHG emissions and techno-economic variables (e.g., sector size, economic output trends, investment trends). For these, we rely mainly on official GHG inventories and sector-level economic statistics, due to their extensive scope. We do not enter methodological debates about the reliability of government statistics. Our main concern is to document relative changes, to enable inter-sector comparisons.

For actors, policies, and governance styles, we require more in-depth kinds of data and analyses. For this, we rely primarily on secondary literatures from energy, buildings, and transport studies, which cover specific dimensions (e.g., on actors and strategies, policies, struggles, learning) or combinations thereof, at various points in time. A significant interpretive challenge concerns making sense of disciplinarily disparate sources to identify the main issues and trends, and to reflect the variety of relevant social groups involved.

Documenting innovation and transition dynamics requires sources that are more focussed on temporal and processual dimensions (e.g., emergence and momentum,

inertia and lock-in, transformative change). For this, we rely primarily on innovation and transitions literatures, which cover a range of analyses of individual niche-innovations or system-level dynamics. A significant interpretive challenge concerns making sense of multiple dynamics to turn them into multi-dimensional yet concise narratives about the focal system and its possible developments. Fortunately, we do not start from scratch. In the past decade, socio-technical transition scholars have made many in-depth analyses of specific low-carbon innovations, on which we can build our aggregate analysis. For our system analyses, we can also build on (socio-political and techno-economic) interpretations from domain-specific experts, many of whom have started to use the MLP as analytical frame, which facilitates our task. The interpretation of these empirical 'building blocks' inevitably introduces subjectivity, but it also allows for creativity, which is necessary to make sense of the many heterogeneous data.

Together, these different aspects and the range of sources mobilised is unprecedented to our knowledge. For instance, existing reports on sector decarbonisation such as those produced by the Committee on Climate Change usually do not cover actors and institutional aspects and adopt a rather narrow interpretation of innovation trajectories (e.g., costs, efficiencies, and barriers).

3.3 Evaluating Reconfigurations in the Making

The bulk of the empirical chapters are concerned with documenting and tracing socio-technical developments over time, by distinguishing relevant analytical dimensions and by following both existing systems and niche-innovations. While we have already discussed how these developmental narratives combine description and interpretation, these are followed by conclusions that make a more interpretive move: the evaluation of reconfigurations in-the-making.

The objective of our evaluation of system reconfigurations is threefold. First, we are interested in explaining a concrete phenomenon: progress with low-carbon performance. We seek to explain this by reference to concrete innovations and the underlying systemic changes, which we analyse through reconfigurations. Second, because of our commitment to the MLP, we seek to evaluate reconfigurations from a specific perspective, which emphasises the dynamic interactions between niches and systems. This leads us to explore reconfigurations as the combined result of a) system lock-in and unlocking, b) processes of niche-innovation (emergence, diffusion), and c) emergent reconfiguration patterns. Third, because we are interested in the unfolding of system reconfigurations over time and into the future, we aim to provide evaluative interpretations concerning prospective trajectories.

In terms of concrete operationalisation, we first provide an overall evaluation of the role of low-carbon innovations in driving GHG emission reductions. To do

this, we seek to attribute the relative importance of examined innovations in system-level decarbonisation, as well as to provide a general interpretation of the core patterns at play (e.g., incremental innovation, diffusion in sheltered niches, substitution). Following this, we examine reconfiguration patterns systematically within each of our analytical dimensions (techno-economic, actors, policy), and qualify whether the changes observed are limited, moderate, or substantial.

For techno-economic reconfiguration, our main concern is to qualify the different kinds of reconfiguration patterns implied by the interaction of the examined niche-innovations with system dynamics. To do so, we first position the examined niche-innovations within Table 2.1, by considering the degree of departure from existing techno-economic configuration's core elements (reinforced or substituted) and its architecture (unchanged or changed). By examining the relative importance and momentum of different types of niche-innovations over time, we are able to describe systemic preferences for a particular techno-economic reconfiguration trajectory, as well as to make informed evaluation about possible developments, particularly in terms of more radical and transformative change.

Concerning actor reconfigurations, we seek to trace the main changes in the goals, agendas, interests, and strategies of actors and networks involved. We are particularly interested in the degree of actor reconfiguration and its evolution over time in each sub-system, that is, their propensity to change/stability and their actual change/stability. To do this, we first provide a synthetic evaluation of major changes concerning established actors and new actor coalitions. Following this, we delve into a more detailed and systematic evaluation of the kinds and degrees of change for each actor category, notably by distinguishing a) actor changes in support of low-carbon transitions (for both incumbents and new entrants), and b) developments indicative of actor lock-ins, resistance to change, or competing issues inhibiting low-carbon transitions. Compounded together, these indicative evaluations build-up into a rich picture of the momentum for change and the degree of inertia (lock-in) as related to various actors.

Concerning institutional reconfigurations, our focus is primarily set on policy interventions and governance style. To evaluate changes in policy instrumentation, we examine the degree of change in the kinds of instruments, their articulation into policy mixes, and their effectiveness in supporting low-carbon developments. We are primarily interested in tracing patterns, that is, regularities, changes, or deviations over time. Similarly, when examining changes in governance styles, we are particularly interested in tracing the key changes over time, which allow us to make informed evaluations about possible future developments.

Last, and this represents yet a higher level of aggregation in pattern tracing, we seek to derive some general interpretation of the scope, depth, and speed of reconfigurations.