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Governing Energy Transitions Under System Complexity:Why Coordination Failures Persist Despite Networked Governance

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Abstract

Energy transitions depend on coordination across interdependent actors, infrastructures and practices. As electrification, sector coupling and decentralisation reshape energy systems, governance challenges have shifted from control-oriented delivery towards problems of interaction, responsibility and system coordination, yet governance arrangements continue to struggle with persistent coordination failures across institutional contexts. This article argues that such difficulties cannot be explained as implementation problems or insufficient cooperation alone. Coordination failures are conceptualised as manifestations of a mismatch between how energy systems function and how they are governed, distinguishing supply-chain governance assumptions from energy systems operating as service networks. The analysis shows how prevailing governance remains oriented towards linear responsibility and asset-based performance, even as outcomes increasingly depend on coordinated action and resource integration in use. Network-based arrangements represent partial adaptations that acknowledge interdependence without reconfiguring underlying governance logics. Building on this diagnosis, three design principles—relational accountability, alignment-based performance measurement, and constitutive coordination—clarify what a genuine shift in governance logic would entail, as distinct from adaptive overlays. The framework is illustrated through regional energy governance experiences in Sweden and comparable European settings, clarifying why coordination failures persist in sustainability transitions characterised by complex socio-technical interdependence.

Keywords: energy governance; energy transitions; network governance; service networks; governance design

1. Introduction

The energy transition is now understood as a societal transformation rather than a purely technological shift. The electrification of energy services, the expansion of variable renewable generation, and the coupling of electricity with heating, transport and digital infrastructures have fundamentally altered how energy systems operate and are governed. Coordination and long-term system steering have moved to the centre of the sustainability debate [1]. That shift is the starting point of this article.

Transition studies frame energy transitions as governance challenges and describe energy systems as shaped by interactions among technologies, institutions and practices, unfolding through non-linear processes over long time horizons [1,2]. From this perspective, policy cannot be reduced to instrument choice or market correction but must engage with how societal coordination is organised across multiple levels and sectors.

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Policy-oriented research documents the limits of hierarchical and sector-based governance in the face of system complexity. Governance scholars argue that energy transitions require participatory and reflexive policy arrangements that can accommodate uncertainty, learning and contestation of goals and pathways [3]. Such approaches treat stakeholder involvement and cross-level coordination as prerequisites for managing long-term structural change.

Innovation and sustainability research has adopted ecosystem perspectives to describe how energy transitions depend on interactions among firms, public authorities, users and intermediaries. These perspectives show that no single actor controls the transition process, and that outcomes depend on the alignment of roles, incentives and expectations across diverse actor constellations [4]. These studies converge on governance arrangements that prioritise coordination and adaptability over centralised control.

A persistent gap remains between governance ambitions and observed outcomes in energy transitions. Many policy initiatives—particularly in maritime, heat and local flexibility pilots in the Netherlands, the United Kingdom and elsewhere—have struggled to scale beyond initial demonstration [5,6], cross-sector solutions remain difficult to sustain, and coordination costs discourage participation by smaller actors—municipalities, energy communities and SMEs operating outside vertically integrated utility structures [7]. These challenges have been documented across different institutional contexts and are not limited to particular technologies or policy instruments.

Infrastructure-focused work explains why such difficulties persist. Studies of energy distribution and infrastructure transformation find that prevailing models of governance continue to prioritise short time horizons and static notions of efficiency, even as system requirements evolve [8]. Investment decisions and regulatory frameworks are often designed around individual assets or sectors, rather than around system-level performance and adaptability over time.

Transition pathway research shows that different governance logics lead to fundamentally different energy system configurations. Comparative pathway analyses show that market-led, government-led and civil-society-led governance approaches do not merely produce different policy mixes, but instead shape how energy demand, supply structures and user practices co-evolve over time [9]. These findings suggest that governance choices influence the architecture of energy systems themselves, not just the pace of decarbonisation.

Network-based forms of governance have gained prominence in response to growing interdependence between actors and infrastructures. Collaboration platforms, public–private partnerships and multi-actor coordination arenas are being increasingly used to bridge sectoral boundaries and facilitate joint action. However, research on network governance has also highlighted significant limitations. Hendriks [10] finds that such networks are dominated by governmental and industrial actors, while questions of accountability, inclusion and responsibility remain unresolved. Network arrangements frequently operate as add-ons to existing institutional frameworks. They rarely transform the frameworks they attach to.

Together, these bodies of research point to a recurring but insufficiently articulated problem. Energy transitions are widely understood as processes that require coordination across interdependent actors, infrastructures and practices. At the same time, many governance instruments remain organised around linear, sector-specific and investment-centred assumptions that are poorly aligned with how contemporary energy systems function. What remains under-theorised is not the need for coordination itself, but the underlying assumptions about how energy systems are organised that continue to structure governance instruments, responsibilities and performance metrics.

This article argues that addressing this tension requires greater attention to the system logics embedded in energy governance. Rather than focusing solely on improving individual policy instruments or governance arrangements, coordination failures are conceptualised as manifestations of a mismatch between how energy systems operate and how they are governed. By synthesising insights from energy governance, infrastructure studies and transition research, the article develops an analytical framing that makes this mismatch explicit and analytically tractable.

The framework developed here is intended to complement, not replace, established socio-technical transition theory. Multi-level perspective analyses have long recognised that transitions unfold through interactions among niche, regime and landscape levels [1,2], and recent work has argued for integrating policy and transition perspectives more explicitly [11]. What the analytical lens developed here contributes is a different cut across this literature: rather than tracing how socio-technical regimes reproduce or destabilise over time, it isolates a specific structural feature of contemporary governance—the mismatch between supply-chain assumptions and service-network functioning—that helps explain why coordination failures persist even where transition dynamics are well documented. The two levels of analysis are complementary: regime dynamics describe what changes and why, while the logic-mismatch framework specifies why prevailing governance instruments cannot fully accommodate the resulting interdependence. The puzzle is not why change is slow, but why particular coordination problems recur.

This article makes three main contributions. First, it offers a problem-oriented synthesis of energy governance research that highlights shared assumptions and recurring challenges across diverse studies. Second, it positions network governance as an incomplete adaptation to increasing system interdependence, rather than as a fully fledged governance alternative. Third, it introduces an analytical framework that helps explain why prevailing governance approaches struggle to support long-term sustainability in energy transitions, and why similar coordination problems recur across different sustainability domains characterised by complex socio-technical systems. These governance challenges are not peripheral to climate mitigation objectives; instead, they increasingly shape the pace, scalability and robustness of energy transitions under climate change.

2. Governing Energy Transitions Under System Complexity

2.1. Governance Responses to System Complexity

A recurring starting point in contemporary energy transition research is the recognition that energy systems are complex socio-technical configurations, rather than merely technical installations. Technologies, institutions, markets and user practices continuously interact, often in ways that are difficult to predict or control [1]. As electrification and sector integration intensify these interactions, the limitations of linear planning models and sector-specific governance arrangements have become apparent [12].

Rather than treating policy as a steering mechanism directed at well-defined objects, transition research treats it as a process unfolding over long time horizons, across multiple arenas of action. The multi-level perspective has been particularly influential in this regard, framing transitions as the outcome of interactions between niche innovations, established regimes and broader socio-technical landscapes [2]. From this standpoint, governance is less concerned with control than with enabling and constraining dynamics of change.

Scepticism towards deterministic policy models has grown, and governance is now described as a matter of shaping conditions under which change can take place, often through indirect and distributed forms of intervention [13]. This move away from command-and-control logics reflects an acknowledgement that transition processes are inherently uncertain and contested.

Policy research has picked up on these insights by emphasising the need for governance arrangements that can cope with uncertainty and disagreement. Voß et al. [14] argue that policies must remain open to revision, allowing goals, instruments and assumptions to be questioned as transitions unfold. On that reading, policy becomes an ongoing learning process rather than a sequence of fixed decisions [15].

Participation features prominently in these responses to complexity. Involving a broader range of actors is commonly justified as a way of mobilising dispersed knowledge and addressing value conflicts that cannot be resolved through technical expertise alone [3]. Participation is thus framed not only as a democratic ideal, but as a functional necessity when governing systems characterised by uncertainty and plurality [16].

Where authority sits spatially and institutionally has also come into focus. Energy transitions span local, regional, national and supranational levels, each of which have distinct responsibilities and capacities. Hooghe and Marks [17] show that misalignment across these levels can undermine policy coherence and slow transition processes. Such tensions are increasingly understood as structural features of transition governance rather than as administrative shortcomings [18].

Innovation studies have reinforced this understanding by emphasising the relational nature of transition processes. Ecosystem perspectives describe energy transitions as emerging from networks of firms, public agencies, users and intermediaries, whose interactions shape innovation pathways over time [4]. From this angle, governance involves coordinating relationships and expectations within and across such ecosystems, rather than targeting individual technologies or organisations [19].

System complexity challenges the effectiveness of hierarchical governance models and calls for approaches emphasising coordination, adaptability and inclusion. Governance is now understood as the management of evolving relationships within interconnected systems, rather than as the exercise of authority over clearly bounded domains [20].

At the same time, this reorientation does not imply the disappearance of intentional steering. Public authorities continue to play a central role, albeit alongside private and civil-society actors, and through a broader repertoire of instruments and practices [21]. As several authors have noted, the challenge lies in reconfiguring steering under conditions of uncertainty and pluralism, rather than abandoning it altogether [22].

Participation, reflexivity and coordination are now routinely invoked in academic and policy debates as responses to transition complexity, and complexity itself has become a dominant explanation for why energy transitions prove difficult to govern [11].

However, this convergence also brings new challenges. While governance responses to complexity are widely endorsed, they often remain articulated as general principles rather than as clearly specified governance architectures. Much of the literature emphasises desirable process attributes, while paying less attention to how existing institutional arrangements channel, constrain or selectively reinterpret these ideas in practice [23].

Participation, reflexivity and multi-level coordination are repeatedly invoked as solutions, even as underlying assumptions about how energy systems are organised remain implicit. Why do established ways of organising responsibility, authority and performance persist within governance systems that explicitly acknowledge complexity?

This is the puzzle the rest of the article addresses.

2.2. Persistence of Linear and Sectoral Governance Assumptions

Despite growing recognition of system complexity, a significant portion of energy governance continues to be organised around linear and sector-specific assumptions. This persistence is less a matter of analytical oversight than of institutional inertia. Governance arrangements, regulatory frameworks and policy instruments are shaped by long-

established ways of defining responsibilities and value within energy systems [12]. These legacies do not simply resist change; they define what change looks like.

A central feature of these arrangements is their reliance on sectoral separation. Electricity, heating and transport have traditionally been governed through distinct policy domains, regulatory regimes and professional communities. Even as energy transitions depend on interactions across these domains, governance structures tend to reproduce these boundaries rather than dissolve them [24]. Cross-sector coordination is often treated as an exception or add-on, rather than as a core organising principle.

Linear assumptions are equally evident in how policy problems are framed. Governance interventions are often designed around sequential models in which policy inputs are expected to generate predictable outputs. This means that planning and regulation are oriented towards discrete projects or infrastructures, with limited attention being given to how these elements interact once deployed in practice [8]. Such models sit uneasily with energy systems shaped by feedbacks, interdependencies and variable use patterns.

These assumptions are reinforced by dominant evaluative frameworks. Performance metrics and accountability mechanisms typically focus on investment volumes, installed capacity or short-term efficiency gains. While such indicators are administratively convenient, they privilege tangible assets over relational and system-level outcomes [22]. Governance success is measured in terms of delivery rather than coordination or adaptability.

Institutional design further contributes to this persistence. Public authorities responsible for energy policy are commonly organised along sectoral lines, with mandates that reflect historical divisions of labour. This organisational structure makes it difficult to address problems that cut across domains, even when those problems are widely recognised [3]. Coordination then becomes a matter of inter-departmental negotiation rather than a built-in feature of governance.

Market-based policy instruments also play a role. Energy markets have traditionally been designed to operate within relatively stable technological and demand conditions. Price signals, contracts and incentives tend to assume well-defined roles for producers and consumers, as well as clear temporal and spatial boundaries. As energy transitions disrupt these assumptions, market arrangements—designed for a settled world—lag behind, reinforcing governance architectures that struggle to accommodate dynamic interaction and shared responsibility [25].

Recent policy developments illustrate rather than resolve this pattern. Landmark instruments such as the U.S. Inflation Reduction Act (2022, with headline commitments around USD 369 billion in energy-related provisions) and the EU's Carbon Border Adjustment Mechanism (transitional phase from October 2023) mobilise unprecedented ambition, yet both operate through mechanisms characteristic of supply-chain logic: uncapped tax credits tied to domestic content, sector-specific investment incentives, and border adjustments organised around embedded emissions in traded goods [26–28]. The European energy crisis of 2022 exposed the same pattern from a different angle. Faced with wholesale electricity prices exceeding 700 EUR/MWh at their peak and disrupted Russian gas supply, governance responses defaulted to interventions oriented towards supply security, pricing controls and fuel substitution, while cross-sectoral coordination and demand-side integration received comparatively marginal treatment [29,30]. In both cases, the response mobilises significant political capital and financial resources, but its underlying governance logic continues to prioritise asset delivery and sectoral instruments over the coordination of interdependent uses.

Pathway-focused transition research provides further insight into the consequences of these assumptions. Comparative analyses demonstrate that governance logics premised on market coordination, state planning or civil-society engagement lead to markedly different

energy system configurations over time [9]. These differences arise not solely from policy choices, but from deeper assumptions about how coordination should occur and where responsibility should reside. Once embedded, such assumptions shape subsequent policy responses and limit the range of feasible alternatives.

Linear and sectoral governance does not persist simply because actors resist change. It reflects the stabilising role of institutions, routines and evaluative practices that favour clarity, control and accountability over adaptability. From this perspective, governance arrangements prioritise manageability, even as the systems they govern become more complex [31].

What is striking, however, is that many governance reforms explicitly acknowledge complexity while leaving these underlying assumptions largely intact. Strategies calling for coordination, participation or integration are layered onto existing frameworks without fundamentally altering how responsibilities are allocated or how performance is assessed [23]. This layering can create the appearance of transformation while preserving the core logic of linear governance.

In practice, the result is a recurring pattern. Coordination problems intensify. Calls for new governance approaches follow. Those approaches are then implemented within institutional settings that continue to privilege sectoral control and linear planning. The resulting tension helps explain why governance innovations often struggle to move beyond pilots or to deliver sustained system-level change.

Understanding why these assumptions persist is critical for explaining governance failure in energy transitions. Rather than treating coordination problems as implementation deficits, this perspective highlights how deeply embedded ways of organising governance shape what is considered possible or desirable.

2.3. Network Governance as an Incomplete Adaptation to Interdependence

As coordination challenges intensify in energy transitions, network-based forms of governance have been promoted as a way of addressing interdependence across actors, sectors and governance levels. Partnerships, platforms and collaborative arrangements are often presented as pragmatic solutions to the limits of hierarchical steering and sector-specific regulation. In this sense, network governance represents a deliberate attempt to adapt governance practices to more relational and interconnected energy systems [32].

At a basic level, network governance responds to a real problem. Energy transitions involve heterogeneous actors who possess different resources, forms of authority and types of knowledge. No single organisation can control system outcomes, and cooperation becomes a practical necessity rather than an optional supplement. Networks are intended to facilitate coordination where formal hierarchies and market mechanisms prove insufficient [33].

In the energy domain, network-based arrangements take many forms—public–private partnerships, multi-stakeholder forums and regional collaboration initiatives among them. Such arrangements are designed to align expectations and mobilise resources across organisational and sectoral boundaries. They are also frequently framed as flexible and context-sensitive alternatives to rigid regulatory approaches.

However, research has consistently shown that network governance is not a neutral or unequivocally progressive response to complexity. Empirical studies indicate that participation in governance networks is often uneven, with government agencies and large incumbent actors exercising disproportionate influence [10]. While networks are intended to broaden involvement, they may reproduce existing power asymmetries rather than challenge them.

This is partly because network governance is commonly layered onto existing institutional structures, as documented for instance in the Norwegian electricity sector's successive reform waves and in comparable collaborative-governance settings elsewhere [34,35]. While networks are created to improve coordination, core responsibilities, regulatory competences and accountability mechanisms typically remain unchanged. Network participants therefore operate within constraints defined by sector-specific mandates and linear planning frameworks [36]. Coordination is encouraged, but rarely institutionalised in a way that fundamentally reshapes governance architectures.

This has important implications for accountability. In network settings, authority is diffuse and decision-making responsibilities are shared. While this can enhance flexibility, it also complicates questions of who is responsible for outcomes and how performance should be assessed. Papadopoulos [37] shows that accountability fragments and becomes opaque when networks lack clear mandates or formalised decision rules.

The problem is not simply one of design. Network governance often emerges as a pragmatic response under conditions where existing institutions are unable or unwilling to change more fundamentally. Networks provide a space for addressing coordination problems without confronting entrenched sectoral divisions or revising core governance logics. In this sense, they function as adaptive overlays rather than transformative mechanisms.

In energy transitions, calls for integration coexist with persistent institutional separation. Networks are frequently tasked with delivering cross-sector coordination, while operating within governance systems that continue to prioritise sectoral accountability and investment-centred performance metrics. Expectations placed on networks can therefore exceed their actual capacity to effect change [38].

From a governance perspective, this creates a characteristic tension. On one hand, network arrangements acknowledge interdependence and seek to manage it through collaboration. On the other hand, they rarely alter the underlying assumptions about how energy systems are organised, measured and governed. As a result, networks may mitigate some coordination problems while leaving their structural causes largely intact.

Repeated mobilisation without corresponding institutional reform has been observed to erode the effectiveness of network arrangements over time, as legacy institutions retain countervailing power [7,35]. When networks are repeatedly mobilised to address systemic problems without corresponding institutional reform, their effectiveness may decline over time. Participation becomes costly, expectations remain unmet, and trust can erode among participants [39]. Rather than enabling sustained coordination, networks risk becoming symbolic gestures of responsiveness.

In this context, it is critical that network governance should not be interpreted simply as success or failure. Instead, it reveals the limits of adaptation within existing governance logics. Networks represent an acknowledgement that energy governance must grapple with interdependence, but they also expose how deeply embedded assumptions about responsibility, control and performance continue to shape governance responses.

Seen in this light, network governance is best understood as an incomplete adaptation to system complexity. It signals movement away from strictly hierarchical models but stops short of reconfiguring the institutional foundations of energy governance. Coordination challenges persist despite the proliferation of collaborative arrangements. Partial adaptation is why.

The implication for energy transition research is that the analytical focus should not be on whether networks are beneficial or problematic per se. Rather, attention should be directed towards the conditions under which network governance is embedded and the extent to which underlying governance assumptions are reconsidered. Without such

reconsideration, networks are likely to remain constrained by the very structures they are intended to overcome.

3. Analytical Framing: Governing Energy Systems Through Competing Logics

3.1. Why Governance Continues to Misfire Under Complexity

The preceding chapters highlight a persistent paradox in energy governance. On one hand, research on energy transitions has developed a sophisticated understanding of system complexity, interdependence and uncertainty. On the other hand, governance practice continues to generate coordination problems that appear both predictable and persistent. Similar observations have been made in earlier transition research, where the gap between conceptual advances and governance outcomes has been repeatedly noted [3].

Many of the difficulties identified in Chapter 2 are routinely framed as problems of implementation, capacity or political will. Coordination failures have been attributed to insufficient collaboration, misaligned incentives or ineffective stakeholder engagement. While such explanations capture important features of governance practice, they tend to treat recurring problems as contingent rather than structural. Critical governance scholarship has long cautioned that this perspective risks overlooking how deeply embedded assumptions shape policy design and limit the scope of feasible interventions [22].

A different interpretation emerges when attention shifts from governance instruments to the underlying logics through which energy systems are understood. How policy makers conceptualise what is being governed—that is, how causality is assumed to operate, how responsibilities are defined, and how performance is measured—profoundly shapes governance arrangements. These assumptions are often institutionalised and reproduced through routines, rules and evaluative practices, making them resistant to change even when their limitations are widely acknowledged [12].

Governance does not misfire because complexity is ignored. It misfires because complexity is acknowledged at the level of discourse, while organising principles rooted in linearity and separable domains remain intact. Reflexive and participatory instruments are introduced, but they operate within institutional settings that continue to privilege control, predictability and sectoral accountability [14]. Governance recognises complexity. It is not reorganised around it.

This analytical perspective also clarifies why many governance innovations struggle to deliver sustained system-level change. While network arrangements and coordination platforms are added to existing frameworks, the basic assumptions underpinning responsibility and evaluation remain unchanged. As several authors have observed, such layering can create the appearance of transformation while preserving the core logic of established governance regimes [3].

Understanding governance failure in energy transitions requires more than identifying deficiencies in policy design or execution. It also requires interrogating the organising logics through which energy systems are governed and asking how these logics shape what governance arrangements can plausibly achieve. Making these logics explicit is a necessary step towards explaining why coordination problems persist despite broad agreement on the need for adaptive and inclusive forms of governance.

The next sections develop this framing.

3.2. Energy Governance as Supply-Chain Thinking

A central claim of this article is that much of contemporary energy governance continues to operate according to assumptions characteristic of supply-chain thinking. While this logic is rarely articulated explicitly, it exerts a strong influence over how problems are

framed, responsibilities allocated and performance assessed. Understanding this logic is necessary for explaining why coordination problems persist despite widespread recognition of system complexity.

At its core, supply-chain thinking conceptualises energy systems as sequences of production, distribution and consumption. Value is assumed to be created upstream and delivered downstream through identifiable channels. Governance, in turn, aims to ensure the efficient functioning of these channels by regulating inputs, optimising flows and securing delivery. Such assumptions have historically been well aligned with centralised energy systems based on large-scale generation and predictable demand [40].

This logic is reflected in how roles within the energy system are defined. Producers, network operators and consumers are treated as distinct categories, each associated with specific responsibilities and decision rights. Policy instruments are typically designed to influence behaviour within these roles rather than to address interactions between them. Even when new actors emerge, they are often accommodated by fitting them into existing role definitions rather than by rethinking the structure of coordination itself [41].

Supply-chain thinking also shapes expectations about causality. Policy interventions are commonly conceived as discrete inputs that generate corresponding outputs. It is expected that investment will lead to capacity, regulation will lead to compliance, and incentives will lead to behavioural change. This sequential logic underpins planning practices, cost–benefit analyses and regulatory impact assessments, all of which assume relatively stable relationships between action and effect [8].

Measurement and evaluation reinforce these assumptions. Performance is frequently assessed through indicators such as installed capacity, investment volumes, or unit-based efficiency metrics. While such measures provide clarity and support accountability, they privilege tangible outputs over relational or systemic outcomes. Coordination, learning and adaptability tend to remain secondary concerns because they are more difficult to quantify and assign to individual actors [22].

Supply-chain thinking is not inherently misguided. It offers a coherent and administratively manageable way of organising governance in systems where flows are relatively stable and responsibilities can be clearly delineated. It also aligns well with legal and organisational structures that prioritise accountability, transparency and control. These strengths help explain why this logic remains deeply embedded in energy governance institutions, even as system conditions change.

This characterisation should not be read as suggesting that supply-chain governance operates without coordination. In electricity systems, the delivery of energy has long depended on tightly coordinated operational functions such as frequency regulation, balancing, contingency planning under N-1 requirements, and inter-operator dispatch. An N-1 requirement means that a system must continue to operate safely and reliably even if any single critical component fails or is taken out of service.

Transmission and distribution system operators coordinate continuously to maintain stability under evolving grid-code requirements, and increasingly with aggregators and prosumers as distributed resources proliferate [42,43]. What distinguishes this coordination from the interdependence characteristic of service networks, however, is not its intensity but its structure. It is organised hierarchically around defined roles and asset-specific responsibilities, with each actor expected to secure its own segment of the delivery chain and operational coordination delegated to specialised intermediaries working within a bounded technical script. Coordination is thus real but constrained—it optimises within an existing division of tasks rather than reconfiguring who is responsible for what [7]. The mismatch identified in this article is therefore not between coordinated and uncoordinated governance, but between two categorically different logics of coordination: one that secures

asset delivery within an established role structure, and one in which value emerges through the ongoing integration of resources across those roles.

However, problems arise when this logic is extended to contexts for which it was not designed. As energy systems become more decentralised and interdependent, outcomes depend on how actors adjust and coordinate in use rather than on how resources are delivered. In such settings, linear causality becomes harder to sustain and governance arrangements built around sequential control struggle to cope with feedbacks and mutual dependencies [12].

A consequence of this mismatch is that governance responses often focus on correcting individual components rather than addressing systemic interaction. Coordination problems are interpreted as failures of compliance, incentives or implementation rather than as signals that the organising logic itself may no longer be adequate. Supply-chain thinking channels attention towards incremental adjustment while rendering alternative ways of organising governance less visible.

This dynamic also helps explain the appeal of network-based governance arrangements discussed in the previous chapter. Networks are mobilised to compensate for coordination deficits that supply-chain-oriented governance cannot easily address. However, because these arrangements are introduced without challenging the underlying logic of responsibility, measurement and control, they often become overloaded with expectations they are poorly equipped to meet.

Supply-chain thinking thus functions as a powerful but largely implicit template for energy governance. It structures how problems are defined and which solutions appear feasible, even in settings where its assumptions are increasingly contested. Making this logic explicit matters. It explains both why linear governance persists and why later attempts at coordination hit ceilings.

Section 3.3 develops the contrasting service-network logic.

3.3. Energy Systems as Service Networks

An alternative way of conceptualising energy systems departs from linear delivery and instead focuses on how energy services are realised through use, interaction and coordination. In service research, value is understood as something that emerges in use when multiple actors integrate resources in specific contexts rather than as something embedded in a product and transferred to a recipient [44]. From this perspective, energy systems cannot be reduced to infrastructures that deliver energy units; they must be understood as configurations that enable and sustain services such as comfort, mobility, reliability and flexibility in practice [45].

A defining feature of this service-oriented perspective is that no single actor produces a service in isolation. Services materialise only when heterogeneous resources—technical, organisational and behavioural—are combined across actors [44]. Resource integration is the fundamental system mechanism through which service performance is generated. Individual service actors are structurally dependent on others, not by choice but by design, because their own contribution has value only insofar as it is aligned with complementary resources within the broader system [46].

This changes how actors and users should be analytically positioned. In service systems, users are not external endpoints of delivery chains but integral participants in value creation [45]. Their practices contribute directly to system performance by shaping demand patterns and system stability. Conversely, system operators and infrastructure providers rely on user practices to realise intended outcomes. What appears as individual behaviour at the micro level is simultaneously a constitutive component of system-level functioning [47].

Service systems research has developed this insight explicitly at the system level. Service systems are defined as dynamic configurations of people, technologies and institutions that co-produce value through interaction [48]. In such systems, performance results from the quality of coordination among interdependent actors rather than from the additive effect of individual actions. This means that mutual adjustment, information exchange and shared expectations are central determinants of system outcomes, not auxiliary features [49].

Temporal dynamics further reinforce this interdependence. Service performance unfolds over time and is shaped by feedback between use, capacity and system state. In energy systems characterised by variability and uncertainty, outcomes depend on collective synchronisation rather than on sequential delivery. Service-network perspectives make this explicit by conceptualising systems as ongoing processes of alignment rather than as chains of causation [47].

These insights resonate with research on collective resource governance, where system outcomes depend on shared use and mutual dependence, not on individual optimisation. Studies of commons governance demonstrate that when resources are jointly relied upon, effective governance requires institutional arrangements that support coordination, monitoring and adaptive rule-making among interdependent actors [50]. This logic closely parallels energy systems in transition, where services are co-produced across organisational and sectoral boundaries.

This parallel with commons governance must, however, be qualified carefully. Classical formulations of collective resource governance emphasise bounded resource systems and distinct communities of users, whereas contemporary energy systems operate through open, digitally mediated and geographically distributed configurations of actors whose boundaries and memberships are fluid. Treating an electricity system as a single, closed commons would therefore overstate the analogy. What remains analytically productive is the polycentric extension of commons theory: the recognition that collective resource situations often involve multiple centres of decision-making that operate with partial autonomy while coordinating across scales [51]. This extension has proven equally applicable to distributed digital infrastructures, where governance is exercised by multiple, partially autonomous centres coordinating around shared but non-bounded resources [52]. Distributed energy resources, such as rooftop solar and battery storage, support the same reading. Grimley and Chan [53] find that distributed energy resource deployments in cooperative electricity systems function as common pool resources negotiated across scales by different decision-making centres over time, not as centrally administered assets. Understood in this way, service-network logic does not require energy systems to satisfy the boundedness of classical commons; it borrows the polycentric insight that interdependence and shared reliance require institutional arrangements which support coordination, monitoring and adaptive rule-making across multiple, partially autonomous centres of governance.

Understanding energy systems as service networks does not entail a normative claim about what governance should look like. Instead, it provides an analytical system model for explaining how energy systems function in practice. By foregrounding resource integration, interdependence and collective performance, the service-network perspective reveals system properties that remain obscured when governance is organised around linear delivery and discrete responsibilities.

The perspective's value here is its system-level orientation: coordination problems become consequences of governing a system whose performance depends on institutionally structured interaction, not failures of individual actors or policy instruments. This provides the analytical foundation for examining the governance consequences of a mismatch between supply-chain assumptions and service-network functioning.

3.4. The Governance Consequences of a Logic Mismatch

Read side by side, the two perspectives expose a fundamental tension in contemporary energy governance. While energy systems increasingly operate as service networks whose performance depends on coordination, interaction and resource integration, governance arrangements remain largely organised around assumptions characteristic of supply-chain thinking. Research on energy governance has repeatedly pointed to similar tensions between system complexity and prevailing governance forms, even if the underlying logic has not always been made explicit [3,22].

A first and immediate consequence of the mismatch concerns how responsibility is allocated. Supply-chain-oriented governance typically assigns responsibility to discrete organisations that are held accountable for delivering specific outputs. This presupposes that system performance can be decomposed into separable contributions. In service-network systems, however, outcomes emerge from interdependent action, which makes responsibility inherently distributed rather than individually attributable. As Papadopoulos [37] observes, attempts to enforce linear accountability under conditions of interdependence often produce fragmented or diluted responsibility, not greater clarity.

Performance measurement raises closely related problems. Governance regimes grounded in delivery and control rely on indicators that can be attributed to individual actors, such as installed capacity, investment volumes or compliance metrics. Such measures privilege tangible outputs over relational and processual dimensions of system functioning. Stirling [22] and Kern and Rogge [31] argue that system performance depends on coordination quality, learning and adaptability—dimensions poorly captured by conventional evaluation frameworks.

The mismatch also produces persistent coordination deficits. Network governance arrangements are frequently introduced to address interaction problems that linear governance cannot resolve. However, these arrangements are commonly expected to operate within institutional environments that continue to prioritise sectoral accountability and hierarchical steering. Networks are thus asked to manage interdependence without corresponding authority or changes in evaluative logic, a pattern widely documented in governance research [10,38].

Temporal dynamics make these difficulties worse. Supply-chain governance assumes sequential causality, where interventions are followed by observable outcomes and subsequent adjustment. Service-network systems require continuous alignment over time, as system performance depends on synchronisation across actors and changing conditions. Studies of infrastructure and transition governance find that governance arrangements organised around discrete planning cycles struggle to cope with such feedback-rich dynamics [8].

These consequences do not indicate failure of specific instruments or actors. They reflect structural limitations associated with governing relational systems through logics designed for linear delivery. Governance reforms often acknowledge complexity rhetorically while leaving core assumptions about responsibility, control and performance intact [14,23], with participatory processes, integrative strategies and collaborative platforms layered onto existing frameworks in ways that enhance communication but rarely reshape how authority and accountability are institutionalised—a dynamic particularly visible at regional and sector-coupling interfaces where interdependence is strongest [3,24].

Understanding governance through the lens of a logic mismatch reframes how governance capacity itself is conceptualised. Capacity is not determined solely by the number of instruments or networks in place, but by the alignment between governance assumptions and system functioning. Where governance logics resonate with how systems operate, co-

ordination can emerge with relatively modest intervention. Where they diverge, persistent coordination problems are a predictable outcome [22].

The argument's analytical reach follows from making the tension between supply-chain and service-network logics explicit, which accounts for recurrent governance difficulties across diverse energy transition contexts. Rather than attributing failure to insufficient ambition or implementation deficits, attention is directed towards the deeper assumptions that structure what governance arrangements can realistically achieve. The mismatch is structural, not accidental.

4. Discussion: Governing Energy Transitions Under Service-Network Conditions

4.1. Implications for Energy Governance Design

Framing the coordination problem as a logic mismatch, rather than as an instrument or implementation failure, has direct implications for how governance itself might be redesigned. If the difficulty lies in governing service-network conditions through supply-chain instruments, the design task is not to add more coordination on top of existing arrangements but to reconfigure the underlying logics that shape responsibility, measurement and coordination in the first place. Three design principles follow from the analysis developed here.

The first concerns responsibility. Under supply-chain assumptions, accountability is allocated to discrete organisations, each expected to secure a defined segment of a delivery chain. Service-network conditions, in contrast, require that at least some accountability be organised around collective system outcomes—jointly held rather than individually attributable. Practically, this suggests moving beyond role-based accountability towards arrangements that formalise shared responsibility for system-level performance: joint reporting obligations across sector-coupling interfaces, shared performance criteria between distribution operators, municipalities and prosumers, and evaluation practices that treat interdependence as a governed rather than residual condition. Recent work on multi-actor local energy planning suggests such shifts are possible in principle but require corresponding changes in how legacy actors are incentivised, since existing regulatory frameworks continue to reward vertical performance over cross-actor alignment [7,42].

The second concerns performance measurement. Supply-chain governance evaluates outcomes through indicators that can be attributed to individual assets or investments—installed capacity, delivered volumes, unit efficiency, N-1 compliance. These measures remain necessary but are structurally incapable of capturing the coordination outcomes on which service-network performance depends. Service-network design therefore requires complementary indicator families that jointly capture engagement quality, distributional outcomes, system-level alignment and adaptive capacity (Table 1). The distinction between an incremental overlay and a genuine change in governance logic becomes empirically identifiable at this level: an overlay retains asset-based metrics as the sole benchmarks of success, whereas a substantive shift in logic gives alignment-based indicators authoritative weight in evaluation and resource allocation [35].

The third concerns coordination mechanisms. Networks introduced alongside unchanged evaluation and accountability regimes reliably become overloaded, as the analysis in Section 3 makes clear. Redesign therefore requires that coordination be treated not as an add-on to linear governance but as its organising principle in settings where service-network conditions dominate. This has procedural implications: iterative loops between consultation, decision-making and operation, with traceable feedback between stages; decision matrices that make the linkage between stakeholder input and governance choices visible and versioned; and adaptive rule-making arrangements that permit continuous

adjustment across polycentric decision centres rather than periodic renegotiation between fixed roles [54]. These design elements do not eliminate hierarchy—legacy institutional structures remain—but they position coordination as constitutive rather than compensatory.

Table 1. Illustrative indicator families for service-network governance.

Indicator Family	Example Indicator	Measurement Approach
Engagement—timeliness	Consultation initiated before site/design lock-in	Timestamps; publication and protocol dates
Engagement—representativeness	Demographic and geographic coverage of participants	Comparison against baseline demographic data; inclusion audit
Engagement—responsiveness	Share of stakeholder input with traceable response	Public decision matrix with version history
Distributional—local ownership	Share of local co-ownership in projects	Ownership registers; contractual disclosures
Distributional—benefit sharing	Municipal return; allocation from local energy funds	Financial reports; fund disclosures
System alignment	Cross-sector integration (heat–electricity–transport coupling)	Sector-coupling capacity ratios; alignment audits
Adaptive capacity	Frequency of governance-instrument revision in response to feedback	Rule-change logs; adaptive review cycles

Taken together, these three principles do not constitute a policy prescription. They function as a design compass for distinguishing governance interventions that reconfigure the underlying logic from those that layer coordination onto structurally unchanged institutions. That distinction is analytically important because it clarifies what governance reforms can and cannot achieve. It is also practically important, because it shifts the burden of transition governance from ever-more-elaborate coordination platforms towards the harder institutional work of rethinking responsibility and evaluation.

4.2. Empirical Resonance: Regional and Transnational Illustrations

The analytical framework developed in this article resonates with governance patterns visible in ongoing regional energy planning processes and in comparative European experience. The examples below are illustrative rather than confirmatory: they show how the mismatch between supply-chain assumptions and service-network functioning manifests in applied settings, and how alternative institutional arrangements begin to shift the underlying logic.

Arvika, Sweden. Arvika municipality's Strategic Energy Plan (2025–2026) exemplifies the conditions under which the mismatch becomes practically consequential. The municipality faces a growing industrial electricity deficit alongside a need to legitimise new local generation and grid reinforcement, and must coordinate between distribution system operators, industry, prosumer initiatives and civil society within the statutory consultation window (17 November 2025–31 January 2026) before the plan proceeds to adoption in autumn 2026 [55–57]. Two friction points are analytically illustrative. First, capacity planning and generation expansion are handled through instruments that assume sequential delivery—investment decisions produce installed capacity, which then meets demand—while the actual coordination challenge lies in synchronising DSO (Distribution System

Operator) network development, municipal spatial planning and prosumer integration in ways that classical supply-chain logic does not accommodate [42,58]. Second, questions of social legitimacy, procedural fairness and place identity are increasingly addressed with the same instrument set designed for technical problems, generating consultation costs and downstream conflict that inclusive early engagement tends to prevent [59].

European comparative cases. Three European examples illustrate how governance arrangements can begin to institutionalise service-network functioning: Middelgrunden in Denmark (40 MW, 50 per cent co-operative ownership by more than 8500 households, commissioned 2000–2001), the Bürgerwindpark model in Schleswig-Holstein (with its Leitfaden now in its fifth edition), and Scottish energy policy over the past decade (Table 2). In each case, the shift in logic is empirically legible in the terms developed in Section 4.1: accountability is jointly held, evaluation includes benefit-sharing and participation metrics, and coordination is treated as constitutive rather than compensatory.

Table 2. Illustrative European cases where governance arrangements begin to institutionalise service-network functioning.

Case	Institutional Mechanism	Shift in Governance Logic	Ref.
Middelgrunden offshore wind (Copenhagen, Denmark; commissioned 2000–2001)	50% cooperative co-ownership with more than 8500 members; project layout iterated in response to public consultation	From pre-committed asset delivery to consultation-driven design; distributed accountability	[60]
Bürgerwindpark model (Germany)	Cooperative ownership combined with community energy funds; standardised process guides that translate procedural principles into replicable practice	Institutionalised local benefit distribution; recognition that financial benefits alone do not automatically produce perceived distributive fairness	[61]
Scottish energy policy (2010s onwards)	Procedural justice adopted as a design principle rather than an afterthought; recognition of affected groups and traceable feedback embedded in consultation frameworks	From adjacent stakeholder engagement to constitutive process design	[59,62]

A stylised technical illustration. The mismatch is also visible at the technical–regulatory interface. Virtual power plants aggregating distributed resources to provide frequency containment reserves must operate under grid codes originally drafted for centralised generation, typically with response requirements in the 30 s range; individual actors—DSOs, aggregators, prosumers—can each fulfil their formal obligations while the system-level provision of ancillary services remains structurally fragile [43]. Coordination in such settings depends less on further contractual specification than on the alignment metrics and adaptive rulemaking described in Section 4.1.

These illustrations do not test the framework empirically. They demonstrate that the logic mismatch is not a purely conceptual construct but a governance feature identifiable in concrete institutional settings, and that the design principles derived from it correspond to arrangements already emerging in practice.

4.3. Broader Relevance for Sustainability Transitions

Although this article is grounded in energy governance, the analytical contribution extends beyond the energy sector. The distinction between supply-chain governance and

service-network system functioning addresses challenges that recur across sustainability transitions in complex socio-technical systems. In domains such as mobility, water, housing and digital infrastructure, system performance increasingly depends on coordination among interdependent actors rather than on the delivery of discrete outputs.

Sustainability transitions research has long emphasised that transformative change involves shifts not only in technology, but also in institutions, practices and modes of coordination [1,2]. The logic-mismatch perspective developed here sharpens this insight by showing how governance difficulties arise when inherited system assumptions are misaligned with how systems function in practice. This helps explain why transitions often stall or fragment even when policy ambitions and technical solutions are in place. The three design principles outlined in Section 4.1—relational accountability, alignment-based measurement and constitutive coordination—provide a first cut at what governance redesign might involve in domains beyond energy.

The relevance of this argument is particularly clear in policy domains characterised by shared resources, distributed agency and long time horizons. In such contexts, governance capacity depends less on central control and more on the ability to sustain coordination over time among actors with different mandates and interests. Research on polycentric commons governance highlights how system outcomes emerge from institutionally structured interaction across scales rather than from individual optimisation [50,51], reinforcing the applicability of a service-network perspective to open, digitally mediated infrastructures beyond classical commons settings [52].

By foregrounding system logics rather than specific instruments, the analysis contributes to debates on sustainability governance evaluation. It suggests that persistent governance challenges should not automatically be interpreted as failures of implementation or ambition but instead seen as signals of deeper misalignment between governing assumptions and system functioning [22]. In this sense, the present article offers an analytical lens that supports comparative reasoning across sustainability domains while remaining sensitive to sector-specific and institutional variation.

5. Conclusions

This article has argued that recurring governance problems in energy transitions cannot be adequately understood as failures of policy instruments or implementation. They reflect a persistent mismatch between how energy systems function and how they are governed. Contemporary energy systems now operate as service networks characterised by interdependence, coordination and resource integration, whereas governance arrangements remain largely organised around supply-chain assumptions centred on delivery, control and sectoral accountability.

By synthesising insights from energy governance, infrastructure studies, service systems research and polycentric commons theory, the article has developed a conceptual distinction between supply-chain governance and service-network system functioning. Applied to the diagnostic questions of responsibility, performance measurement and coordination mechanisms, this distinction helps explain why coordination failures recur across diverse energy transition contexts even when policy ambition and technical capacity are high (Section 3.4). It further shows that network-based governance arrangements typically represent incomplete adaptations to interdependence rather than fundamental shifts in governance logic—a distinction with direct implications for how climate-related transitions are evaluated.

Building on this diagnosis, the article has outlined three design principles for governance arrangements attempting to operate under service-network conditions: relational rather than individual accountability, alignment-based rather than solely asset-based per-

formance measurement, and coordination treated as constitutive rather than compensatory (Section 4.1). These principles do not constitute a policy prescription. They function as a design compass that makes visible the difference between governance interventions that reconfigure the underlying logic and those that layer coordination onto structurally unchanged institutions. Regional planning processes such as the Arvika municipality's Strategic Energy Plan in Värmland, alongside comparative European cases in Scotland, Denmark and Germany, illustrate that arrangements consistent with this compass are empirically identifiable and already emerging in practice (Section 4.2).

The article's contribution is analytical. It does not propose a new governance model, nor does it prescribe policy instruments for specific national contexts. Its purpose is to make explicit the system assumptions embedded in governance design and to clarify what governance arrangements can plausibly achieve when those assumptions are misaligned with system functioning. Beyond the energy sector, the logic-mismatch perspective offers a portable lens for sustainability transitions in domains where performance depends on collective coordination over time—mobility, water, digital infrastructure and circular systems included. The framework has not been tested empirically in a comparative multi-case design across such domains, and doing so is the natural next step. Future research can use this perspective to examine how governance assumptions evolve and how alternative system logics might be institutionalised across sustainability domains.

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