

Efficiency Versus Permission

Transaction Cost Economics and Regulatory
Feasibility of Battery Energy Storage for System
Services in the Dutch Electricity System

MSc Thesis — Complex Systems Engineering & Management

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Efficiency Versus Permission

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Feasibility of Battery Energy Storage for System
Services in the Dutch Electricity System

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Cover: High-voltage pylon, power supply and electricity [1]

Preface

This thesis marks the end of my Master's in Complex Systems Engineering and Management at TU Delft, and the end of my time as a student. Looking back, I do so with pride. It was not always easy, but it was worth it.

At TU Delft, I want to thank Laurens de Vries, my first supervisor, for his guidance throughout the process. He helped me form the problem, structure the thesis, and, perhaps most importantly, relativise the TenneT perspective when I needed an outside view. Our discussions, and the occasional conversation about sailing, always helped me see the bigger picture. I want to thank Rutger van Bergem, my second supervisor, for his guidance on the economic dimensions of the thesis. His sessions fundamentally changed how I understood the topic, and I came away from each one thinking differently than when I arrived.

I want to thank Ibtihal Abdelmotteleb, my supervisor at TenneT. She gave me this project, believed in it from the start, and was involved every step of the way. I will not forget the morning we spent in Rotterdam going through the entire TCE analysis together, transaction by transaction, printed out on paper. That session shaped the heart of this thesis. Beyond the content, she helped me find my way inside TenneT, made sure I never felt lost, and turned our weekly meetings into something I genuinely looked forward to.

I also want to thank Paul Pottuijt for welcoming me into the team and giving me this opportunity. TenneT turned out to be the perfect place to end my master's: it is an organisation where everything I learned during my studies, the interaction between technology, institutions, policy, and markets, comes together in practice.

TenneT, as an organisation, provided me with more than just a research setting. The many coffee conversations with colleagues from the System Operations Future Design team and beyond, some of whom I met multiple times to work through a specific question, shaped my understanding of the sector in ways that no paper ever could. Thank you to everyone who made time for me.

I am also grateful to everyone who agreed to be interviewed for this research. Their openness, expertise, and sometimes very direct opinions made the analysis richer and more grounded than it would otherwise have been.

Finally, I would like to thank my parents, Job, my roommates, fellow graduates, and other close friends. Your support, whether during coffee breaks, words of encouragement, or other moments throughout this journey, has meant so much to me. Thank you for listening, understanding, and always being there.

I am proud of what this thesis became. The topic matters, the questions are real, and I hope that those who read it will find it as fascinating as I did. Wishing you an insightful and enjoyable read.

*A.L. (Annegien) Koopal
Delft, May 2026*

Summary

The Dutch electricity grid is kept stable by services that most people never think about. When a power plant suddenly trips offline, something must prevent the frequency from collapsing. When a cable becomes overloaded, something must redirect the flow. For decades, these functions were provided automatically by conventional power plants as a by-product of simply being online. As those plants retire and are replaced by wind and solar, these functions disappear with them. TenneT, the Dutch transmission system operator, is the party that must procure these services and find new ways to provide them as the conventional generation phases out.

Battery energy storage systems (BESS) are technically capable of filling the gap. But unlike a conventional generator, a BESS does not automatically provide grid stability. Every service must be explicitly contracted, specified, and monitored. That means someone must decide who owns the battery, who controls it, and under what conditions. That raises the governance question: what is the efficient governance structure for BESS providing system services in the Dutch electricity system, does the Energy Act 2026 permit it, and where it does not, what is the best feasible alternative?

This thesis applies transaction cost economics (TCE) to derive a governance prediction for each of the six system services: balancing, voltage control, congestion management, synthetic inertia, system strength, and black start. TCE argues that organising any exchange is itself costly: finding a counterparty, writing a contract, monitoring performance, and enforcing obligations all consume resources. The analysis shows that the same physical BESS receives a different governance prediction depending on which service it provides. Balancing services can be procured through competitive tendering because the product is standardised and any qualified provider can participate. Voltage control and congestion management require long-term bilateral contracts because the provider must be physically present at a specific location and cannot easily be replaced. Synthetic inertia, system strength, and black start require TenneT to own and operate the asset directly because performance cannot be adequately verified under contract, and the service is too critical to accept any residual risk of non-delivery.

The most significant finding goes beyond the predictions themselves. The governance outcome for each service is not fixed by the technical properties of the BESS. It is shaped by a regulatory choice: whether standardised product definitions exist. Where European network codes define exactly what a service looks like, how it is measured, and what a provider must demonstrate, competitive markets become feasible. Where those definitions do not exist, as is currently the case for synthetic inertia and system strength, the same technical complexity makes contracting impossible. Standardisation decisions are therefore simultaneously governance design decisions.

The Energy Act 2026 creates an additional layer of complexity. It prohibits TenneT from owning storage assets by default and requires regulatory approval through two routes that have never been used for a BESS in the Netherlands. For three of the six services, the governance form that economics predicts to be efficient is therefore not yet legally accessible in practice.

To bridge this gap, the thesis develops the System Services Governance Framework: a structured decision tool that guides TenneT through the governance choice for any given service, integrating economic efficiency analysis and legal feasibility checks into a single procedure. Applied to three cases at the Utrecht Lage Weide 150 kV node, where the planned closure of a gas-fired fleet in 2030 will simultaneously remove congestion management capacity and inertia from the grid, all three produce a recommendation for long-term bilateral contracting. That recommendation is not permanent. It reflects current conditions: a legal rule that makes direct ownership expensive.

The governance arrangements designed in the next few years will determine whether the stability services lost through the retirement of conventional generation are secured before the gaps open. This demands a nuanced understanding of the gap between *efficiency versus permission*.

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Nomenclature

Abbreviations

Abbreviation	Definition
ACER	Agency for the Cooperation of Energy Regulators
ACM	Autoriteit Consument en Markt (Authority for Consumers and Markets)
aFRR	automatic Frequency Restoration Reserve
BESS	Battery Energy Storage System
CHP	Combined Heat and Power
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
FCR	Frequency Containment Reserve
FINC	Fully Integrated Network Component
FGU	Flevopolder, Gelderland and Utrecht
GFM	Grid-Forming (inverter)
IBR	Inverter-Based Resource
mFRR	manual Frequency Restoration Reserve
N-0	operation at full physical limit with no contingency reserve
N-1	security standard requiring the grid to remain secure following the loss of any single network element
N-2	security standard requiring the grid to remain secure following the loss of any two simultaneous network elements
NC ER	Network Code on Emergency and Restoration
NIE	New Institutional Economics
RoCoF	Rate of Change of Frequency
SoC	State of Charge
SSGF	System Services Governance Framework
TCE	Transaction Cost Economics
TSO	Transmission System Operator
ULW150	Utrecht Lage Weide 150 kV node
vRES	variable Renewable Energy Sources

1

Problem Definition

The retirement of conventional power plants removes functions that the Dutch electricity system can no longer take for granted. Wind and solar do not automatically stabilise the grid the way conventional generators did. Those functions must now be arranged differently.

This chapter establishes why that task is urgent, why battery energy storage systems (BESS) are a candidate solution, and why the governance question, how those arrangements should be organised, has not yet been answered. It concludes by identifying the knowledge gap this thesis addresses and stating its research objective and scope.

1.1. Increasing need for system services

The ongoing transition of the electricity system towards high shares of variable renewable energy sources (vRES) is fundamentally changing system operations. The phase-out of conventional generation reduces the availability of inherent system support [2].

The Dutch electricity system operates within the Continental European synchronous area, a single interconnected grid in which stability is maintained collectively by all connected conventional generators. These generators contributed to system security in two distinct ways. Stability services, including inertia, fault current, voltage support, and black start, emerged passively as a by-product of being online; no explicit arrangement was required. Alongside this, they formed the dispatchable pool on which the transmission system operator (TSO) relies for balancing and congestion management. As inverter-based resources (IBRs) displace conventional generation, both contributions are lost simultaneously. Wind turbines and solar panels connect to the grid through power electronic inverters and do not passively exhibit these services; their variability and locational concentration further intensify congestion at specific network nodes. Both categories of services must therefore be secured through deliberate arrangements [2].

System services are the technical functions that a TSO must secure to maintain safe and reliable system operation. The six services examined in this thesis are balancing, which corrects real-time deviations between supply and demand; congestion management, which manages network constraints and power flows; synthetic inertia, which limits the rate of change of frequency following disturbances; system strength, which maintains a stable voltage reference and provides fault current during disturbances; voltage control, which maintains voltage levels within acceptable limits; and black start, which enables system restoration after a large-scale blackout [3, 4, 5].

Scenario studies and system operator assessments consistently indicate that these structural changes will lead to shortages of system services in the coming decade. The Netbeheer Nederland Scenarios Edition 2025 indicates that, in several future scenarios, existing and planned assets will be insufficient to ensure robust system operation from around 2030 onwards [2]. Similar concerns are raised at the European level, where the European Network of Transmission System Operators for Electricity

(ENTSO-E) highlights growing difficulties in maintaining inertia and short-circuit power as conventional generation is displaced [6]. Dutch system inertia has already declined from 87 GWs in 2020 to 61 GWs in 2024 and is projected to fall below the ENTSO-E minimum for 70% of the time by 2030 [7]. The Dutch TSO, TenneT, has responded by investing in synchronous condensers to sustain inertia levels [8]. The planned closure of the Eneco combined heat and power fleet from 2030 makes the challenge concrete: a substantial share of synchronous inertia is permanently removed from the system, and the dispatchable capacity TenneT currently contracts for congestion management at that location is simultaneously lost [9].

Taken together, these assessments point to an urgent, structural increase in the need for assets to support system services. The existing arrangements cannot be extended: they depend on the implicit provision of conventional generators that are retiring on a fixed schedule, and no arrangement can substitute for assets that will no longer exist. Replacement assets must therefore be in place before the retirements occur, and must collectively cover the aggregate service contribution of the retiring fleet across multiple service types simultaneously [6].

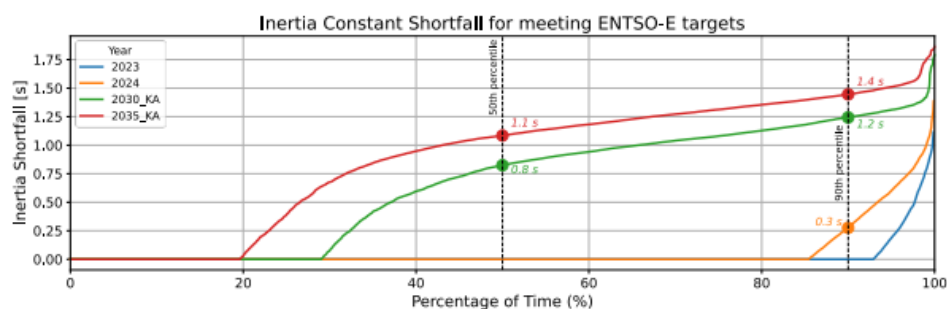


Figure 1.1: Inertia constant shortfall duration curves for the Dutch transmission system under four scenarios (2023, 2024, 2030, 2035). The y-axis shows the shortfall in GWs relative to the ENTSO-E recommended minimum; the x-axis shows the percentage of time that shortfall is exceeded. By 2030, Dutch system inertia is projected to fall below the ENTSO-E minimum for 70 percent of operating hours. [7]

1.2. The role of the TSO and relevant stakeholders

TenneT is the owner and operator of the 110 kV, 220 kV, and 380 kV transmission grid in the Netherlands. Its statutory tasks are to transport electricity, maintain the balance between supply and demand, and support the energy market [10]. Securing system services is central to all three: it underpins the resilience of the transmission grid and ensures that the market can function under all system conditions.

Several actors shape the space within which TenneT operates. Autoriteit Consument & Markt (ACM) is the national energy regulator responsible for supervising TenneT and enforcing Dutch energy law [11]. BESS operators are the counterparties that own and operate flexible assets and can provide system services on TenneT's behalf. ENTSO-E sets European-level technical standards and network codes that determine how services are defined and procured across the synchronous area [12]. The European Commission and Agency for the Cooperation of Energy Regulators (ACER) set the regulatory baseline through Directive 2019/944 and Regulation 2019/943, which govern how electricity markets and network operations are organised across the EU [13].

1.3. Current state and limitations of existing solutions

The provision of system services in the Netherlands is currently organised through a combination of market-based mechanisms, regulated procurement, and implicit provision by conventional generation assets. Balancing is the most mature service: TenneT procures Frequency Containment Reserve, automatic Frequency Restoration Reserve, and manual Frequency Restoration Reserve through competitive platforms shared with neighbouring TSOs [14]. Congestion management relies on operational redispatch and bilateral contracts [9]. Voltage support is procured through tender-based arrangements, though participation is limited to a small number of technically suitable assets at specific transmission

nodes [15]. Black start is secured through long-term contracts with strict technical requirements [16]. Stability services, synthetic inertia and system strength have no explicit market products in the Netherlands. They are currently ensured through grid design standards, the residual presence of conventional generation, and regulated investments in synchronous condensers [8].

As conventional generation retires, the assets that implicitly provided several of these services are removed, and no arrangements yet exist to replace what they delivered [5]. The gap between the services the system requires and the assets available to provide them is not a temporary adaptation problem; it is structural, and it grows as the energy transition progresses.

1.4. BESS as a candidate solution

BESSs are technically capable of contributing to all six services and can be installed at specific grid nodes within shorter lead times than conventional generators. Their modular design, fast response, and compatibility with grid-forming inverter control make them well-suited to fill the gap left by the retirement of conventional generation [3].

Technical capability alone does not resolve the problem. Unlike conventional generators, which provide system services as an automatic consequence of being online, a BESS must be configured, contracted, and controlled to deliver each service [17]. System services are critical functions whose failure has systemic consequences that cannot be corrected after the fact; TenneT requires not only an efficient arrangement but one that guarantees delivery with sufficient certainty. The central question is therefore not whether BESS can replace conventional generation; it can, but how the arrangement to deploy it should be organised.

1.5. The knowledge gap

Before 1 January 2026, the Dutch electricity law provided no pathway for TenneT to own or operate a BESS; all system services had to be procured from private BESS operators through market-based mechanisms. The Energy Act 2026 is the successor to the Electricity Act 1998 and the Gas Act, consolidating Dutch energy law into a single statutory framework. Its entry into force on 1 January 2026 changed the legal conditions for TenneT by opening, for the first time, conditional pathways for TenneT to own storage assets directly [18]. This creates the central problem this thesis analyses:

What is the efficient governance structure for battery energy storage providing system services in the Dutch electricity system, does the Energy Act 2026 permit it, and where it does not, what is the best feasible alternative?

Answering that question requires an analytical framework that systematically derives governance recommendations from each service's characteristics. Three governance structures are available to TenneT. Market governance takes the form of competitive tendering, in which TenneT periodically awards contracts to whichever BESS operator offers the required service at the lowest price. Hybrid governance takes the form of long-term bilateral contracting, in which TenneT negotiates a dedicated service agreement with a specific BESS operator for a defined service at a defined grid location. Hierarchy takes the form of direct ownership, in which TenneT itself owns and operates the BESS. Because the six services differ substantially in their technical requirements, asset specificity, and verifiability, no single governance structure is efficient across all of them. Transaction cost economics (TCE), as developed by Williamson (1985, 1991), provides the framework for determining which form is appropriate for each [19, 20]. By analysing the characteristics of individual transactions, TCE derives governance predictions from the structure of the problem rather than by assumption. These predictions must then be tested against the Energy Act 2026.

1.6. Research objective and scope

The objective of this thesis is to develop a governance framework that produces service-specific recommendations for system services provided by a BESS in the Dutch electricity system, grounded in TCE and tested against the Energy Act 2026. The thesis directly addresses a question raised by Ten-

neT practitioners in light of the new legal landscape created by the Energy Act 2026. The analysis is conducted from TenneT's perspective throughout: TenneT is the procuring party for all six services in scope, and the governance arrangements it designs are the subject of the framework. The analysis is bounded by the Dutch transmission system and the Energy Act 2026, which constitute the binding institutional environment. The planning horizon runs from 2030 to 2035, the period in which the retirement of conventional generation creates the structural need for BESS-based system services.

1.7. Relevance

The scientific relevance of this thesis lies in its application of Williamson's transaction cost economics to a context in which it has not previously been applied: BESS-based system services in a liberalised electricity market with explicit ownership restrictions. The thesis further extends the alignment framework of Künneke, grounded in North's institutional economics, to a new technical and regulatory context, contributing to the literature on infrastructure governance in transitioning energy systems. The societal relevance is direct: the governance arrangements that TenneT designs over the next five years will determine whether the stability services lost through the retirement of conventional generation are replaced before the service gaps open. The framework provides a systematic and theoretically grounded basis for those decisions, at a moment when no such basis currently exists.

This thesis aligns with the Complex Systems Engineering and Management programme by addressing the interaction between changes in technical infrastructure and the institutional frameworks that govern it. The energy transition turns the electricity system into a more uncertain, multi-actor socio-technical system in which technical constraints and regulatory design jointly shape feasible solutions. The research, therefore, adopts a systems perspective on how governance structures influence the integration and operation of flexibility resources such as BESS.

1.8. Thesis outline

Chapter 2 develops the theoretical framework, introducing New Institutional Economics, Williamson's transaction cost economics, North's institutional environment, and Künneke's alignment framework, which together form the thesis's analytical foundation. Chapter 3 establishes the technical background, characterising the six system services and the BESS properties that determine which services it can provide and under what constraints. Chapter 4 describes the research design and methodology, translating the theoretical framework into an operational analytical procedure. Chapter 5 applies TCE to each of the six services, assessing transaction characteristics and deriving a governance prediction for each. Chapter 6 tests those predictions against the Energy Act 2026, identifies where the efficient governance structure is legally available and where governance gaps exist, and examines European comparative practice. Chapter 7 integrates both analyses into the System Services Governance Framework, a sequential decision tool that produces a governance recommendation for any defined BESS-based system service. Chapter 8 applies the framework to the Utrecht Lage Weide node through a case study examining synthetic inertia, N-1 curative congestion management, and a combined multi-service configuration. Chapter 9 presents the discussion. Chapter 10 presents the conclusions and recommendations. Chapter 11 presents the personal reflection.

2

Theoretical Framework

This chapter develops the analytical foundation for the governance analysis that follows. It draws on Williamson's transaction cost economics, North's institutional economics, the alignment framework of Künneke, Ménard and Groenewegen, and Ostrom's design principles. Section 2.1 introduces New Institutional Economics. Section 2.2 presents Williamson's four-layer model. Section 2.3 examines the institutional environment. Section 2.4 develops transaction cost economics as the analytical core. Section 2.5 introduces the alignment framework. Section 2.6 applies Ostrom's design principles. Section 2.7 synthesises the four perspectives into the analytical approach of this thesis.

2.1. New Institutional Economics

This thesis is based on the theoretical foundation of New Institutional Economics (NIE). NIE studies the rules and norms that humans devise to reduce uncertainty and control their environment [21]. NIE is based on the observation that institutions matter. These include formal institutions, such as written agreements and regulations, as well as informal institutions, such as codes of conduct and norms. These institutions define the framework within which interaction takes place [21, 22].

Neoclassical economics, NIE's theoretical forerunner, is an economic theory that focuses on marginal analysis to determine prices, output, and resource allocation. It assumes that exchange is costless and that markets function frictionlessly [23]. NIE goes a step further: it rejects this assumption. Organising economic activity is costly in itself. Searching for trading partners, negotiating terms, drafting contracts, monitoring performance and enforcing agreements all consume resources. These costs determine which organisational forms emerge, persist and perform well, and which do not [24, 19].

These costs arise from two fundamental attributes of human behaviour. The first is bounded rationality: while people intend to act rationally, their ability to foresee future events, process complex information and design comprehensive agreements is limited [25]. It is simply not possible to write a contract that anticipates every situation that may arise during the lifetime of a long-term exchange. The second feature is opportunism: when gaps or ambiguities exist in an agreement, parties may exploit them to their own benefit [19]. It is the combination of the two that makes organising exchange a significant problem. If either of these conditions were absent, governance structures would be unnecessary. Governance structures are the mechanisms through which order is established, and transactions are organised and protected [20].

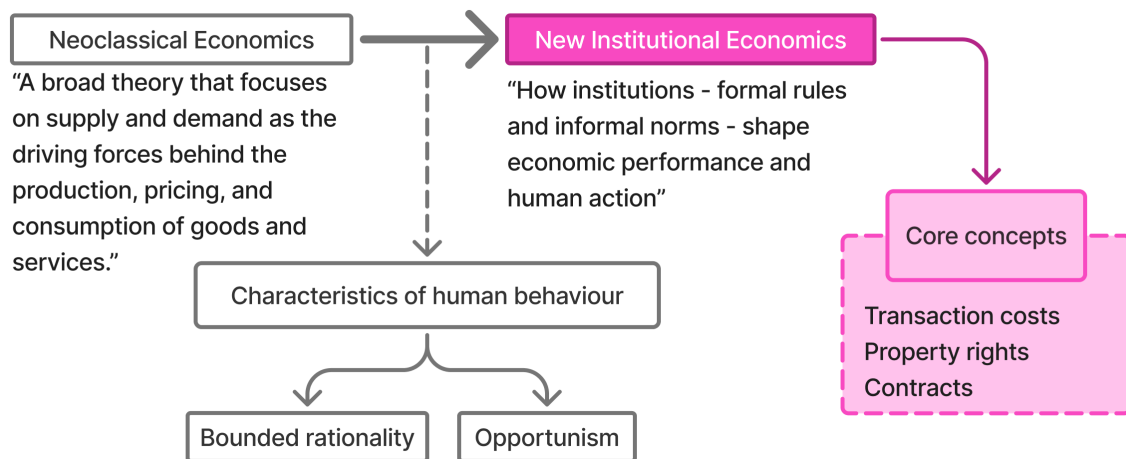


Figure 2.1: Neoclassical economics treats exchange as costless; NIE rejects this by incorporating bounded rationality and opportunism as behavioural foundations. These give rise to NIE's core analytical concepts: transaction costs, property rights, and contracts. (Author's own, based on [19])

2.2. Williamson's four-layer model

In his 2000 publication, Williamson proposes a four-layer model to structure the analysis of institutions [26]. Each layer operates at a different level of abstraction and changes at a different speed. Together, they form a hierarchy of constraints: decisions made at higher layers determine what is possible at lower ones.

Layer 1: Embeddedness. This layer captures informal institutions, such as social norms, customs, traditions and culture. These change very slowly, over centuries. They form the deep background where all formal rules and organisational arrangements operate. This layer is acknowledged, but falls outside the scope of this thesis.

Layer 2: Institutional environment. This layer consists of the formal rules of the game, such as laws, constitutions, property rights and regulatory frameworks [22]. These change over decades through legislative and political processes. Layer 2 defines what is legally permitted and sets the constraints within which governance structures must be designed. For this thesis, the institutional environment includes energy legislation, unbundling rules, and the regulatory conditions that determine whether a TSO can own storage assets.

Layer 3: Governance. This layer concerns the organisation of transactions. Given the constraints set by Layer 2, transaction cost economics operates at this level to determine which governance structure minimises total costs. Layer 3, therefore, determines what is economically optimal, and Section 2.4 develops this analysis in detail.

Layer 4: Resource allocation. This layer describes day-to-day operational decisions, such as prices, quantities, and output levels, in real time. In the context of this thesis, this is the level at which a BESS is dispatched. The governance structure chosen at Layer 3 directly shapes how those dispatch decisions are made.

The layers do not always point in the same direction. Layer 2 defines what is legally permitted. Layer 3 determines what is economically efficient. These two answers do not always align, and that tension runs through the entire thesis.

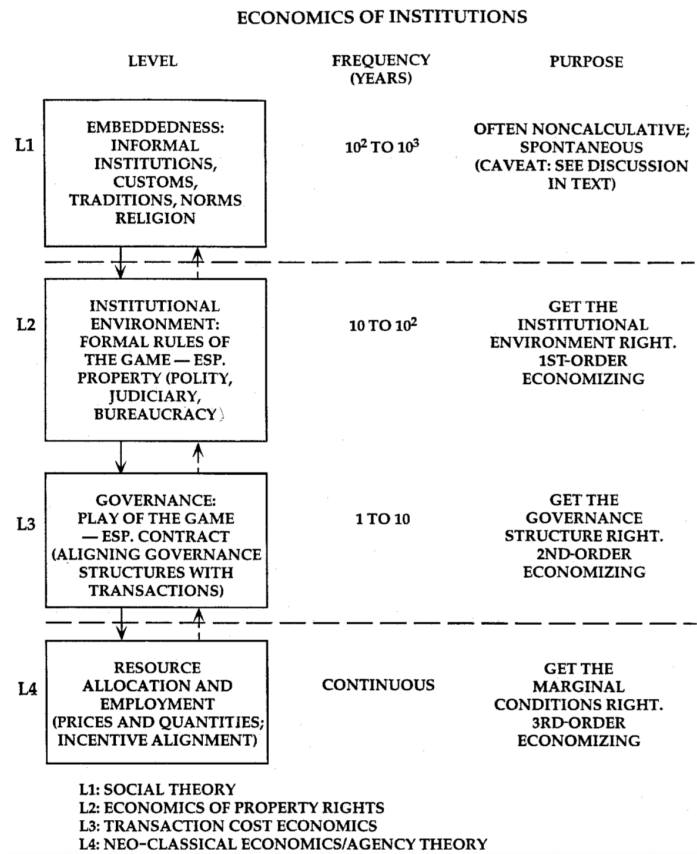


Figure 2.2: Williamson's four-layer model. Each layer changes at a different speed and constrains what is possible at lower ones. For this thesis, Layer 2 defines what governance arrangements are legally permitted and Layer 3 determines which is economically efficient. [26]

2.3. Layer 2: The Institutional Environment

The institutional environment is the set of formal rules governing economic activity. North (1990) refers to these as the 'rules of the game': the laws, regulations and property rights that determine what individuals and organisations can and cannot do [22].

Formal and informal constraints

North (1990) defines institutions as the humanly devised constraints that structure political, economic and social interaction [22]. These constraints take two forms. Formal rules, including constitutions, laws, property rights and regulations, are codified and enforced by the state. Informal constraints, such as customs, traditions and codes of conduct, evolve slowly through social practice. Their primary purpose is to reduce uncertainty and create order. Institutions make complex economic exchange possible [22].

These rules are not neutral. They reflect prior political decisions about how an industry should be organised. Those choices have real consequences for governance outcomes. North (1990) refers to this as path dependency: once an institutional direction has been set, it becomes difficult and costly to reverse, even when the original rationale no longer applies. The default of market-based procurement in European electricity markets was designed for a system dominated by large conventional generators, and it remains in place long after the conditions that justified it have changed [22].

Property rights

Property rights are a core component of the institutional environment. North (1990) identifies them as part of the formal rules that constitute Layer 2. They are specified and enforced by the state. Their distribution is ultimately a regulatory and political question [22]. Demsetz (1967) defines property rights as a bundle of components: the right to use an asset, the right to collect the returns it generates, and the right to sell or transfer it [27].

This distribution directly determines how the exchange must be organised. If one party holds all three rights, that party has full control. However, rights can also be split across parties. One party may own a storage asset while another holds the right to decide when it is charged and discharged. In such cases, the parties must coordinate, and governance structures, contracts, operating protocols, and monitoring mechanisms are the tools used to do so [28].

Enforcement and regulatory oversight

Formal rules only constrain behaviour if they are enforced. North (1990) argues that the capacity to enforce contracts and property rights at low cost is a fundamental determinant of how well an institutional framework performs [22]. In regulated network industries, this enforcement is delegated to specialist agencies.

The regulator's role in governance design extends beyond monitoring compliance. It also acts as a gatekeeper for exceptions. When a regulated entity considers the standard governance model insufficient for a specific service, it must demonstrate to the regulator that an alternative arrangement is justified and proportionate. This gives the regulator an active role in shaping governance outcomes, not merely enforcing existing rules. In the Netherlands, this role is fulfilled by ACM, and its implications for BESS-based system services are examined in Chapter 6.

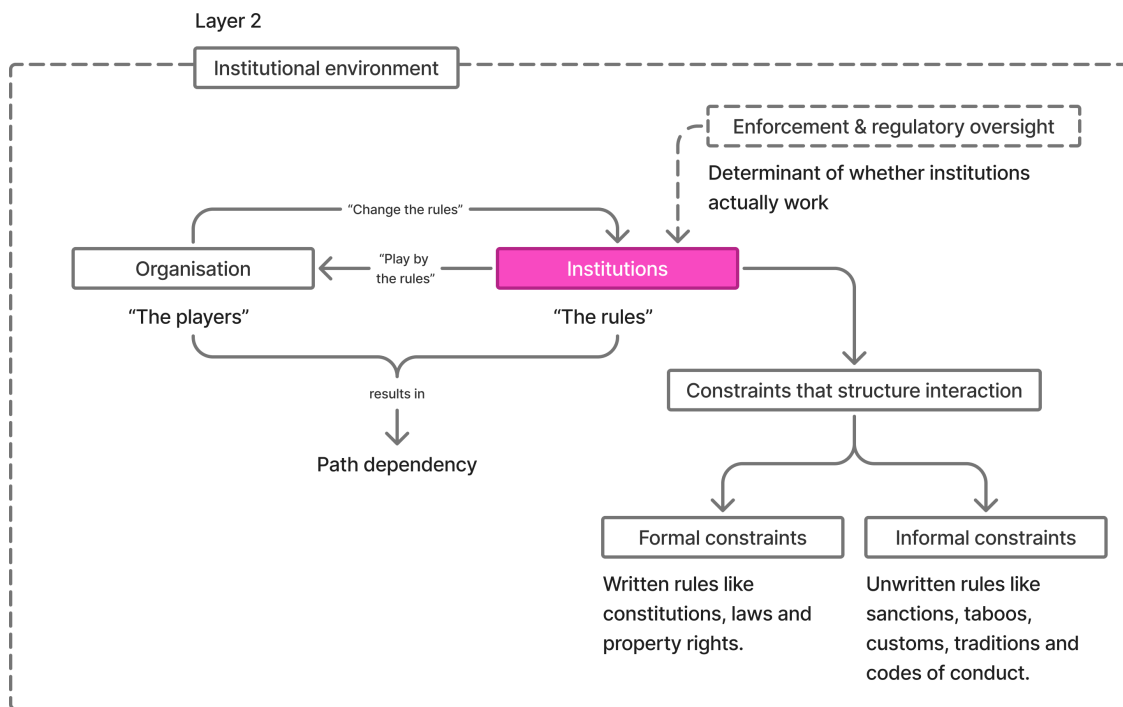


Figure 2.3: The institutional environment (Layer 2). Formal constraints include laws and property rights; informal constraints include customs and codes of conduct. Enforcement determines whether institutions bind behaviour in practice. Interaction between organisations and institutions produces path dependency. (Author's own, based on [22])

2.4. Layer 3: Transaction Cost Economics

The analytical core of this thesis is transaction cost economics (TCE). While Layer 2 defines what is legally permitted, TCE operates at Layer 3 to analyse what is economically efficient. The central idea is that the organisation of a transaction should depend on its characteristics [19].

Transaction Cost Theory

TCE takes individual transactions as its starting point. Williamson (1985) defines a transaction as a transfer of a good or service across a technologically separable interface [19]. In practice, this means any exchange of a good, a service, or a right between two parties.

TCE rests on the two behavioural assumptions introduced in Section 2.1. Bounded rationality means that contracts cannot anticipate every contingency; they will always be incomplete. Opportunism means that parties may exploit those gaps for their own benefit. TCE uses these two assumptions to determine which governance structure minimises the costs of organising a given transaction [23] [25].

TCE distinguishes two types of costs. Production costs are the costs of actually delivering a service: building the asset, operating it, and maintaining it. Transaction costs are the costs of organising the exchange: finding a counterparty, writing the contract, monitoring performance, enforcing terms, and resolving disputes. The central logic of TCE is that the efficient governance structure is the one that minimises the sum of both [19].

This shifts the focus from the cost of the asset itself to the cost of the surrounding transactions [20]. A single asset can be the object of several transactions simultaneously, each with its own characteristics and potentially requiring a different governance structure. A BESS illustrates this directly. One party may hold the right to call on the battery's capacity. Another may hold the right to decide when it charges and discharges. Each is a separate transaction that must be governed independently.

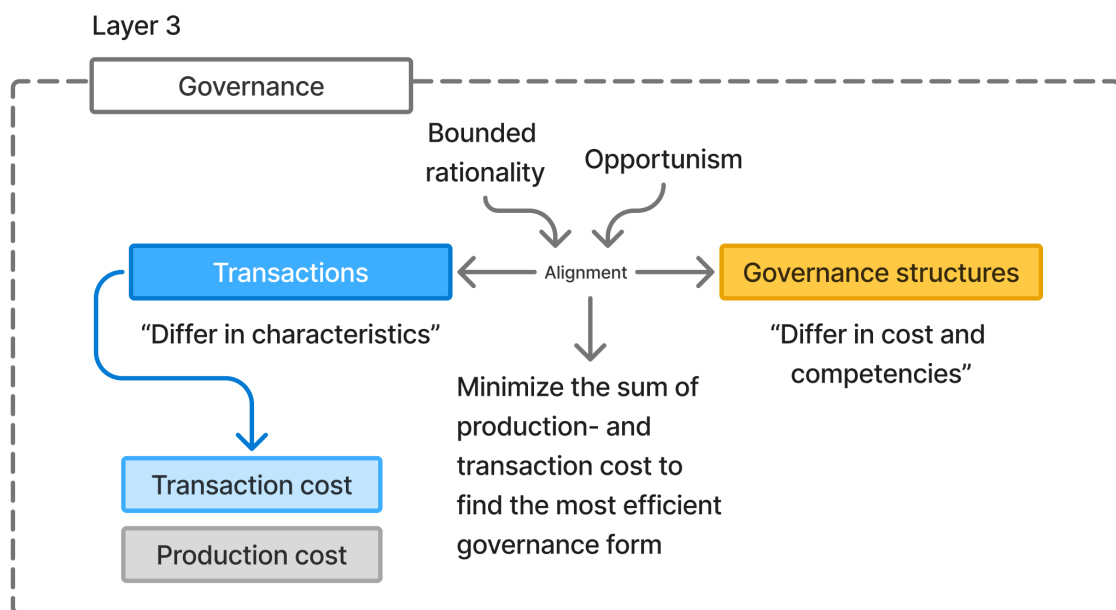


Figure 2.4: TCE at Layer 3. Each transaction must be aligned with the governance structure that minimises the sum of production and transaction costs. Bounded rationality and opportunism make this alignment necessary. This discriminating alignment is the central analytical operation of Chapter 5. (Author's own, based on [19])

Transaction characteristics

Williamson identifies three attributes that determine the cost of organising a transaction and, consequently, the most efficient governance structure.

The most important of these is **asset specificity**. It describes the extent to which an investment is tied to a specific transaction and would lose value if redeployed elsewhere [19]. The higher the asset specificity, the more dependent the parties become on each other, and the greater the risk that one party will exploit this dependence. Williamson distinguishes five types:

Table 2.1: The five types of asset specificity identified by Williamson (1985) [19]

Type	Definition
Site specificity	Value of the asset depends on its location.
Dedicated asset specificity	Investment primarily made to serve a single buyer.
Temporal specificity	Timing of the exchange is critical.
Physical asset specificity	Asset configured for a specific purpose.
Human asset specificity	Specialised knowledge built up through the transaction.

The second characteristic is uncertainty: the extent to which future conditions relevant to the transaction are unknown or unobservable. Because bounded rationality limits what parties can foresee, uncertainty directly affects how difficult and costly it is to write and enforce contracts. Williamson (1989) distinguishes three forms:

Table 2.2: Types of Uncertainty identified by [29]

Type	Definition
Primary uncertainty	Future external conditions, such as prices, demand, or network conditions, are unknown.
Secondary uncertainty	One party has access to information that the other does not.
Tertiary uncertainty	A party deliberately exploits gaps in the contract or limitations in monitoring.

When all three forms are high, contracts become increasingly difficult and expensive to design, monitor, and enforce [29].

The third characteristic is the **frequency** with which the transaction occurs. When transactions occur frequently, it makes sense to invest in more specialised governance, because the setup and maintenance costs are shared across many transactions. Infrequent transactions are usually managed using simpler mechanisms, unless asset specificity or uncertainty is very high [30].

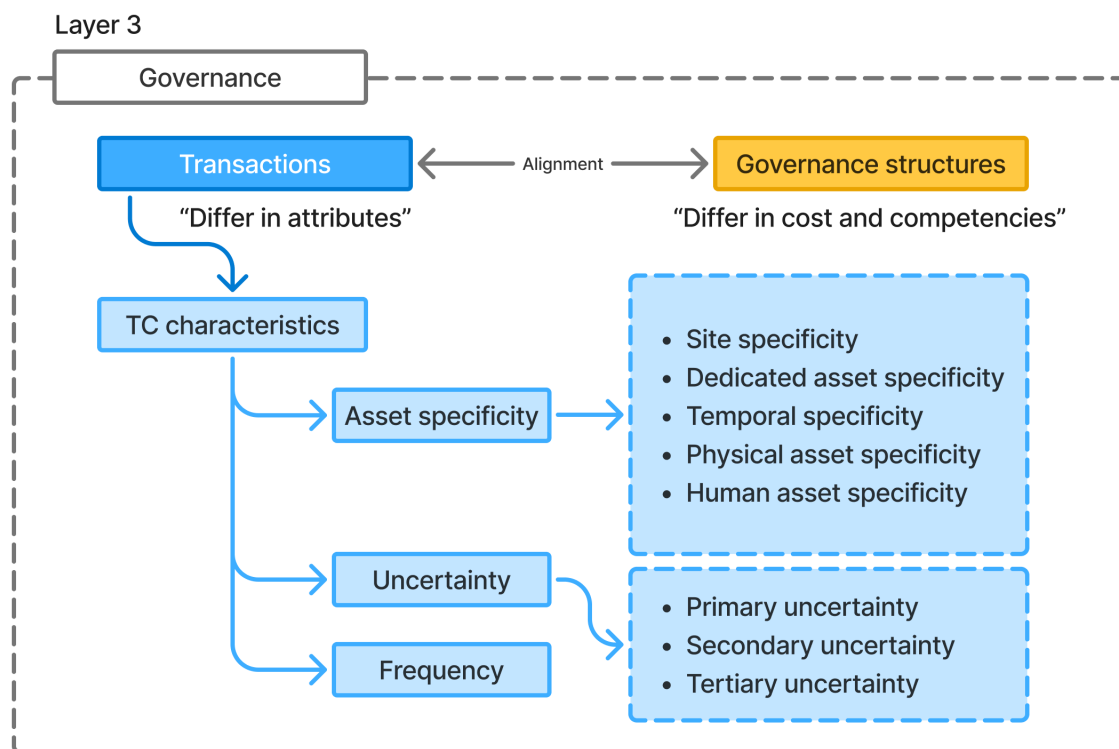


Figure 2.5: The three transaction cost characteristics applied in Chapter 5. Asset specificity is decomposed into five types; uncertainty into three types. Frequency captures how often the transaction recurs. Together they determine the efficient governance structure through discriminating alignment. (Author's own, based on [19, 20])

The Governance spectrum

Based on the transaction characteristics introduced above, TCE predicts which governance structure will minimise total costs. The core logic is that the more complex and risky a transaction, the more control the governance structure needs to provide. Williamson (1991) formalises this as the discriminating alignment hypothesis: transactions that differ in their attributes should be aligned with governance structures that differ in their costs and competencies [20].

Governance structures differ in how they handle adaptation. Adaptation is the ability to respond to changing circumstances. This difference determines which structure is most efficient for a given transaction. Williamson distinguishes two types of adaptation. Autonomous adaptation occurs when parties adjust independently to changing circumstances, for example, a price rise prompting a generator to increase output. Markets excel at this. Cooperative adaptation occurs when a change requires a co-ordinated response between parties, a sudden loss of generation requiring multiple assets to respond simultaneously in a specific sequence. Hierarchy excels at this because a single authority can direct the response without having to renegotiate with each party individually [19].

TCE identifies three fundamental governance structures on a continuum. At one extreme, market governance organises exchange through price signals and competition, with no administrative relationship between the parties. In the Dutch electricity system, this means TenneT procures balancing power through daily auctions. At the other extreme, hierarchical governance organises exchange through ownership and direct control. This is TenneT owning and operating an asset directly, as it does with its transmission infrastructure. Between these two poles sits hybrid governance: long-term contracts between TenneT and a private asset owner that combine market incentives with administrative control. The appropriate position on this continuum depends on the characteristics of the transaction, as illustrated in Figure 2.6 [20].

Governance structures differ along three dimensions. The first is how parties are motivated to perform.

In markets, a party's earnings depend directly on its own performance, creating strong incentives. In hierarchies, behaviour is monitored and directed by a central authority instead. The second is how well the structure responds to change. Markets handle situations where each party can adjust independently. Hierarchies handle situations where a coordinated response is required. The third is how disputes are resolved. Markets rely on courts and contract law. Hierarchies resolve disputes through internal administrative decisions [20].

Table 2.3: Distinguishing Attributes of Market, Hybrid, and Hierarchy governance structures [20]

Attributes	Market	Hybrid	Hierarchy
<i>Instruments</i>			
Incentive intensity	++	+	0
Administrative controls	0	+	++
<i>Performance attributes</i>			
Adaptation (A)	++	+	0
Adaptation (C)	0	+	++
<i>Contract law</i>	++	+	0

The table reveals a clear pattern. Market and hierarchy are opposites: where one scores strongly, the other scores weakly. The hybrid structure sits between the two in all five respects [20]. There is no sharp boundary between the three structures. As transactions become more complex, the appropriate governance structure shifts gradually from market to hybrid to hierarchy.

Market governance

Market governance is the governance structure closest to the neoclassical ideal of frictionless exchange. It organises exchange through price signals and competition, with no ongoing relationship between buyer and seller. It is characterised by three attributes. First, incentive intensity is high: a supplier's earnings depend directly on its own performance, so the rewards and consequences of decisions fall entirely on the party that makes them. Second, administrative control is low: there is no authority monitoring or directing behaviour; parties act independently. Third, disputes are resolved through classical contract law, meaning courts enforce the agreed terms. Agreements are therefore short-term and specific, with most contingencies specified in advance [20].

In the Dutch electricity system, the day-ahead market illustrates this clearly. Generators and suppliers trade electricity one day before delivery through a competitive auction. Prices are set by supply and demand, products are standardised, and no ongoing relationship exists between buyer and seller.

Market governance works well when asset specificity is low. However, as asset specificity increases, switching becomes costly. A buyer can no longer simply replace one supplier with another, and the competitive pressure that keeps market governance efficient begins to disappear [20].

Hierarchical governance

Hierarchical governance organises exchange through ownership and direct control. One party owns both sides of the exchange. Instead of contracts or price signals, it directs operations through internal authority. It is characterised by three attributes. First, incentive intensity is low: individual units are not rewarded or penalised based on their own performance. The owner bears the financial consequences of the whole operation. Second, administrative control is high: a central authority monitors and directs behaviour. It can issue instructions without renegotiating terms. Third, disputes are resolved internally through administrative decisions rather than courts. Williamson refers to this as forbearance [20].

In the Dutch electricity system, this is the standard for transmission assets. TenneT owns the 110kV, 220kV and 380kV grid, including lines, transformers and substations, and dispatches them directly.

Hierarchy is the most effective response to high asset specificity combined with high uncertainty. However, the price is the loss of competitive pressure: without the discipline of the market, the organisation

may become less efficient over time. This is why regulators typically restrict the scope of hierarchical governance in liberalised markets [19].

Hybrid governance

Hybrid governance sits between market and hierarchy. It is the governance structure that NIE uniquely explains. Neoclassical economics recognised only two ways to organise exchange: through markets or through firms. It could not account for the wide variety of long-term contractual arrangements that exist between these two extremes.

In a hybrid structure, two legally independent parties enter a long-term contractual relationship without merging into a single organisation. They pool resources and coordinate closely, but each retains ownership of its own assets and remains responsible for its own financial results. This structure is chosen when a transaction is too complex for a simple competitive tender, but full ownership by one party is either unnecessary or legally prohibited.

It is characterised by three attributes. First, incentive intensity is moderate. A party's earnings still partly reflect its own performance. However, the long-term relationship softens the sharp rewards and penalties of pure market competition. Second, administrative control is intermediate. Behaviour is not directed by a central authority. Instead, the contract imposes obligations that both parties must meet. Third, disputes are not resolved through courts alone. The parties rely on the contract itself and, where needed, a third party to manage disagreements. Williamson refers to this as neoclassical contract law [19].

In the Dutch electricity system, TenneT's long-term contracts for reactive power support illustrate this clearly. TenneT signs a contract of five to ten years with a power plant to guarantee the provision of reactive power and voltage support at a specific grid node. The provider retains ownership and operational control of the asset. TenneT holds the right to call on it and sets the conditions under which it must be available. Neither party owns the other's assets, but both are bound by the terms of the contract.

Hybrid governance takes many forms. Williamson (1985) distinguishes two varieties. Trilateral governance applies to occasional transactions with moderate asset specificity. A third party safeguards the arrangement and resolves disputes. The connection of an offshore wind farm to TenneT's transmission grid illustrates this: a commercial wind developer such as Shell or Vattenfall enters a one-time connection agreement with TenneT, and because the transaction is occasional and neither party has built sufficient mutual trust, ACM acts as the institutional third party. ACM sets the connection tariffs and rules, and resolves disputes about delivery timelines or technical specifications. Neither party needs to develop a long-term relationship because the third party provides the necessary governance safeguard [19].

Bilateral governance applies to recurrent transactions with high asset specificity. It is not simply a two-party contract. It is a governance structure that emerges when both parties have made investments so specific to the relationship that neither can easily walk away. This mutual dependence becomes the governance mechanism itself. The parties develop safeguards through the long-term relationship rather than relying on external enforcement. The operational relationship between TenneT and a regional distribution system operator illustrates this: the two parties interact daily, have built joint operational structures, and have developed shared procedures for coordination and dispute resolution without requiring external intervention for every decision.

Ménard (2004) extends this by identifying a wider range of hybrid forms [31]. Not all are relevant to network infrastructure governance. Franchising, cooperatives, collective trademarks, and virtual firms are developed primarily in consumer-goods contexts and do not apply here. Three forms are relevant to this thesis: long-term bilateral contracts, partnerships and alliances, and joint ventures. These differ in how they allocate control rights and share risk. All, however, combine market incentives with administrative coordination to varying degrees [31]. For the BESS transactions analysed in this thesis, bilateral governance is the most relevant form. The transactions are recurrent, asset specificity is high, and the relationship between TenneT and a private BESS operator is long-term by necessity.

Figure 2.6 illustrates the governance continuum with the different hybrid governance structures. The

horizontal axis represents asset specificity; the curves show the transaction costs of each governance structure at a given level of specificity. The efficient governance structure at any point is the one with the lowest curve. As asset specificity rises, hybrid governance becomes cheaper to organise than market governance, and hierarchy becomes cheaper still at the highest levels.

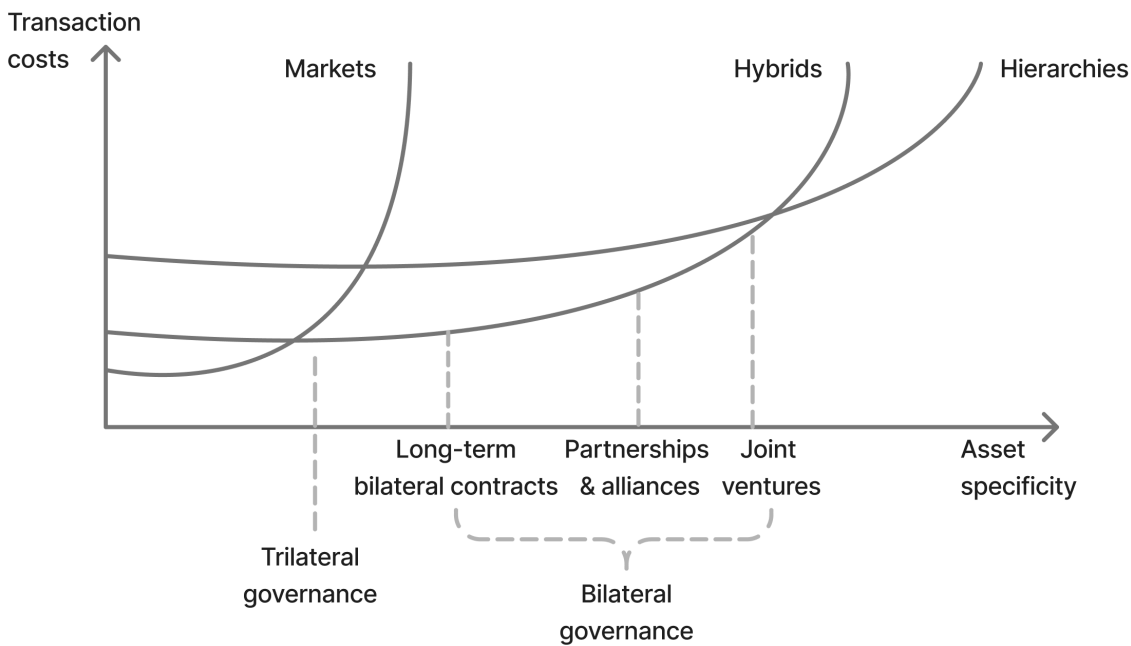


Figure 2.6: Transaction costs as a function of asset specificity for markets, hybrids, and hierarchies. The efficient governance structure is the one with the lowest curve at a given level of asset specificity. Within the hybrid range, trilateral governance applies at moderate asset specificity and bilateral governance applies where mutual dependence is deep. (Author’s own, based on [20, 31])

The relationship between transaction characteristics and the predicted governance structure is summarised in Figure 2.7. As asset specificity increases and uncertainty rises, governance shifts along the continuum from market to hybrid to hierarchy. This figure presents the analytical template to be applied to each system service transaction in Chapter 5.

		Asset-specificity:		
		Non-specific	Mixed	Idiosyncratic
		Uncertainty:		
			Intermediate	High
Frequency:	Occasional	Market governance	Trilateral governance	
	Recurrent		Bilateral governance	Unified governance

Figure 2.7: Discriminating alignment of transaction attributes to governance structures. As asset specificity rises from non-specific to idiosyncratic and uncertainty increases, the efficient governance structure shifts from market governance through trilateral and bilateral hybrid governance to unified (hierarchical) governance. Frequency determines whether occasional or recurrent transactions warrant stronger safeguards. [32]

From asset specificity to governance hazards

Transaction characteristics (asset specificity, uncertainty, and frequency) together determine which governance structure minimises total costs. Of these, asset specificity is the most important and the most complex driver. As asset specificity increases, parties become more dependent on each other. This dependence makes the transaction harder to organise and creates opportunities for exploitation. Four concepts from the TCE literature explain this mechanism: the fundamental transformation, lock-in, hold-up, and quasi-rent [19]. These are not independent problems. They form a causal chain: each concept follows from the previous one. Together, they explain why higher levels of asset specificity require stronger governance responses. Understanding this chain is essential for Chapter 6, where the governance implications of investing in location-specific storage assets are assessed.

Fundamental transformation. Before an investment is made, many suppliers compete for the opportunity. The buyer has options and can choose freely. Once the investment has been made, that changes. The winning supplier has committed resources to a specific asset in a specific location. It cannot easily walk away. The buyer cannot easily replace it. What was once a competitive market has become a relationship between two parties who need each other. Williamson refers to this shift as the fundamental transformation [19].

Lock-in. The result of the fundamental transformation is lock-in. Neither party can exit the relationship without significant loss. The asset owner cannot relocate a site-specific investment. The buyer cannot quickly replace the asset. This mutual dependence creates the conditions for hold-up [33].

Hold-up. A hold-up occurs when one party exploits the other's locked-in position to renegotiate terms after a transaction-specific investment has been made [33]. It does not require bad intentions. It is a structural consequence of asset specificity: once one party is locked in, the other has an incentive to seek better terms. Anticipating hold-up matters as much as preventing it. If investors expect to be exploited after committing to a specific asset, they may demand higher risk premiums or decline to invest altogether.

Quasi-rent. Quasi-rent quantifies the hold-up problem. It is the difference between the value of an asset in its current use and its value in the next-best alternative [33]. The larger this gap, the stronger the incentive for the other party to seize that value by renegotiating terms. For location-specific assets, quasi-rents can be substantial. This is why the governance structure must include safeguards that prevent one party from exploiting the other's locked-in position.

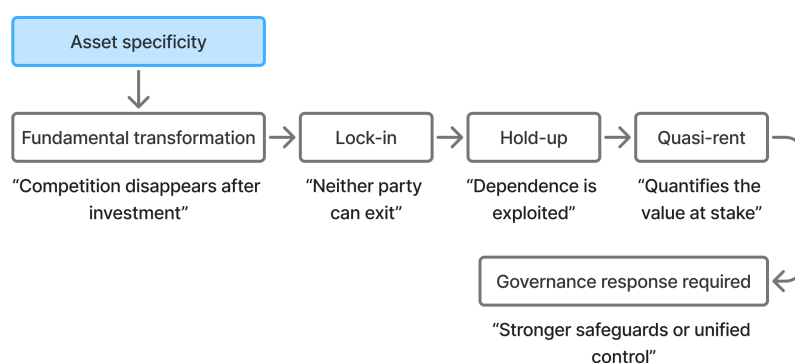


Figure 2.8: The causal chain from asset specificity to the need for a governance response. Once a transaction-specific investment is made, competition disappears (fundamental transformation) and neither party can exit without loss (lock-in). This creates the conditions for hold-up, whose magnitude is quantified by the quasi-rent. The larger the quasi-rent, the stronger the governance response required. (Author's own, based on [19, 33])

The cost comparison logic

TCE does not claim that one governance structure is always superior. Instead, it offers a comparative logic: the efficient structure is the one that minimises the sum of production and transaction costs [19].

This trade-off can be expressed formally. Let the total cost of a governance structure g be the sum of production costs and transaction costs:

$$C_{\text{total}}(g) = C_{\text{production}}(g) + C_{\text{transaction}}(g) \quad (2.1)$$

Transaction costs consist of two components. Ex ante costs arise before the contract is signed: negotiating terms, designing safeguards, and selecting partners. Ex post costs arise after the contract is signed: monitoring performance, managing unforeseen contingencies, and enforcing the agreement [19].

The efficient governance structure is the one that minimises $C_{\text{total}}(g)$.

Figure 2.9 illustrates this logic. As asset specificity increases, the governance costs of market governance rise while the production cost advantages of vertical integration become more attractive. At the critical point, vertical integration becomes the more efficient choice.

This logic forms the analytical basis for Chapter 5, in which the characteristics of each system service transaction are assessed and matched to the governance structure that TCE predicts is most efficient.

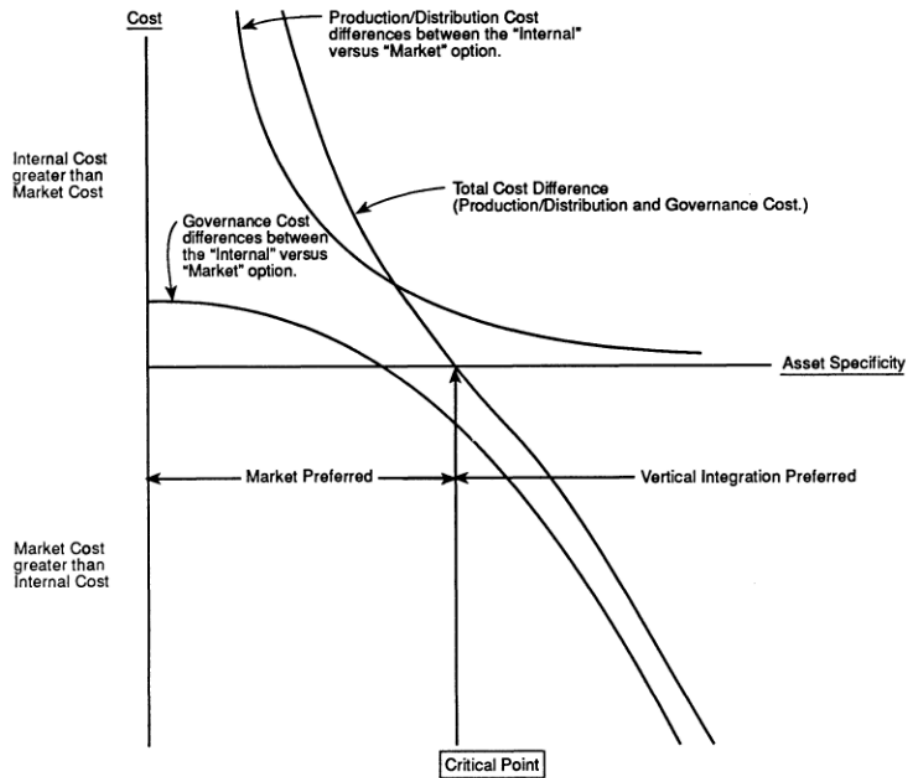


Figure 2.9: The cost comparison logic of TCE. As asset specificity increases, governance costs of market procurement rise while production cost advantages of vertical integration grow. At the critical point, vertical integration becomes the more efficient choice. This crossover determines where hierarchy minimises total costs relative to market governance. [19]

2.5. Network Infrastructure Governance

TCE provides a powerful framework for analysing governance choices, but it has two limitations relevant to this thesis. First, it treats asset specificity, uncertainty, and frequency as given. It does not explain where those characteristics come from. Second, TCE is a pure cost-minimisation framework. It accepts some risk of governance failure as tolerable if the expected cost of that risk is low enough. For critical infrastructure, this is insufficient. The alignment framework of Künneke, Ménard and Groenewegen (2021) addresses both limitations. It is not a replacement for TCE but a necessary extension of it [34].

Critical functions: where TCE reaches its limits

The alignment framework introduces the concept of critical functions: tasks whose failure threatens the integrity of the system as a whole. The six system services examined in this thesis all qualify as critical functions: without them, the electricity system cannot operate safely or be restored after a failure. For these services, TCE's cost-minimisation logic alone is insufficient. TCE can accept some probability of non-delivery if the expected cost is low enough. For critical functions, this trade-off requires closer examination: non-delivery does not simply impose a cost, it may trigger a cascade of failures that no nearby asset can cover. Because critical functions are essential to society and deeply tied to the public interest, their governance is subject to regulatory oversight. The alignment framework thus adds a dimension to TCE that pure cost-minimisation cannot capture, and connects it to the institutional environment of Section 2.3.

Technology determines transaction characteristics

The second contribution of the alignment framework is methodological. TCE takes asset specificity, uncertainty, and frequency as inputs. It does not explain where those inputs come from. The alignment framework fills this gap. It grounds transaction characteristics in the technical properties of the asset: the physical characteristics of the infrastructure that determine how it must be operated and governed. Site specificity follows from grid physics [35]. Physical asset specificity follows from the technical configuration of the asset [36]. Uncertainty follows from the observability constraints of the technology [37]. Transaction frequency follows from whether the physical condition a service addresses can arise continuously or only under specific conditions. Without this step, transaction characteristics in Chapter 5 would be assumed rather than derived. The alignment framework justifies using the technical properties established in Chapter 3 as the foundation for the governance analysis that follows.

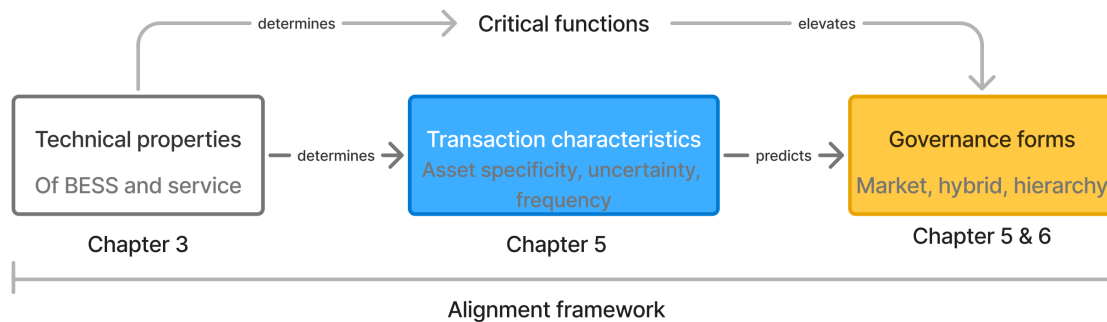


Figure 2.10: The alignment framework of Künneke, Ménard and Groenewegen. Technical properties of the BESS and the service determine transaction characteristics (Chapter 3), which predict the efficient governance structure (Chapters 5 and 6). Where a service constitutes a critical function, this elevates the governance requirement beyond pure cost minimisation. (Author's own, based on [34])

2.6. Ostrom's Design Principles

Ostrom (1990) developed design principles to explain why some institutions succeed in governing shared natural resources (fisheries, irrigation systems, and forests) without resorting to privatisation or state control [38]. These are known as common pool resources. The principles describe the conditions under which self-organising groups of users can sustainably manage a shared resource over time.

Although developed for commons governance, the principles share a theoretical foundation with the NIE framework introduced in Section 2.1. Cox et al. (2010) note that Ostrom's design principles follow North's conception of institutions as mechanisms for reducing uncertainty in complex environments [39]. This means they can be applied alongside the TCE approach of this thesis. They have since been shown to work in a wide range of institutional settings beyond commons governance [39].

In the context of this thesis, they serve a specific purpose: identifying the minimum contractual requirements that a hybrid arrangement between TenneT and a private BESS operator must satisfy to be durable and enforceable. A hybrid contract faces governance hazards that are structurally similar to those found in commons arrangements, such as incomplete specification, monitoring difficulties, opportunistic behaviour, and the risk of disputes. The design principles provide a systematic basis for addressing these hazards.

Of Ostrom's eight principles, six are directly applicable to the context of a hybrid contract. Principles 3 "collective choice arrangements" and 8 "nested enterprises" assume that multiple users govern themselves as a group. This does not apply to a two-party arrangement between TenneT and a private BESS operator. The six applicable principles are:

- **Principle 1 — Clearly defined boundaries:** The service obligation must be precisely specified, including what the TSO can call on, when, and under what conditions.
- **Principle 2 — Congruence:** Contract terms must reflect the specific operational constraints of each service at the specific node.
- **Principle 4 — Monitoring:** The arrangement must include mechanisms to verify compliance.
- **Principle 5 — Graduated sanctions:** Non-compliance should trigger escalating consequences rather than immediate termination.
- **Principle 6 — Conflict resolution:** An agreed procedure for resolving disagreements must be in place.
- **Principle 7 — Recognition:** The arrangement must be recognised as legitimate by the regulator.

Ostrom's design principles provide the analytical basis for translating the governance hazards identified in Chapter 6 into concrete contractual obligations.

2.7. Synthesis

This chapter has introduced a theoretical framework built on four complementary perspectives within New Institutional Economics, each operating at a different analytical level.

Section 2.1 introduced New Institutional Economics as the overarching theoretical tradition, grounding the analysis in the observation that organising exchange is costly and that institutions shape which governance structures emerge and persist.

Section 2.2 presented Williamson's four-layer model, which structures the analysis across four levels operating at different speeds. The model establishes the central tension that runs through the thesis: Layer 2 defines what is legally permitted, and Layer 3 determines what is economically efficient, and the two do not always point in the same direction.

Section 2.3 established the institutional environment as the set of formal rules that constrain governance choices. These rules are not neutral: they reflect prior political decisions about how an industry should be organised, and through path dependency, they remain in place even when the context that justified them has changed. This perspective forms the theoretical foundation for Chapter 6, which examines whether the Energy Act 2026 permits the governance structures that TCE predicts to be efficient.

Section 2.4 introduced transaction cost economics as a tool for determining what is economically efficient. By analysing asset specificity, uncertainty, and frequency, TCE predicts which governance structure (market, hybrid, or hierarchy) minimises total costs. The key concepts of fundamental transformation, lock-in, hold-up, and quasi-rent explain the mechanisms by which asset specificity creates governance challenges. This perspective forms the theoretical foundation for Chapter 5.

Section 2.5 extended TCE in two ways through the alignment framework of Künneke, Ménard and Groenewegen (2021). First, it explains where transaction characteristics come from. The alignment framework derives them directly from the technical properties of the asset and the service it provides, rather than assuming them. Second, it introduces critical functions as a dimension that pure cost minimisation cannot capture. For services whose failure is systemic, the governance structure must

provide certainty of delivery. Together with Section 2.3, this perspective feeds directly into the TCE analysis of Chapter 5.

Section 2.6 introduced Ostrom's design principles as a systematic basis for specifying the minimum contractual requirements of a hybrid bilateral arrangement. Grounded in the same NIE tradition as the rest of this framework, six principles are selectively applied to address the governance hazards identified in Chapter 6.

Together, these four perspectives define the analytical approach of this thesis in two steps. The first step determines what is economically efficient. Each system service is broken down into its underlying transactions. Each transaction is assessed on its characteristics and matched to the governance structure that minimises total costs. This analysis is conducted independently of the legal framework. The second step determines what is legally feasible. The efficient governance structure identified in step one is compared against the constraints of the institutional environment. Where the two align, the efficient structure is also legally available. Where they do not, a governance gap exists, and the analysis identifies the best feasible alternative within the legal boundaries.

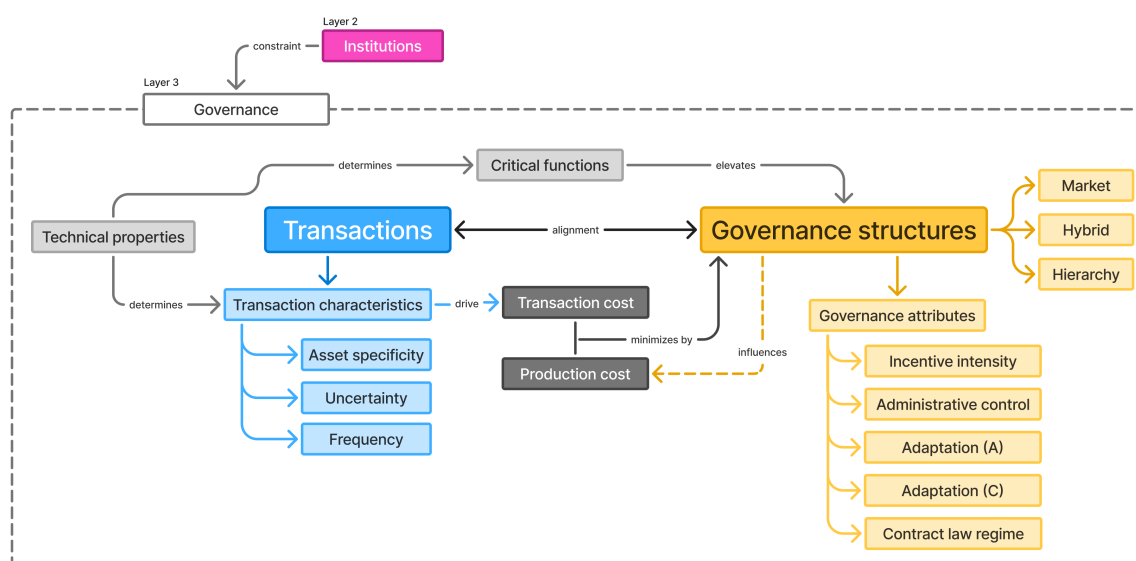


Figure 2.11: The complete analytical framework integrating Layers 2 and 3. Technical properties determine transaction characteristics, which drive transaction and production costs. Alignment between transactions and governance structures minimises total costs. Institutions at Layer 2 constrain which governance structures are legally available. Critical functions elevate the governance requirement beyond cost minimisation alone. (Author's own, based on [19, 20, 34, 22])

3

Technical Characteristics of Battery Energy Storage and System Services

This chapter establishes the technical foundation for the governance analysis in Chapter 5. Transaction characteristics, asset specificity, uncertainty, and frequency cannot be asserted; they must be derived from the properties of the asset and the service it provides. This chapter establishes those properties.

Section 3.1 introduces the system services that TenneT must explicitly secure as the Dutch electricity system transitions towards high shares of vRES. Section 3.2 describes the BESS technical characteristics that determine which of those services they can provide and under what constraints. Section 3.3 examines the technical requirements for each service in detail, with extended treatment of synthetic inertia and congestion management, which form the basis of the case study in Chapter 8. Section 3.4 examines which service combinations are technically compatible and the conditions under which revenue stacking is feasible.

3.1. System needs in High-vRES Power Systems

The electricity grid in continental Europe operates as a single synchronous area. All large conventional generators, gas, coal, and nuclear, spin in unison, locked to a shared frequency of 50 Hz. As a passive by-product of normal operation, they provide a set of stabilising functions that keep the grid secure. None of this requires explicit instruction. It happens automatically, as long as these machines are online [6].

The ongoing transition of the electricity system towards high shares of vRES is displacing conventional generators with IBRs, mostly wind and solar PV. Wind turbines and solar panels work differently. They connect to the grid through power electronic inverters and do not passively exhibit these properties. This means that as conventional generators are retired and replaced by IBRs, what was once automatic must now be arranged deliberately. System operators must secure these functions explicitly through dedicated arrangements with assets capable of providing them.

Six services are examined in this thesis, each corresponding to a stabilising function that conventional generators once provided passively.

Balancing keeps generation and demand in continuous equilibrium. Any mismatch causes the frequency to deviate from 50 Hz. Balancing services correct that deviation in real time, before it grows large enough to cause damage.

Voltage control keeps voltage levels within acceptable limits across the network. Voltage is local: a problem at one point in the network cannot be solved by an asset elsewhere. It must be managed at or near the point where it departs.

Congestion management prevents power flows from exceeding the physical limits of lines and trans-

formers. As renewable generation concentrates in specific areas, flows on nearby lines can approach those limits. Congestion management relieves the constraint on maintaining network security.

Synthetic inertia replaces the natural resistance to frequency changes that rotating machines once provided. Without it, the grid responds faster and more violently to disturbances. Critically, synthetic inertia must be present at the moment a disturbance occurs. It cannot be activated afterwards.

System strength refers to the grid's ability to maintain a stable voltage reference during faults. Conventional generators provided this through their physical coupling with the grid. As they are retired, specific network locations become electrically weak and vulnerable to instability.

Black start enables the grid to recover after a large-scale blackout. A black start asset can energise a dead network segment without relying on an external supply, providing the stable reference from which the rest of the system can be rebuilt.

BESS are increasingly considered for providing all six of these services. Their ability to respond rapidly, be deployed at specific network locations, and be configured for different technical functions makes them well-suited to fill the gap left by the retirement of conventional generators [40].

3.2. BESS Technical Characteristics

BESS are increasingly discussed as flexible assets for system operation, beyond their traditional role in energy shifting, and arbitrage [40]. Among storage technologies, lithium-ion batteries dominate grid-connected applications that require fast response and operational flexibility [41]. A key advantage is modularity: BESS can be deployed at specific locations in the transmission network, where services are most needed [42]. This matters because several of the services described in Section 3.1 have a strong locational component.

Converter control modes

All BESS connect to the grid through a power electronic inverter. The inverter's control mode determines which services the asset can provide.

Grid-following inverters synchronise to an existing grid reference. They measure the voltage and frequency at the connection point and inject current accordingly. They can provide balancing, congestion management, and reactive power support. However, they require a stable external reference to operate. In weak-grid or low-inertia conditions, their ability to stabilise the grid is limited [43].

Grid-forming inverters (GFM) work differently. They establish their own voltage and frequency reference and behave more like a voltage source than a current source. They can operate stably even when the external grid is weak or absent. This enables them to provide services that grid-following inverters cannot, including synthetic inertia and dynamic stability support [4].

A key distinction between the two modes concerns synthetic inertia. A grid-forming BESS responds to frequency fluctuations through its own internal dynamics, without waiting for an external trigger. This response is always present when the asset is online. A grid-following BESS can deliver fast frequency response, a triggered power injection when a frequency deviation is detected, but fast frequency response is fundamentally different from synthetic inertia. It is reactive rather than continuous [36]. The governance implication is direct: synthetic inertia requires the asset to be continuously available, not merely available when called upon.

Table 3.1 summarises the indicative capability of each control mode across the six services.

Table 3.1: Indicative capability of grid-following and grid-forming BESS to provide system flexibility services [4].

System service	Grid-following BESS	Grid-forming BESS
Balancing	✓	✓
Congestion management	✓	✓
Synthetic inertia	△	✓
Dynamic stability	△	✓
Short-circuit contribution	△	△
Voltage control	✓	✓
Black start	×	△

✓ = generally feasible; △ = limited or context-dependent; × = not suitable as primary function.

State of charge constraints

The most fundamental operational constraint of a BESS is its state of charge (SoC). State of charge describes the amount of energy currently stored relative to the maximum capacity [44]. It directly limits what the asset can do at any given moment. A BESS at a low state of charge cannot discharge to support frequency [3]. A BESS at a high state of charge cannot absorb power to relieve congestion [45].

Different services impose different state-of-charge requirements. Synthetic inertia requires the asset to maintain sufficient bidirectional headroom at all times: enough stored energy to discharge, and enough remaining capacity to absorb. When the asset operates close to its active power limit in either direction, the available headroom shrinks, and its inertia contribution reduces accordingly [46]. Black start imposes a stricter requirement: the asset must remain fully charged at all times, ready to energise a dead network segment without warning [3]. Congestion management during periods of high solar generation imposes a directional requirement: the asset must have sufficient capacity to absorb excess injection, rather than insufficient supply.

Using a single BESS to provide multiple services adds significant complexity to state-of-charge management. Because a BESS can only discharge for a limited time before depleting its stored energy, the BESS operator must constantly monitor the state of charge and reallocate capacity between services to ensure the BESS can fulfil all contracted obligations. Availability for each service must therefore be explicitly reserved or continuously monitored [47].

A related constraint is intertemporal interdependencies. It is not sufficient for the asset to be at the right state of charge at a given moment. The trajectory required to reach that state also matters operationally. The state of charge at a single point in time does not fully describe the asset's availability [48].

Degradation and cycling

BESS degradation takes two forms. Cyclic ageing results from active charging and discharging; calendar ageing occurs over time, even when the BESS is idle. Both cause capacity fade and an increase in internal resistance, reducing the energy the asset can store and deliver. These changes accumulate and cannot be reversed [45]. Cyclic ageing is driven by cycle depth, cycling frequency and intensity, and temperature, with degradation increasing exponentially at extreme depths of discharge [49][50][51].

Different grid services impose different stress profiles. Balancing and congestion management require rapid, frequent cycling, accelerating capacity degradation significantly [52]. Black start imposes the opposite profile: the asset rarely activates, but maintaining a permanent full state of charge accelerates calendar ageing [4]. Every cycle permanently consumes a fraction of the BESS's finite lifespan. BESS operators must therefore explicitly account for degradation costs when pricing long-term contracts and market bids [47].

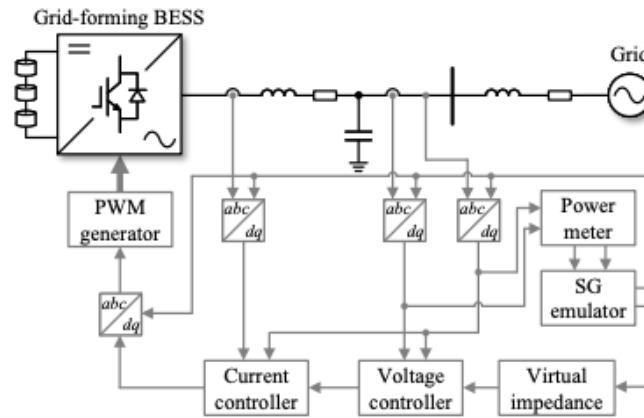


Figure 3.1: Control structure of a grid-forming BESS. The asset connects to the grid through a PWM generator and converter stage. A current controller, voltage controller, and virtual impedance block work together to establish an independent voltage and frequency reference, enabling the asset to operate stably without an external grid signal. A synchronous generator emulator replicates the dynamic behaviour of a conventional machine. [4]

3.3. System Services: Technical requirements

This section examines the technical requirements for each of the six services introduced in Section 3.1. For each service, three things are established: the physical system it addresses, the technical capability BESS must have to provide it, and the limitations BESS has relative to conventional assets.

Table 3.2: Technical overview of six BESS-based system services

Service	Physical system need	Required BESS capability	Key operational constraint	BESS limitation relative to conventional assets
Balancing	Continuous generation-demand balance to maintain 50 Hz	Fast bidirectional active power response	SoC must be maintained within operating range	Limited energy duration; cycling causes degradation
Voltage control	Stable voltage levels at specific network buses	Four-quadrant reactive power control	Continuous monitoring of local voltage	Current-limited relative to synchronous condensers
System strength	Voltage stiffness and fault current during disturbances	Grid-forming control	Continuous availability at the weak node	Inverter current limit of 1.1–1.5 per unit versus 5–6 per unit for synchronous machines
Synthetic inertia	Arrest rapid frequency change following generation loss	Grid-forming control with bidirectional headroom	Headroom must be maintained at all times	Contribution reduces when operating near active power limit
Congestion management	Relieve thermal overloading of lines and transformers	Controllable charge and discharge at a specific node	Directional SoC requirement depending on congestion type	Strictly bound by SoC; value is primarily determined by network location
Black start	Re-energise a dead network segment without external supply	Grid-forming control; permanent full state of charge	Full charge must be maintained at all times	Vulnerable to inrush currents; cannot serve as a standalone primary provider at a large scale

Balancing

The grid must continuously balance generation and demand to maintain system frequency at 50 Hz. Any mismatch causes the frequency to deviate. If left uncorrected, that deviation can grow and trigger cascaded outages across the network [6].

Balancing services correct these deviations in real time. Three primary balancing products in Europe are relevant for BESS. Frequency Containment Reserve (FCR) is the first line of response: it activates automatically and symmetrically within seconds of a frequency deviation. Automatic Frequency Restoration Reserve (aFRR) restores frequency to 50 Hz after FCR has contained the initial deviation. Manual Frequency Restoration Reserve (mFRR) is activated by the system operator and operates over a longer timeframe [53].

A BESS acts as a highly dynamic resource for balancing. Using droop control, it instantly injects power into the grid when the frequency falls below 50 Hz and absorbs power when the frequency rises above it. Response times range from milliseconds to seconds. The state of charge must be maintained within an operating range sufficient to sustain that response in both directions [5].

BESS have two limitations relative to conventional generators for balancing. First, energy duration is finite: a BESS can only balance the grid until its battery is depleted or fully charged [52]. Second, the continuous cycling required for balancing causes incremental degradation of the BESS cells over time [3].

Voltage control

Voltage must stay within acceptable limits at every point in the network. Fluctuations occur due to sudden load changes or intermittent renewable generation, such as midday solar peaks causing over-voltage and evening peaks causing undervoltage. Voltage is local: a problem at one bus cannot be solved by an asset connected elsewhere. It must be managed at or near the point of deviation [5].

A BESS provides voltage control through reactive power injection and absorption. This requires four-quadrant power converters that can independently control reactive power output regardless of the active power operating point. The system must continuously monitor local grid voltage and adjust its reactive power output to keep voltage within the required band [54, 55].

BESS inverters are current-limited, typically restricted to around 1.1-1.5 times their rated current. Conventional generators and synchronous condensers can provide reactive power well beyond their rated current by means of their physical excitation systems. A BESS cannot replicate this overload capability [4].

System strength

System strength refers to the grid's ability to maintain stable voltages and provide fault current during disturbances [43]. A strong grid can deliver a large instantaneous short-circuit current when a fault occurs. Traditional protection relays rely on this current to reliably detect and isolate faults [17]. As conventional generators retire and IBR penetration increases, fault current levels fall [43]. Specific network locations become electrically weak, and conventional protection schemes may fail to operate correctly [4].

A BESS equipped with grid-forming control can act as a voltage source and help stabilise weak network nodes [43]. By establishing its own voltage and frequency reference, it can actively support the grid during disturbances rather than passively following an external signal [5].

However, BESS inverters are strictly current-limited. During a fault, a synchronous condenser can inject five to six times its rated current [17]. A BESS inverter is capped at approximately 1.1 to 1.5 times its rated current [4]. This is a fundamental hardware limitation of power electronic devices. As a result, a BESS cannot replicate the fault-current contribution of a synchronous machine and cannot independently provide system strength as conventional assets do.

Hybrid arrangements pairing a BESS with a synchronous condenser are widely discussed in the literature as a solution to this limitation. The synchronous condenser provides the fault current and physical inertia. The BESS provides fast controllable active and reactive power response. Together, they can deliver a more complete grid support package than either technology can achieve on its own [51] [43].

Black start

After a large-scale blackout, the grid cannot restart on its own. It requires an asset capable of energising a dead network segment from scratch without relying on an external power supply. This asset must independently establish and sustain a stable voltage and frequency reference while surrounding units reconnect and synchronise [5].

A BESS with grid-forming control can support this process [5]. Paired with other assets in a restoration sequence, it can help establish a stable voltage and frequency reference during network re-energisation

[4]. However, it cannot currently serve as a standalone primary black-start provider at scale. Energising transmission lines, transformers, and motors creates large inrush currents that current-limited BESS inverters struggle to absorb unless significantly oversized [52]. Additionally, the asset must remain fully charged at all times, as a blackout can occur without warning. Maintaining a permanent full state of charge removes that capacity from other uses and accelerates calendar ageing [4].

For these reasons, BESS are discussed in the literature as supporting resources in restoration sequences rather than as primary black start providers [56].

Synthetic inertia

When generation and demand are suddenly mismatched, frequency deviates from 50 Hz. In a system with large conventional generators, this deviation is resisted automatically. The rotating masses of those machines store kinetic energy, which is released instantaneously when a mismatch occurs, thereby slowing the rate of change of frequency and buying time for control systems to restore balance.

The inertia contribution of a conventional generator is quantified through the inertia constant H , defined as the ratio of the kinetic energy stored in the rotating mass to the rated apparent power of the machine [57]:

$$H = \frac{E_{\text{kin}}}{S} = \frac{J \cdot \Omega_r^2}{2 \cdot S} \quad [\text{s}] \quad (3.1)$$

The total kinetic energy stored in the rotating mass is then:

$$KE = H \cdot S \quad [\text{MWs}] \quad (3.2)$$

The significance of H for system operation follows directly from the Rate of Change of Frequency (RoCoF) equation. For a power imbalance ΔP relative to system load P_{LOAD} , the initial rate of change of frequency is [57]:

$$\text{RoCoF}|_{t=0^+} = \frac{\Delta P_{\text{imbalance}}}{P_{\text{LOAD}}} \cdot \frac{f_0}{2H} \quad (3.3)$$

The lower the total system inertia H , the faster the frequency changes following a power imbalance. ENTSO-E recommends maintaining H above 2 seconds, which keeps RoCoF below 1 Hz/s in most scenarios [57]. This threshold matters because protection relays require a minimum time to measure frequency deviations and react. Events with RoCoF exceeding 1 Hz/s have historically resulted in grid collapse because protection systems could not respond in time. At 2 Hz/s, generators begin disconnecting themselves to avoid damage, which can trigger a cascade of further disconnections [57]. In the Netherlands, system inertia has declined from a mean of 87 GWs in 2020 to 61 GWs in 2024, and is projected to fall below the ENTSO-E minimum for 70% of the time by 2030 [7].

As conventional generation exits the system, total inertia declines, and RoCoF increases for the same disturbance size. Synthetic inertia is the primary means by which this effect can be replicated using inverter-based assets [5].

A grid-forming BESS responds to frequency fluctuations through its own internal dynamics, without waiting for an external trigger. This response is always present when the asset is online. It is fundamentally different from fast frequency response, which is a triggered power injection that activates when a frequency deviation is detected, and a grid-following inverter can also deliver [36]. Synthetic inertia cannot be activated on demand. It must be present at the moment the disturbance occurs [46].

Providing synthetic inertia requires the asset to maintain sufficient bidirectional headroom at all times: enough stored energy to discharge and enough remaining capacity to absorb. When the asset operates close to its active power limit in either direction, the available headroom shrinks, and the inertia contribution reduces accordingly [46]. Headroom must be maintained continuously, not just at moments of activation.

Two categories of measures are available to address inertia shortfalls [7]. Fixed measures, such as synchronous condensers, provide inertia continuously at all times, raising the entire inertia duration curve. Dynamic measures, such as GFM-BESS, can be deployed specifically at moments of inertia shortfall, making them more flexible but more complex to implement. An optimal strategy requires a combination of both.

No standardised product definition for synthetic inertia exists at the European level. The measurement methodology for quantifying the inertia contribution of a GFM-BESS is still under development [58]. Verification of actual performance under normal conditions is structurally difficult: the response can only be fully observed during a real-world frequency disturbance.

Typical inertia constants by plant type are summarised in Table 3.3. Combined-cycle gas turbines, which form the backbone of the Dutch conventional fleet, carry an H of approximately 5.5 seconds [59].

Table 3.3: Typical inertia constants by plant type [59].

Plant type	Typical H [s]
Nuclear	6.0
Combined-cycle gas turbine	5.5
Single-shaft gas turbine	4.5
Large-scale hydro	3.0
Diesel genset	2.0
Converter-based units	0.0

Congestion management

Power flows through lines, and transformers are physically limited by their thermal capacity. Congestion occurs when those flows approach or exceed that limit [45]. As renewable generation concentrates at specific injection points, offshore wind clusters and large solar parks, power must travel longer distances to reach demand centres, increasing the risk of thermal overloading on specific corridors [5].

TenneT operates the Dutch transmission system in accordance with the N-1 security standard, where N denotes the total number of network elements and the subtracted number denotes the count of simultaneous element failures the system must remain secure against. Under N-1, the grid must remain secure following the loss of any single element: a line, a transformer, or a generator. In meshed networks, N-0 operation, running assets at their full physical limit with no contingency reserve, is generally not permitted because a single element failure would immediately cause cascade overloading of interconnected elements [60]. Under N-1 conditions, a contingency alters the power-flow distribution across the remaining network, potentially pushing other elements beyond their limits. The N-2 standard, requiring security after two simultaneous element failures, applies in specific critical situations [61].

Two categories of measures are available to maintain N-1 security. Preventive measures are activated before a contingency occurs: the system operator identifies a forecast constraint and resolves it before the binding element is lost. Curative measures are activated after a contingency occurs: the system operator activates additional capacity to relieve the constraint that emerges following the N-1 event [62]. Combining preventive and curative measures increases grid utilisation: lines can be loaded closer to their physical limits during normal operation because curative capacity is available to manage post-contingency situations [60]. The congestion management service examined in the case study in chapter 8 is N-1 curative: a BESS provides the curative capacity that TenneT activates after a specific element trips.

Curative measures must be activated within seconds of the contingency occurring: if the curative resource fails to respond, the line is exposed to overloading with no remedial action available, and thermal damage can occur within a short timeframe [60].

The location dependency of congestion management follows directly from Kirchhoff's laws [63]. Power flows distribute across the network according to the impedance of each path; they do not follow instructions. The value of a BESS for congestion management is therefore primarily determined by its location in the network. An asset at a node with low electrical coupling to the binding constraint provides limited relief regardless of its power rating, while an asset at or near the constrained node provides maximum effect [3].

Different congestion patterns impose different state-of-charge requirements on the BESS. During periods of high solar generation, excess injection at the constrained node causes congestion; the BESS must have sufficient capacity to absorb it. During periods of high demand with insufficient local generation, the BESS must have sufficient charge to meet the discharge demand. The required direction of response depends on the time of day and the prevailing generation mix, and must be accounted for in the asset's operating schedule [3].

Unlike synthetic inertia, congestion management typically involves an advance notice window. The system operator identifies a forecast constraint hours ahead and can verify the asset's state of charge before activation. This advance notice is the defining technical property that distinguishes congestion management from stability services: it makes pre-activation verification possible [51].

3.4. Multi-service operation and revenue stacking

A single BESS can, in principle, provide multiple services simultaneously [64]. Whether this is technically feasible depends on whether the services impose compatible state-of-charge requirements. Not all combinations are compatible, and the degree of compatibility determines how much commercial freedom the BESS operator retains alongside the system service obligation.

Synthetic inertia and congestion management represent a compatible combination. Synthetic inertia requires the asset to maintain sufficient bidirectional headroom at all times, but does not require a specific state-of-charge level or direction. Congestion management requires a directional state-of-charge response, but only at the moment of activation. Between activations, the asset retains commercial freedom. A GFM-BESS can therefore maintain the headroom required to provide continuous inertia while remaining available for congestion-management dispatch [46]. A single asset at a congestion-critical node can therefore contribute to system-wide frequency stability while simultaneously serving as the curative resource for that specific network constraint. This is the combination examined in the case study in chapter 8, where a single asset at the Utrecht Lage Weide node is assessed for both services simultaneously.

Black start imposes the strictest constraint: the asset must remain fully charged at all times because a blackout can occur without warning. Any discharge, whether for balancing, congestion management, or market participation, reduces the stored energy available for restoration and directly compromises the primary obligation. Black start therefore structurally excludes simultaneous participation in any service that requires discharge. Balancing and congestion management can in principle be combined, but both require frequent bidirectional cycling, and the combined cycling load accelerates degradation more rapidly than either service alone. Where two services impose conflicting directional state-of-charge requirements, the BESS operator must reserve a portion of the asset's capacity exclusively for each, reducing the capacity available for the other and therefore the commercial value of both [47][49].

In the Netherlands, BESS can participate in the day-ahead and intraday energy markets, as well as the FCR and aFRR balancing markets, subject to technical prequalification requirements. These revenue streams can be stacked with system service obligations where state-of-charge requirements are compatible [65].

3.5. Synthesis

Three distinctions that emerge from this chapter determine how transaction characteristics are scored in Chapter 5.

The first is between services that are always-on and those that are dispatchable. Synthetic inertia and

system strength must be present at the moment a disturbance occurs; they cannot be activated after the fact. This continuous availability requirement is the primary source of temporal asset specificity and irreducible information asymmetry in those transactions.

The second is between system-wide and node-specific services. Frequency-related services, including synthetic inertia, affect the entire synchronous area: an asset anywhere in the system contributes to the inertial response regardless of its location. Voltage control, system strength, and congestion management are node-specific: the asset must be at the correct location to provide the service, and an asset with low electrical coupling to the binding constraint provides limited relief regardless of its power rating. Location-boundedness is the primary source of site specificity in those transactions.

The third is between services whose performance can be verified before activation and those whose performance can only be observed during an actual disturbance. For congestion management, TenneT can confirm the asset's state of charge and availability in advance of the event, because forecast constraints are identified hours ahead. For synthetic inertia and system strength, no such verification is possible under normal operating conditions: the response can only be fully observed when a real disturbance occurs. TenneT therefore cannot routinely confirm whether the contracted service is being delivered. This makes performance monitoring structurally incomplete, which has direct consequences for how the arrangement must be governed.

Together, these three distinctions explain why the six services produce governance predictions that span the full market-to-hierarchy continuum.

4

Research Design and Methodology

This chapter translates the theoretical framework developed in Chapter 2 into a concrete research design. Section 4.1 establishes the research approach. Section 4.2 presents the research question and sub-questions. Section 4.3 describes the data sources. Section 4.4 operationalises the analytical framework. Section 4.5 describes the framework design approach. Section 4.6 describes the expert interview procedure. Section 4.7 presents the case study design. Section 4.8 addresses research quality.

4.1. Research Approach

Energy infrastructures are socio-technical systems in which physical assets and institutional arrangements are tightly interdependent. Technology sets the boundaries of what is operationally feasible; institutional arrangements determine how those possibilities are organised and used. The Dutch electricity transmission system exemplifies this: it is characterised by physical interdependence, system-level criticality, high sunk costs, and deep regulatory embeddedness [34]. These properties shape the transaction characteristics that TCE analyses and constrain the governance options that are legally available. The alignment framework of Künneke, Ménard and Groenewegen (2021) was developed specifically for this class of system. It provides the analytical bridge between the theoretical framework developed in Chapter 2 and the governance analysis in Chapter 5, translating the physical characteristics of the infrastructure established in Chapter 3 into assessable transaction dimensions.

The design of such infrastructures has remained fragmented across three logics. Engineers focus on physical robustness and reliability. Economists analyse how transactions should be organised to minimise cost and mitigate governance risk. Regulators focus on the legal frameworks that determine what arrangements are permissible. These logics are not always aligned [66]. TCE on its own produces governance predictions without asking whether they are legally available; regulatory analysis on its own identifies what is permitted without asking whether it is efficient; technical analysis on its own establishes what is feasible without asking how it should be governed. This thesis integrates all three: the technical properties of BESS and system services established in Chapter 3 determine the transaction characteristics, TCE translates those characteristics into governance predictions in Chapter 5, and the Energy Act 2026 determines which predictions are legally available in Chapter 6.

The primary output is a governance framework: an artefact in the design science sense [67][68]. The framework is grounded in established theory, addresses an identified institutional problem, and is evaluated through expert interviews and a case study. This distinguishes the thesis from pure explanatory research, which would stop at identifying the governance gap, and from consultancy, which would propose solutions without theoretical grounding.

The analysis is deductive: the theoretical framework generates governance predictions, which are evaluated against technical properties and legal constraints. Qualitative methods are most appropriate for this analysis. The core variables, asset specificity, governance risk, and institutional fit, are dimensions

to be assessed and aligned rather than quantities to be measured. BESS-based system services are not yet procured at scale in the Netherlands, leaving no contracting records or market data from which to draw statistical inference.

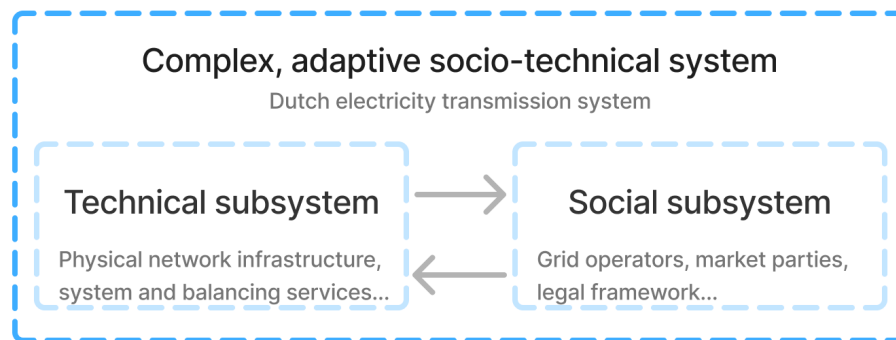


Figure 4.1: The Dutch electricity transmission system as a complex adaptive socio-technical system, comprising a technical subsystem of physical infrastructure and a social subsystem of grid operators, market parties, and legal frameworks. The two subsystems are mutually interdependent. (Author's own)

4.2. Research Design

The central research question is:

What is the efficient governance structure for battery energy storage providing system services in the Dutch electricity system, does the Energy Act 2026 permit it, and where it does not, what is the best feasible alternative?

Three sub-questions structure the analysis:

1. What are the transactions involved for BESS providing system services, what are their characteristics, and what governance structure does TCE predict as efficient?
2. Does the Energy Act 2026 permit the TCE-predicted governance structure, and if not, what is the best feasible alternative within the legal boundaries?
3. What governance framework can be derived from the TCE analysis and the regulatory analysis to guide governance decisions for BESS providing system services, and what recommendations does it produce when applied to the Dutch transmission system?

The research proceeds in three sequential steps, illustrated in Figure 4.2. The first applies TCE to each service using the technical properties from Chapter 3, independently of the legal framework. The second assesses whether the predicted governance structures are permitted under the Energy Act 2026 and identifies feasible alternatives where they are not. The third integrates both analyses into the decision framework, which is evaluated through expert interviews and applied in the case study.

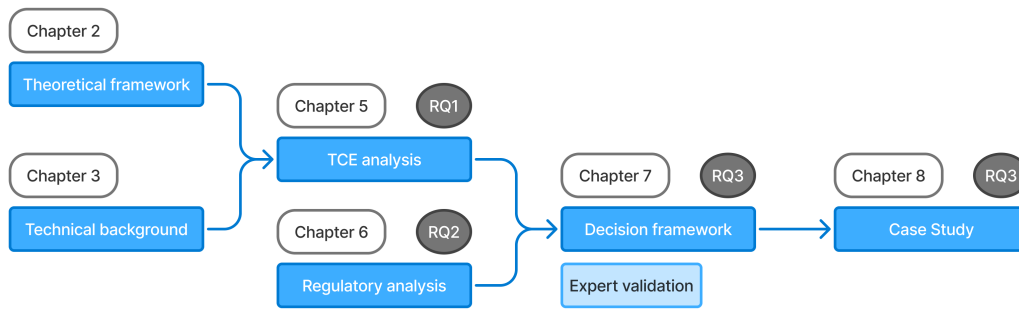


Figure 4.2: Research design and analytical steps. The theoretical framework (Chapter 2) and technical background (Chapter 3) inform the TCE analysis (Chapter 5, RQ1) and the regulatory analysis (Chapter 6, RQ2). Both analyses are integrated into the decision framework (Chapter 7, RQ3), which is validated through expert interviews before being applied in the case study (Chapter 8, RQ3). (Author's own)

4.3. Data Collection

This study draws on four categories of sources to support the economic, regulatory, and design-oriented components of the analysis.

Academic literature and technical reports establish the theoretical and technical foundations. This includes literature on transaction cost economics, institutional economics, and the technical characteristics of BESS-based system services, which provide the basis for characterising the transactions analysed in Chapter 5.

Legal and regulatory documents provide the institutional layer. The primary sources are the Energy Act 2026, ACM regulatory frameworks, relevant EU electricity legislation, and publicly available TenneT documentation. These form the basis for the regulatory analysis in Chapter 6.

Expert interviews are used to validate the decision framework developed in Chapter 7. Respondents assess whether the framework's structure, criteria, and cost logic reflect the operational realities of BESS governance in the Dutch transmission system. The selection of respondents and interview procedure are described in Section 4.6.

Case-specific data support the application of the framework in Chapter 8. This includes publicly available system studies, scenario assumptions, and operational characteristics relevant to future operation of the transmission system in the Netherlands.

4.4. Analytical Framework Operationalisation

The theoretical framework developed in Chapter 2 identifies three transaction characteristics, asset specificity, uncertainty, and frequency, as the determinants of governance structure. Operationalisation translates these characteristics into assessable dimensions that can be scored consistently across all six services and eight transactions. Without this translation, the theoretical constructs remain too abstract to produce service-specific governance predictions [68].

The analysis follows a two-step logic. The first step determines the economically efficient governance structure using TCE as developed by Williamson [19, 20]. This step is conducted independently of the legal framework, so that the efficient governance structure is derived from the structure of the transaction rather than from what happens to be legally available. The second step assesses whether that governance structure is permitted under the Energy Act 2026 [18]. Separating the steps ensures that legal constraints are identified as constraints on efficiency rather than assumed away. The two

steps are then integrated to produce a recommendation that is both economically grounded and legally feasible.

Transaction Cost Analysis

TCE is operationalised by translating its three core characteristics, asset specificity, uncertainty, and frequency, into transaction-level assessment criteria applied consistently across all services. Each service is decomposed into eight transactions capturing the governance relationship between the BESS operator and TenneT: land acquisition (T1), grid connection (T2), availability obligation (T3), dispatch and control rights (T4), market participation and SoC conflict (T5), telemetry and information rights (T6), degradation and cycling rights (T7), and termination (T8). Three transactions are generic; five are service-specific.

Each transaction is assessed qualitatively against a structured scoring rubric. Asset specificity is decomposed into five types: site, dedicated, temporal, physical, and human specificity. Uncertainty is assessed across three types: primary, secondary, and tertiary, as defined in Section 2.3. Each dimension is scored as low, moderate, or high, with transaction-specific assessment questions that ground each judgement in the operational realities of the service.

The governance implication of each transaction is determined by its highest score across asset specificity and uncertainty, consistent with the discriminating alignment hypothesis [20]. Frequency acts as a modulator. The dominant pattern across all transactions produces a recommendation on the market-hybrid-hierarchy continuum.

Regulatory Analysis

The analysis draws on three layers of regulatory sources. The first is EU primary law, principally Article 54 of the EU Electricity Directive (2019/944), which establishes the general prohibition on TSO ownership of storage and defines the available exception routes. The second is Dutch national law, in particular the Energy Act 2026 and its explanatory memorandum, supplemented by ACM regulatory decisions and TenneT's operational documentation. The third is comparative European practice: regulatory frameworks and procurement arrangements of TSOs in Germany, Italy, France, Belgium, and Spain, which operate under the same EU legal baseline yet differ in their national implementations. Where the Energy Act 2026 does not permit the TCE-predicted governance structure, this comparative layer provides a basis for identifying feasible alternatives.

For each service, the analysis asks two questions: whether the Energy Act 2026 permits the TCE-predicted governance structure, and if not, what the closest feasible alternative is within the legal boundaries. The analysis is interpretative. It identifies what the framework permits in principle and what institutional changes would be required to align legal feasibility with economic efficiency. It does not constitute legal advice and does not predict regulatory decisions in specific cases.

4.5. Framework Design Approach

The governance framework is the primary artefact of this thesis. Its purpose is to translate the two-step analytical logic into a structured, reproducible decision tool that produces a concrete governance recommendation for each BESS-based system service. In design science terms, it constitutes a method artefact: a structured procedure for determining which governance arrangement is most appropriate in a given case, rather than a description of what is efficient or legally available in the abstract [67, 68].

The TCE section of the framework is organised as a sequential gate structure. Each gate makes a directional decision, determining which path to follow and progressively narrowing the solution space. This mirrors the discriminating alignment hypothesis: given the characteristics of a transaction, TCE points toward a specific governance structure rather than a range of equally valid options [20]. The framework contains six gates: Gate 0 defines the service and decomposes it into its constituent transactions; Gate 1 assesses market viability; Gate 2 assesses criticality; Gate 3 assesses contractibility; Gate 4 assesses efficiency; and Gate 5 identifies the appropriate hybrid form where relevant.

The legal feasibility check takes the TCE output as its input. It asks whether the recommended governance structure is permitted under the Energy Act 2026 and EU unbundling rules, walks through the applicable legal pathways, and produces a recommendation that integrates both economic efficiency and legal feasibility.

The transition readiness check applies where the TCE section recommends hierarchical governance. It assesses whether that form is achievable before the service gap opens, given that TSO ownership of a BESS requires ACM approval under strict conditions. Where hierarchy is legally available in principle but not practically achievable within the required timeframe, the check identifies the most appropriate interim arrangement.

The specific gate criteria, assessment questions, and cost logic are presented in Chapter 7.

4.6. Expert Interviews

The expert interviews validate and refine the decision framework developed in Chapter 7. They assess whether the gate structure, criteria, and cost logic reflect the operational realities of BESS governance as experienced by TenneT practitioners, and identify where terminology, criteria, or cost logic require adjustment.

Four TenneT experts were selected through purposive sampling: one regulatory expert with direct responsibility for the legal feasibility dimensions addressed in the framework, and three market design experts responsible for service procurement and governance arrangements relevant to the services analysed. Respondents were selected based on direct operational relevance rather than statistical representativeness.

The interviews are semi-structured and take place after the framework is fully developed. Interviews were conducted online via Microsoft Teams, with the framework shared with respondents in advance. Each interview was recorded, transcribed, and synthesised into structured notes, which form the primary data source for the validation assessment in Chapter 7.

Four respondents are sufficient for face validity assessment of a design artefact. Face validity asks whether the artefact reflects operational reality as judged by people with direct relevant expertise, not whether findings generalise across a broader population. Statistical representativeness requires large samples to account for variance; face validity requires only that assessors can identify systematic misalignments in structure, criteria, or cost logic. Four respondents with direct operational responsibility for the governance dimensions the framework addresses fulfil that requirement. Additional respondents would increase redundancy rather than analytical coverage, given that the framework is evaluated against a defined institutional context rather than a variable population [67]. Interviews are conducted with informed consent, and respondents are anonymised in the thesis.

4.7. Case Study Design

The case study applies the decision framework developed in Chapter 7 to two BESS-based services in the Dutch transmission system, testing whether it produces governance recommendations that are both theoretically defensible and operationally recognisable to TenneT practitioners.

The two services are synthetic inertia and N-1 curative congestion management at the Utrecht Lage Weide 150 kV node. The location is determined by the planned closure of the Eneco CHP fleet from 2030, which permanently removes inertia from the Utrecht sub-grid and simultaneously creates a congestion management challenge at that node. Both services are selected because TenneT is actively designing procurement arrangements for them, making the case study directly relevant to ongoing governance decisions.

The two services are first evaluated individually, then in combination on a single asset. Synthetic inertia requires a continuous grid-forming operation rather than dedicated capacity reservation, making it the only service in this analysis that can be provided simultaneously with another service. The combined analysis tests whether the framework can address the governance challenge that arises when a

single asset is expected to provide multiple services with potentially conflicting availability and control requirements.

The case study follows a purposive single-site design. The Utrecht Lage Weide node concentrates two of the most complex governance challenges currently facing TenneT at a single location within a defined timeframe, providing analytical leverage rather than statistical representativeness. The cost comparisons produced by the framework are qualitative and directional. The findings are specific to the Dutch transmission context and are not intended to generalise beyond it.

4.8. Research Quality

Internal validity

The deductive structure of the analysis protects internal validity. The theoretical framework is fixed before the analysis begins, and each service is assessed against the same criteria in the same sequence. The structured scoring rubric and transaction-specific assessment questions ensure that governance predictions are grounded in defined criteria rather than ad hoc judgment. The gate structure of the decision framework reinforces this: each gate applies a consistent decision logic across services.

The principal threat to internal validity is the qualitative nature of scoring. Classifying transaction characteristics as low, moderate, or high involves judgment, and different analysts might score the same transaction differently. This is partially mitigated by the rubric, which explicitly defines scoring criteria, and by the expert interviews, which provide an independent check on whether the scores reflect operational reality.

External validity

The TCE analysis is grounded in general theory and could in principle be applied to other jurisdictions operating under similar regulatory frameworks. The regulatory analysis is specific to the Dutch institutional context. It does not generalise directly to other Member States, although the European comparison in Chapter 6 identifies analogous governance tensions in other jurisdictions. The case study findings are specific to the Utrecht Lage Weide node and do not represent all BESS governance challenges in the Dutch transmission system. The value of the case study lies in analytical depth, not breadth.

Reliability

The structured rubric and sequential gate logic make the analytical procedure transparent and reproducible. A reader with access to the same sources could follow the same procedure and arrive at comparable conclusions. The expert interviews provide an additional reliability check: where four independent practitioners with direct operational knowledge assess the framework as reflecting operational reality, this increases confidence that the scoring and gate logic are not idiosyncratic. The analysis relies primarily on publicly available sources. Where non-public data was unavailable, conservative assumptions were applied and noted in the analysis.

5

Governance predictions from Transaction Cost Economics

The preceding chapters have established the theoretical framework and the technical properties of the six system services. This chapter brings those two threads together by decomposing each service into its underlying transactions, assessing them on asset specificity, uncertainty, and frequency, and deriving a governance prediction for each. Section 5.1 describes the analytical approach. Section 5.2 analyses the generic transactions. Section 5.3 analyses the service-specific transactions. Section 5.4 synthesises the results.

5.1. Analytical approach

The analysis is conducted from TenneT's perspective. TenneT is the procuring party: it defines the service requirement, bears the risk of non-delivery, and is responsible for designing governance arrangements that ensure reliable service provision over the asset's operational lifetime [69]. The counterparty in each arrangement is an independent BESS operator.

Figure 5.1 summarises the analytical logic established in Chapter 2 and applied throughout this chapter. Williamson's discriminating alignment hypothesis provides the analytical basis for determining how: transactions that differ in their attributes must be aligned with governance structures that differ in their costs and competencies [20]. As established in Section 2.4, the efficient governance structure is the one that minimises the sum of production costs and transaction costs. Transaction costs consist of two components: ex-ante costs, incurred before the contract is signed, and ex-post costs, incurred after.

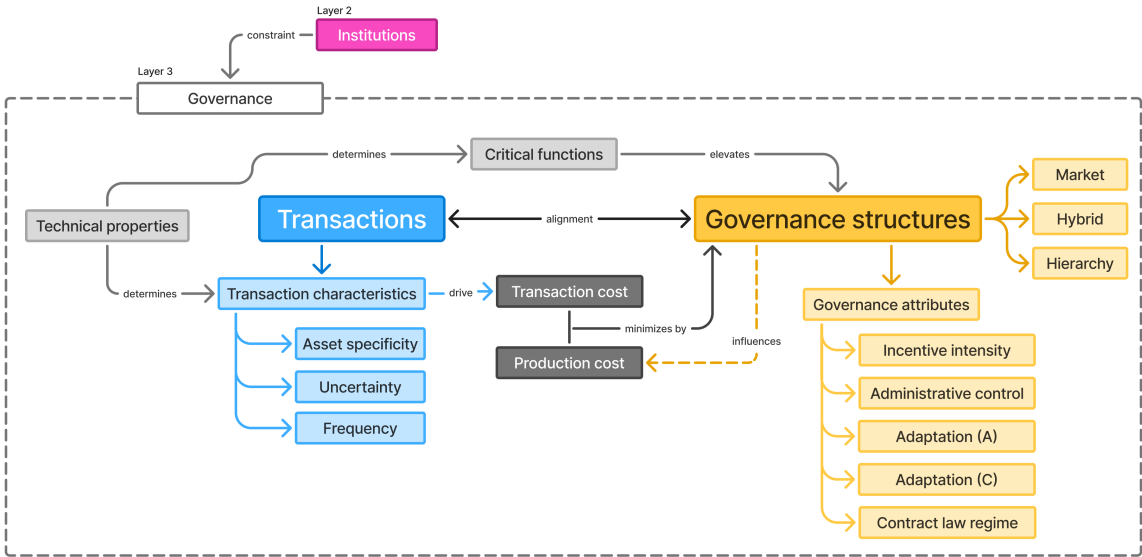


Figure 5.1: Analytical framework for TCE analysis, reproduced from Chapter 2. (Author’s own, based on [19, 20, 34, 22])

Every BESS service arrangement is decomposed into eight transactions covering the full lifecycle of the relationship, divided into three generic transactions (T1, T2, T8) and five service-specific transactions (T3 through T7), illustrated in Figure 5.2.

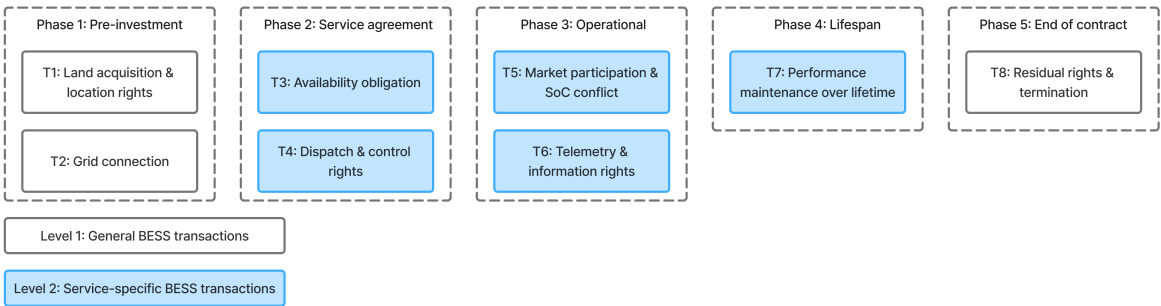


Figure 5.2: The eight transactions covering the full lifecycle of a BESS service arrangement, divided into Level 1 generic transactions (T1, T2, T8) and Level 2 service-specific transactions (T3, T4, T5, T6, T7).

The analysis identifies the governance structure TCE predicts to be most economically efficient for each service, independently of what the legal framework permits. Chapter 6 compares the predictions established in this chapter against the constraints of the Energy Act 2026.

Each dimension (asset specificity, uncertainty, and frequency) is scored on a three-point scale. A low score indicates that the dimension creates no material governance challenge and that standard contractual arrangements can manage it. A moderate score indicates that some governance safeguards are needed, but that contractual arrangements can provide them. A high score indicates that the dimension creates a severe governance hazard that standard contracts cannot adequately address. Where a dimension is analytically irrelevant, it is marked N/A and excluded from the scoring. Each score is grounded in a transaction-specific assessment question presented alongside the scoring tables in Appendix B.

The governance structure predicted for each transaction follows from how the three dimensions interact with one another. Where one dimension produces a severe hazard, it drives the governance response. A governance structure must be designed to handle the worst case: if the most severe hazard is left unaddressed, the entire arrangement can fail at that point regardless of how well the other dimensions

are managed.

5.2. Generic transactions

This section analyses the three transactions that apply to any BESS deployment in the Dutch transmission system, regardless of the service the asset provides. These transactions are generic not because they are simple, but because their governance challenges arise from building and connecting the asset, rather than from what system service it is contracted to deliver.

T1 and T2 – Land acquisition and grid connection

T1 and T2 are one-time transactions that occur before any service-specific obligation is incurred. T1 concerns the acquisition of the land on which the BESS is placed. T2 concerns the connection between the BESS and the high-voltage transmission grid.

At this stage, neither transaction commits the asset to a specific service or a specific relationship with TenneT. The land is generally substitutable, and while the connection point technically matters, alternatives at nearby nodes typically exist. At this stage, the BESS operator retains full commercial freedom: the asset can be redirected, sold, or redeployed without significant loss of value, and the BESS operator can freely choose which market to participate in or which service to provide. The fundamental transformation has not yet occurred because neither transaction commits the asset to a specific service or a specific relationship with TenneT. Some uncertainty does exist in both transactions, driven by permitting conditions and changes to the technical rules governing grid connection over a 15- to 20-year asset life. These reflect general market risks, such as shifts in environmental regulation or planning policy, rather than hazards specific to the relationship between TenneT and the BESS operator. With no bilateral dependency, a standard market contract with provisions for changing circumstances is sufficient.

T8 – Residual rights and termination

T8 concerns the terms under which the contract ends: what happens to the asset, who holds the remaining rights, and how the relationship is closed out. Because those terms are agreed at the outset, they shape the incentives of both parties throughout the entire duration of the contract. This section considers the BESS as a general asset, before any service-specific obligations have been incurred.

When the contract ends, the BESS operator regains full control over the asset. At the generic level it has not been configured for a specific service and can therefore be sold or redeployed on the open market. Site specificity is moderate: TenneT no longer has a provider at that specific location and must either negotiate a new arrangement with the same BESS operator or find an alternative. Some uncertainty exists: future regulatory change is unpredictable, the BESS operator holds private information about the actual condition of the asset, and has an incentive to present that condition favourably at termination. Because this analysis considers a general asset before any service-specific investment has been made, no bilateral dependency has arisen, neither party is locked in, and the hold-up problem does not arise. A standard market contract with clear termination provisions is sufficient.

Where service-specific asset specificity has deeply constrained the BESS operator's ability to redeploy the asset, this changes. The asset loses value outside this specific relationship, giving TenneT leverage to renegotiate terms at the moment the BESS operator is most financially exposed. The hold-up risk at termination becomes material and the governance requirement rises accordingly. That challenge is addressed in the T7 analysis for each service in Section 5.3.

Synthesis T1, T2 & T8

All three generic transactions score low. Before any service-specific investment has been made, neither party is locked in, bilateral dependency has not yet arisen, and a standard market contract with provisions for changing circumstances is sufficient. The governance challenges emerge in Section 5.3, where service-specific investments commit the asset to a particular location and service, the fundamental transformation takes hold, and the choice of governance structure becomes consequential.

Table 5.1: Transaction characteristics — generic transactions (T1, T2, T8)

Generic Transactions — T1, T2, T8				
Transaction	Asset specificity	Uncertainty	Frequency	Governance implication
T1 — Land acquisition	Moderate	Moderate	Once	Low
T2 — Grid connection	Moderate	Moderate	Once	Low
T8 — Residual rights & termination	Moderate	Moderate	Once	Low

5.3. Service-specific transactions

This section applies the transaction framework to each of the six services in order of increasing governance complexity, building on the generic baseline established in Section 5.2. The six services are analysed in the following order: balancing, voltage control, congestion management, synthetic inertia, system strength, and black start. For each service, the five service-specific transactions (T3 through T7) are assessed and a governance prediction is derived from the transaction that creates the most severe governance hazard. Balancing is treated briefly because it establishes the market baseline. The stability services (synthetic inertia, system strength, and black start) receive more detailed treatment because their governance hazards are driven by technical properties that must be explained before the prediction can be understood.

Balancing (FCR, aFRR, mFRR)

Balancing services are the clearest case for market governance in this analysis and serve as the analytical baseline.

The reason is standardisation. ENTSO-E network codes precisely specify technical requirements, response times, measurement methodologies, and telemetry obligations across all connected transmission systems in Europe [70]. Because every provider must meet the same specifications, TenneT can compare and switch between providers without significant loss of service quality. This eliminates dedicated asset specificity: the asset is not committed to TenneT as the sole buyer. It also eliminates temporal specificity: response times are standardised and predictable. Balancing services are not location-bound: a BESS can provide frequency response from anywhere in the synchronous area, which keeps site specificity low. Because every provider operates under the same product definitions and telemetry obligations, performance can be verified straightforwardly, and uncertainty stays low across all dimensions.

The only transaction where this picture shifts slightly is T5. When the battery is frequently activated for balancing, its state of charge (SoC) is depleted. SoC is the battery's available energy reserve. Commercial trading relies on the same reserve, so the two uses compete. However, the tension is moderate because activations are short in duration: the reserve is drawn down temporarily and recovers quickly enough for the asset to remain available for commercial trading. Because the asset retains its commercial value outside this specific relationship with TenneT, the fundamental transformation does not take hold and the governance prediction is market.

Table 5.2 summarises the transaction characteristics.

Table 5.2: Transaction characteristics — balancing (FCR, aFRR, mFRR)

Service-specific Transactions — Balancing (FCR, aFRR, mFRR)				
Transaction	Asset specificity	Uncertainty	Frequency	Governance implication
T3 — Availability obligation	Low	Low	High	Low
T4 — Dispatch & control rights	Low	Low	High	Low
T5 — Market participation & SoC conflict	Moderate	Low	High	Low
T6 — Telemetry & information rights	Low	Low	High	Low
T7 — Degradation & cycling rights	Low	Low	Low	Low

Governance prediction: market. Standardisation keeps asset specificity and uncertainty low across all transactions. Because the service is not location-bound and bilateral dependency never arises, market governance is the unambiguous TCE prediction for balancing services.

Voltage control

voltage control differ from balancing in one defining respect: reactive power is consumed by the grid itself as it travels through cables and transformers, meaning very little of it reaches a distant node [63]. The asset must therefore be physically present at the voltage-stressed node. In practice, the Dutch electricity system does not have enough assets at any specific voltage-stressed node to sustain meaningful competition. The market is not liquid enough at the node level, and market governance is ruled out from the outset.

Once the BESS operator commits capital to a specific location, the fundamental transformation takes hold and lock-in follows on both sides: the BESS operator cannot easily relocate, and TenneT cannot easily replace it. The asset is committed to TenneT as the primary buyer at that node, but because it can still provide other services at the same location, dedicated specificity is moderate rather than high. Voltage conditions are partly foreseeable but depend on the unpredictable output of wind and solar generation, making primary uncertainty moderate. Reactive power provision is activated frequently. Each activation produces a measurable output that TenneT can verify in real time. This means the BESS operator cannot easily misrepresent its availability or performance without detection. Information asymmetry and opportunism are therefore low.

T4 through T7 all score low. Reactive power requires no energy from the battery's reserve, so the SoC conflict between service provision and commercial trading that creates governance problems elsewhere does not arise. The BESS operator retains full commercial freedom. Because the battery is not cycled to deliver the service, degradation is minimal, and the asset retains its physical condition, preserving its value at termination.

Table 5.3 summarises the transaction characteristics.

Table 5.3: Transaction characteristics — voltage control

Service-specific Transactions — Voltage & Reactive Power Support				
Transaction	Asset specificity	Uncertainty	Frequency	Governance implication
T3 — Availability obligation	High	Moderate	Continuous	High
T4 — Dispatch & control rights	Low	Low	High	Low
T5 — Market participation & SoC conflict	Low	N/A	Low	Low
T6 — Telemetry & information rights	Low	Low	High	Low
T7 — Degradation & cycling rights	Low	Low	Low	Low

Governance prediction: strong hybrid — bilateral. High site specificity at T3 rules out market governance. Because the governance challenge is concentrated in T3 alone and uncertainty is moderate and manageable, full hierarchical governance is also not necessary. A long-term bilateral contract is sufficient: one that secures the BESS operator's presence at the specific node for the duration of the agreement, specifies the performance obligations the BESS operator must meet, and requires real-time reporting of reactive power output so TenneT can verify compliance continuously [19] [31].

Congestion management

Congestion management differs from the services analysed so far in one important respect: the governance prediction depends on transaction frequency, the rate at which the asset is called upon to deliver the service. Unlike voltage control, the asset does not have to be at the exact congested node: active power can travel farther through the grid, and being electrically close is sufficient. The more frequently congestion occurs at the nearby node, the more often the asset is activated. The more often it is activated, the more committed it becomes to TenneT as the sole buyer, and the stronger the governance response that is needed. At occasionally congested nodes, the governance challenge is

moderate. At chronically congested nodes, the asset is activated on the majority of operating days and the governance challenge is severe.

In both cases, congestion activations are typically anticipated hours in advance. This advance notice allows TenneT to verify whether the asset is ready before the activation window opens, which makes compliance straightforward to monitor and limits the scope for opportunism.

Future grid conditions introduce moderate uncertainty: the congestion pattern at a node depends on how the wider grid develops, which renewable energy projects are built, and how transmission capacity expands over a 15- to 20-year asset life.

The remaining transactions, covering dispatch rights, commercial participation, telemetry, and degradation, score low to moderate depending on node type. At chronically congested nodes, activations on the majority of operating days reduce the battery's available reserve for commercial trading, constraining the BESS operator's ability to generate independent revenue.

Table 5.4 summarises the transaction characteristics.

Table 5.4: Transaction characteristics — congestion management (node-dependent)

Service-specific Transactions — Congestion Management (node-dependent)				
Transaction	Asset specificity	Uncertainty	Frequency	Governance implication
T3 — Availability obligation	Mod. (occ.) / High (chr.)	Moderate	Variable	Moderate
T4 — Dispatch & control rights	Low	Low	Variable	Low
T5 — Market participation & SoC conflict	Low (occ.) / Mod. (chr.)	Low	Variable	Low
T6 — Telemetry & information rights	Low	Low	High	Low
T7 — Degradation & cycling rights	Low (occ.) / Mod. (chr.)	Low	Low	Low

Governance prediction: hybrid, node-dependent. Market governance requires competition among providers. Because only assets located near the specific congested node can deliver the service, the pool of viable providers is limited and the competitive pressure that market governance relies on is substantially weakened. Site specificity therefore rules out market governance in all cases, regardless of how often congestion occurs. At occasionally congested nodes, a trilateral hybrid arrangement is appropriate: a long-term contract that secures the BESS operator's presence near the congested node, specifies state of charge obligations, and requires telemetry before each activation, with a third party acting as an independent monitor to safeguard the arrangement and resolve disputes. At chronically congested nodes, the rate of activation commits the asset so deeply to TenneT that the parties must develop stronger mutual safeguards through the long-term relationship itself, without relying on a third party. This is a bilateral hybrid arrangement. A single procurement model for all congestion management is therefore unlikely to be efficient.

Synthetic inertia

Synthetic inertia is the most governance-intensive service in this analysis because it combines three conditions simultaneously: a continuous availability requirement, an autonomous response with no activation window, and the complete absence of standardisation. Grid-forming control responds to frequency deviations by adjusting the converter's output instantaneously, without waiting for a signal from TenneT.

At T3, asset specificity is high. Synthetic inertia has a stabilising effect across the entire synchronous area: because a frequency disturbance affects all connected systems simultaneously, injecting inertia at one location has the same effect as injecting it at another nearby, keeping site specificity moderate. The high score is driven instead by temporal specificity: the asset must respond autonomously within milliseconds of a frequency deviation with no dispatch signal, which means it must be continuously available. No regulatory framework standardises what continuous availability means for this service, making the requirement difficult to specify. Actual activations are rare, so TenneT cannot observe performance under normal operating conditions. This means the BESS operator can reduce its actual

availability to pursue commercial revenues without TenneT being able to detect it between disturbances. The BESS operator is not deeply locked in: the physical asset retains its full commercial value outside this relationship, and switching to another service requires only a software parameter change at low cost. The quasi-rent is therefore small and bilateral lock-in does not arise. All three uncertainty dimensions are high and the governance recommendation is high.

At T4, asset specificity is low: grid-forming control is becoming a standard capability and the control parameters are documented and transferable, meaning another BESS operator could take over the asset without losing the value embedded in those settings. The governance hazard is driven by secondary and tertiary uncertainty: TenneT cannot observe whether control parameters are correctly maintained between verification checks because those parameters are internal to the converter and cannot be read remotely. The BESS operator can therefore alter them without being detected. The governance recommendation is moderate.

At T5, asset specificity is high because the state of charge must be correct at every moment. The battery must maintain a small reserve in both charging and discharging directions at all times, because a frequency disturbance can cause frequency to rise or fall and the asset must be able to respond in either direction. Because only a fraction of the total capacity is needed to cover typical frequency deviations, the headroom requirement is small and the majority of the battery's capacity remains available for commercial use. Because TenneT cannot continuously observe the state of charge, the BESS operator has a persistent incentive to reduce that reserve in favour of market revenues. The governance recommendation is high.

At T6, asset specificity is high because no standardised methodology exists for measuring synthetic inertia provision. The telemetry infrastructure must be designed, negotiated, and built specifically for this arrangement and cannot be drawn from existing market standards [58]. Once agreed, however, both parties know exactly what data must be reported, keeping uncertainty low. The governance recommendation is high, driven by asset specificity alone.

At T7, the governance recommendation is moderate. Actual activations are rare, so physical degradation from cycling is limited, and the bidirectional headroom requirement leaves the majority of the battery's capacity available for commercial cycling.

Table 5.5 summarises the transaction characteristics.

Table 5.5: Transaction characteristics — synthetic inertia

Service-specific Transactions — Synthetic Inertia				
Transaction	Asset specificity	Uncertainty	Frequency	Governance implication
T3 — Availability obligation	High	High	Continuous	High
T4 — Dispatch & control rights	Low	High	Continuous	High
T5 — Market participation & SoC conflict	Moderate	Moderate	Continuous	Moderate
T6 — Telemetry & information rights	High	Low	Continuous	High
T7 — Degradation & cycling rights	Moderate	Low	Low	Moderate

Governance prediction: hierarchy. The combination of unobservable control parameters at T4, a continuous state of charge constraint that TenneT cannot monitor at T5, and the absence of any standardised telemetry methodology at T6 creates a governance problem that no contractual arrangement can resolve. TenneT cannot see inside the converter, cannot continuously observe the state of charge, and has no standard against which to verify performance. No contract can change any of those facts. TCE therefore predicts that TenneT should own and operate the BESS directly. Under direct ownership, TenneT sets the control parameters itself, monitors the asset continuously, and does not depend on a contractual counterparty to maintain availability.

System strength

System strength shares the core governance characteristics of synthetic inertia: autonomous response, continuous availability, and the absence of standardisation. System strength comprises two compo-

nents: dynamic stability, which a BESS can contribute to through grid-forming control, and short-circuit capacity, which requires fault-current injection and lies beyond what a standalone BESS can deliver. One additional complication established in Chapter 3 makes the governance problem more severe: a standalone BESS cannot provide fault current. The analysis covers only the dynamic stability contribution and explicitly acknowledges the short-circuit gap.

The transaction profile for dynamic stability closely follows that of synthetic inertia, with three important differences. First, site specificity at T3 is high rather than moderate for two reinforcing reasons: fault current must be delivered at the exact point in the grid where the fault occurs, and dynamic stability contribution through grid-forming control weakens with distance, so the asset's location is a binding constraint on both counts. Second, the information problem at T4 is more severe than for synthetic inertia: unlike synthetic inertia where partial verification is possible during normal frequency disturbances, dynamic stability performance under fault conditions can only be confirmed during a real fault event, which may never occur during the asset's operational lifetime. Third, T5 scores high rather than moderate because the continuous grid-forming requirement leaves less room for commercial trading than the small reserve obligation of synthetic inertia, and the BESS operator has a persistent incentive to use that capacity for market revenues instead. T6 and T7 are consistent with synthetic inertia.

Table 5.6 summarises the transaction characteristics.

Table 5.6: Transaction characteristics — system strength

Service-specific Transactions — System Strength				
Transaction	Asset specificity	Uncertainty	Frequency	Governance implication
T3 — Availability obligation	High	High	Continuous	High
T4 — Dispatch & control rights	Low	High	Continuous	High
T5 — Market participation & SoC conflict	High	High	Continuous	High
T6 — Telemetry & information rights	High	High	Continuous	High
T7 — Degradation & cycling rights	Moderate	Low	Low	Moderate

Governance prediction: hierarchy. The verification problem at T3 and T4 is more acute than for synthetic inertia: the asset's fault current capability can only be confirmed during a real fault event, which may never occur during the asset's operational lifetime. No contract can provide the certainty of delivery that a critical stability service requires under those conditions. Combined with high site specificity and the commercial use conflict at T5, where the continuous grid-forming requirement structurally limits the BESS operator's ability to generate independent revenue, hierarchy is the unambiguous TCE prediction.

Black start and system restoration

Black start represents the most extreme availability requirement in this analysis. As established in Chapter 3, a BESS cannot serve as a standalone primary black start provider at scale. Its role is limited to providing a stable voltage and frequency reference during network re-energisation. This requires the BESS to be co-located with or electrically close to the assets it is helping to re-energise, making location a binding constraint from the outset. The restoration sequence is country- and network-specific: each TSO designs its own plan, and the asset must fit into a defined sequence at a specific location. The product-level standardisation that keeps asset specificity low for balancing does not exist here.

The transaction profile shares the core characteristics of system strength, with one analytically distinct feature at T5. A gas turbine with black-start capability remains commercially operational between activations: it consumes fuel only when dispatched, and its capacity is otherwise available for other uses. A BESS must hold its entire energy reserve in permanent readiness throughout the contract because the moment a blackout occurs, the full reserve must be available immediately. This permanently excludes commercial use, not merely constrains it. Unlike synthetic inertia, where a small bidirectional headroom leaves most of the battery's capacity available for trading, black start requires the entire capacity to be reserved at all times. No contractual arrangement can resolve this conflict: the service obligation and commercial use are structurally incompatible.

At T4, the steps the asset must follow during a restoration sequence can only be fully verified during a real blackout or a scheduled drill. Drills are infrequent, and the BESS operator can restore correct parameters before a drill while deviating between drills without detection. Secondary and tertiary uncertainty are therefore high. T7 is low: actual activations are extremely rare, so cycling impact is minimal.

Table 5.7 summarises the transaction characteristics.

Table 5.7: Transaction characteristics — black start and system restoration

Service-specific Transactions — Black Start & System Restoration				
Transaction	Asset specificity	Uncertainty	Frequency	Governance implication
T3 — Availability obligation	High	High	Continuous	High
T4 — Dispatch & control rights	Low	High	Low	High
T5 — Market participation & SoC conflict	High	Moderate	Continuous	High
T6 — Telemetry & information rights	High	Low	Continuous	High
T7 — Degradation & cycling rights	Low	Low	Low	Low

Governance prediction: hierarchy. Where synthetic inertia and system strength are driven primarily by information asymmetry that no contract can resolve, black start is driven by a structural conflict at T5: the service requires the entire battery reserve to be held in permanent readiness, and commercial use is therefore impossible for the duration of the contract. No contractual arrangement can resolve that conflict. Combined with high site specificity, the inability to verify restoration capability except during a real blackout, and the fact that a failed black start means the grid cannot be restored after a system collapse, hierarchy is the unambiguous TCE prediction [20].

5.4. Synthesis

The six governance predictions span the full continuum from market to hierarchy. Table 5.8 summarises the dominant transaction characteristics and governance prediction for each service.

Table 5.8: Governance predictions across all six services

Overview — Transaction Characteristics and Governance Predictions						
Service	T3	T4	T5	T6	T7	Governance prediction
Balancing	Low	Low	Low/mod.	Low	Low	Market
Voltage control	High	Low	Low	Low	Low	Hybrid — bilateral
Congestion mgmt.	Mod./high	Low	Low/mod.	Low	Low	Hybrid — tri-/bilateral
Synthetic inertia	High	High	Mod.	High	Mod.	Hierarchy
System strength	High	High	High	High	Mod.	Hierarchy
Black start	High	High	High	High	Low	Hierarchy

Asset specificity and uncertainty combined per transaction. Mod. = Moderate.

The pattern that emerges across the six services is consistent and explicable. Two variables drive the shift from market to hybrid governance: standardisation and site specificity. Together they determine ex-ante costs: how costly it is to specify the service and design the arrangement before the contract is signed, and ex-post costs: how difficult it is to monitor performance and enforce obligations afterwards. The shift from hybrid to hierarchy is driven by different mechanisms for each service: the structural incompatibility of the full capacity requirement with commercial use for black start, and the combination of autonomous response and the impossibility of verification for synthetic inertia and system strength.

Where standardisation exists and site specificity is low, as with balancing, both cost categories remain low. All providers operate under the same product definitions, so the service is easy to specify before the contract is signed. Every provider can be monitored against the same telemetry obligations, so performance is easy to verify afterwards. Asset specificity stays low across all transactions, bilateral dependency never arises, and market governance is the unambiguous TCE prediction.

Where standardisation exists, but site specificity overrides it, ex-ante costs remain manageable, but ex-post costs rise because the bilateral dependency created by a location-specific investment must be actively governed. For voltage control, reactive power cannot travel far, and the provider must be present at the specific stressed node. Once the investment is made, the fundamental transformation takes hold: the operator cannot easily relocate, and TenneT cannot easily replace it. This bilateral dependency drives up ex-post costs: the arrangement must be actively governed for the full duration of the contract. A long-term bilateral contract that secures the operator's presence at that node and requires real-time telemetry to verify compliance is sufficient to manage those costs. For congestion management, the same location dependency applies, but the governance prediction depends on the frequency of congestion. At occasionally congested nodes, advance notice makes compliance easy to verify, and a trilateral arrangement with an independent third-party monitor is sufficient. At chronically congested nodes, the frequency of activation commits the asset so deeply to TenneT that stronger bilateral safeguards are required.

Where standardisation is entirely absent, the three services arrive at hierarchy through different mechanisms.

For synthetic inertia, the driver is information asymmetry alone. The physical asset retains its full commercial value outside this relationship and lock-in does not arise. The hierarchy prediction is not about dependency between the parties: it is about the impossibility of verification. TenneT cannot observe whether control parameters are correctly maintained, cannot continuously monitor the state of charge, and has no standardised methodology against which to verify performance. The ex-post costs of enforcing a contractual arrangement exceed what any contract can deliver.

For system strength and black start, the governance problem is more severe because lock-in and information asymmetry compound each other. Site specificity is high in both cases: fault current must be delivered at a specific weak node, and a black start asset must fit into a defined restoration sequence at a specific location. Once the investment is made, the asset has little value outside this specific arrangement. The quasi-rent is large: the gap between the asset's value in this role and its value in any alternative use is substantial, making the operator highly vulnerable to hold-up by TenneT after the investment is committed. For system strength, the fault-current gap adds a verification problem on top: performance can only be confirmed during a real fault event, which may never occur during the asset's operational lifetime. For black start, the driver is structural incompatibility: the service requires the entire battery reserve to be held in permanent readiness, which makes commercial use impossible for the duration of the contract. In all three cases, TCE predicts direct ownership and operation by TenneT.

The policy implication follows directly. Standardised product definitions and telemetry protocols for stability services would reduce both the ex-ante cost of specifying those services and the ex-post cost of verifying compliance. This would shift the frontier of efficient governance toward hybrid arrangements. Without standardisation, hierarchy remains the TCE prediction for the most critical services, not because direct ownership is inherently preferred, but because the transaction characteristics leave no viable contractual alternative.

These predictions are the output of a pure TCE analysis, conducted independently of the legal framework. Whether the Energy Act 2026 permits these governance structures, and where it does not, what the best feasible alternative is, are the questions addressed in Chapter 6.

6

Regulatory Feasibility: The Legal Boundaries of Efficient Governance

The preceding chapter derived a governance prediction for each service from its transaction characteristics alone, independently of the legal framework. This chapter tests those predictions against the institutional environment. Section 6.1 establishes the European Union (EU) regulatory baseline. Section 6.2 examines the Dutch regulatory framework. Section 6.3 derives five analytical observations from that framework. Section 6.4 assesses the legal feasibility of each governance prediction and identifies the best feasible alternative where the efficient form is unavailable. Section 6.5 situates the Dutch governance gaps within the broader EU landscape.

6.1. The European Union regulatory baseline

The analysis in this chapter operates at the institutional environment layer of Williamson's four-layer model: the formal rules that constrain what governance structures are legally available, in North's terms, the rules of the game. Those rules do not originate in national law. Their foundational constraints are set at the EU level through the Clean Energy Package of 2019 and implemented in Dutch legislation through the Energy Act 2026. Three EU instruments are directly relevant to this thesis, illustrated in Figure 6.1. Directive 2019/944 governs who may own storage assets [71]. Regulation 2019/943 governs how generation, storage, and demand response must be redispatched and procured, establishing market-based procedures as the default [72]. The Network Code on Emergency and Restoration governs how restoration services must be organised [73]. Because ownership and procurement are governed by separate instruments, each requires its own exception route. National law cannot create additional routes beyond those the EU framework permits.

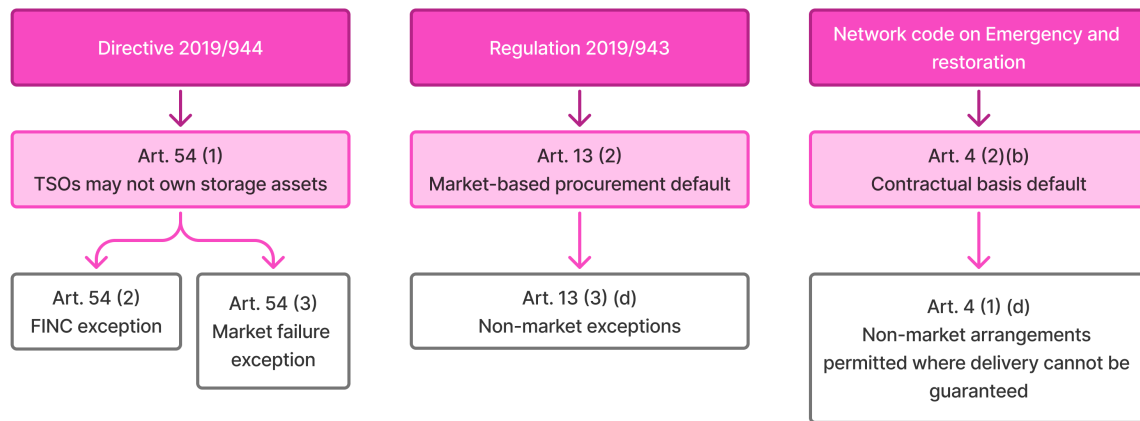


Figure 6.1: EU regulatory baseline governing BESS ownership and procurement. Directive 2019/944 Art. 54 prohibits TSO ownership of storage, with exceptions for FINC recognition and demonstrated market failure. Regulation 2019/943 Art. 13 establishes market-based procurement as the default, with non-market exceptions where gaming would result. The Network Code on Emergency and Restoration permits non-market arrangements where delivery cannot be guaranteed. (Author's own, based on [71] [72] [73])

Directive 2019/944, Art. 54 – The ownership prohibition and its exceptions

Article 54(1) of Directive 2019/944 establishes the general prohibition: transmission and distribution system operators may not own, develop, manage, or operate energy storage facilities [71]. The underlying rationale is twofold. Storage services should be competitive and market-based, and cross-subsidisation between regulated network functions and commercial storage activities should be prevented [74].

Article 54(2) names two exception routes. Under the first, a TSO may own a storage facility if the national regulatory authority recognises it as a fully integrated network component, meaning an asset that functions exclusively for network operation rather than commercial purposes. Under the second, ownership is permitted where a competitive tendering procedure has demonstrated that no market party is willing to provide the service, and the national regulatory authority has conducted ex-ante review and granted approval. Both exceptions require notification to ACER and the European Commission. These two routes are the EU-level foundation for the FINC route and the ACM exemption in the Energy Act 2026, examined in Section 6.2.

Regulation 2019/943, Art. 13 – The market-based procurement default

Regulation 2019/943 sets the rules for how redispatching must be organised. Article 13(2) establishes that redispatching of generation, storage, and demand response must be market-based by default [72].

Article 13(3)(d) carves out a legally significant exception to the market-based default. Where congestion at a specific node is so frequent and predictable that market parties would game their bids to exploit it, non-market-based redispatching becomes legally permissible at the EU level. Gaming means withholding capacity and offering it back at a premium precisely when TenneT has no alternative. This makes congestion worse rather than better. The Member State must either have established an action plan to address congestion or ensure a minimum cross-zonal capacity in line with Article 16(8). This is the EU-level foundation for the market procurement obligation that the Energy Act 2026 implements at the national level.

Network Code on Emergency and Restoration, Art. 4 – Restoration services and the market feasibility limit

The Network Code on Emergency and Restoration establishes the EU-level framework for system defence and restoration, including black start. Two provisions are directly relevant to the governance analysis. Article 4(1)(d) requires TSOs to use market-based mechanisms to ensure network security

and stability, but qualifies this obligation with the phrase "as far as is possible." This qualification matters: it explicitly recognises that market-based procurement is not always feasible for restoration services, leaving legal room for non-market arrangements where contractual governance cannot guarantee delivery. Article 4(2)(b) establishes that restoration service providers act on a contractual basis subject to regulatory approval, confirming that market-based tendering is the default procurement route for black start under EU law [73].

Together, the three instruments establish a two-track constraint on any TSO operating within the EU framework. The ownership track prohibits direct investment in storage assets except through two narrow routes. The procurement track requires market-based procedures by default, with narrow exceptions where market governance is demonstrably infeasible. Both tracks operate simultaneously and independently: satisfying one does not satisfy the other. Section 6.2 shows how the Energy Act 2026 implements both tracks in Dutch law.

6.2. The Dutch regulatory framework - Energy Act 2026

The EU regulatory baseline established in Section 6.1 shapes how Dutch law implements these rules in the *energiwet 2026* (hereinafter: Energy Act 2026). The Energy Act 2026 entered into force on 1 January 2026, replacing the *Elektriciteitswet 1998* and consolidating Dutch energy law into a single framework [75]. The Energy Act 2026 operates at two levels relevant to this thesis: ownership rules that determine whether TenneT may own a storage asset at all, and procurement rules that determine how services must be purchased from the market. Both levels sit in what Williamson calls the institutional environment (Layer 2) and constrain the governance structures (Layer 3) that TenneT may use [26].

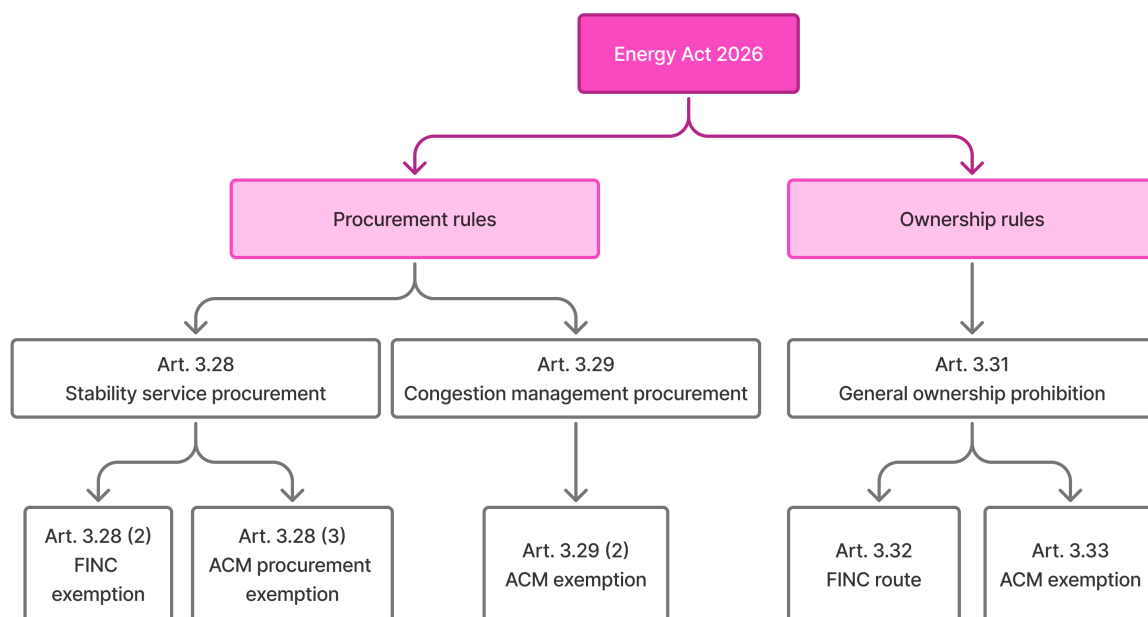


Figure 6.2: Dutch regulatory framework for BESS under the Energy Act 2026. Procurement rules govern stability services (Art. 3.28) and congestion management (Art. 3.29), each with ACM exemption routes. Ownership rules establish a general prohibition (Art. 3.31) with two exception routes: FINC recognition (Art. 3.32) and an ACM exemption (Art. 3.33). (Author's own, based on [18])

Article 3.31 - Ownership rules

Article 3.31 of the Energy Act 2026 establishes the general prohibition: TSO may not own, develop, manage, or operate an electricity storage facility unless one of two exceptions applies. The first is recognition of the facility as a fully integrated network component (FINC) under Article 3.32 (hereinafter: FINC route). The second is an exemption granted by ACM under Article 3.33 (hereinafter: ACM exemption).

Article 3.32 sets out the conditions for FINC recognition. ACM may recognise a storage facility as a FINC on application by TenneT, provided two cumulative conditions are met: the facility must satisfy the properties of a FINC, and it must be suitable for storing electricity. The Energy Act 2026 defines a FINC as an integrated part of the distribution or transmission system used by a system operator exclusively for ensuring safe and reliable system management, and explicitly not for balancing or congestion management [76].

FINC recognition solves two legal problems at once. The first is the ownership problem: a facility recognised as a FINC falls under the exception in Article 3.31(a), meaning TenneT is permitted to own and operate it. The second is the procurement problem: under Article 3.28(2), the obligation to procure a service through a competitive market tender does not apply where TenneT performs that service itself using a FINC. Where TenneT owns a recognised FINC, it may therefore provide the service directly without first running a market tender.

Article 3.33 provides an alternative route when FINC recognition is unavailable. ACM may grant TenneT an exemption for a specific storage facility if three cumulative conditions are met: the facility must be necessary for TenneT to fulfil its statutory system tasks under Article 3.25; TenneT may not use the facility to buy or sell electricity or any other energy carrier; and TenneT must demonstrate that market parties cannot provide the facility at reasonable cost or within a reasonable timeframe. The third condition is the most demanding in practice. TenneT must actively demonstrate market failure, but the method for doing so is its own choice.

The Article 3.33 exemption is not permanent. ACM must conduct a public consultation at least every five years to evaluate whether market parties are able and willing to provide the facility. If so, the exemption must be withdrawn, and TenneT is granted a transition period of up to eighteen months to cease using the asset, unless the facility has been recognised as a FINC under Article 3.32 in the meantime. The implications of this review cycle for investment security are examined in Section 6.3

Articles 3.28 & 3.29 - Procurement rules

The Energy Act 2026 defines non-frequency ancillary services as services used by a system operator for voltage regulation in steady state, fast reactive current injection, inertia for local system stability, short-circuit current, black start capabilities, and island operation capability [76]. This definition encompasses the four stability services analysed in this thesis (voltage control, synthetic inertia, system strength, and black start) and establishes that Article 3.28 applies directly to them. Balancing services fall outside this definition as frequency-related services and are governed separately under Articles 3.26 and 3.27, which require market-based procurement of balancing capacity and energy through transparent and non-discriminatory procedures. Congestion management is governed separately under Article 3.29.

Article 3.28 governs the procurement of non-frequency ancillary services. TenneT must procure these services through transparent, non-discriminatory, and market-based procedures. Two exemptions are available. Under Article 3.28(2), the market procurement obligation does not apply where TenneT performs the service itself using a FINC, reinforcing the dual function of FINC recognition noted above. Under Article 3.28(3), ACM may grant TenneT an exemption from the market procurement obligation for a specific non-frequency ancillary service if it judges that market-based procurement is not economically efficient. This is a procurement-level route that does not require TenneT to own the asset and is therefore legally lighter than the Article 3.33 route.

Article 3.29 governs the procurement of congestion management and system management services. The market procurement default applies here as well. Under Article 3.29(2), ACM may grant an exemption if it judges that market-based procurement is not economically efficient, or that such procurement would lead to serious market distortions or more congestion.

ACM - Gatekeeper & institutional safeguard

ACM, introduced in chapter 1, is the national regulatory authority responsible for implementing the Energy Act 2026 and overseeing TenneT's compliance with it [18, 77]. Its role in this thesis is twofold. First, ACM acts as a gatekeeper: TenneT cannot deviate from the market procurement default or the ownership prohibition without a positive ACM decision. This applies to every exception route examined

in this chapter. Second, ACM acts as an institutional safeguard. Under Article 5.4 of the Energy Act 2026, any party with a dispute about how TenneT exercises its statutory tasks may submit a complaint to ACM, and ACM's decision is binding [18]. Under Article 24 of the Competition Act, ACM prohibits the abuse of a dominant position, which prevents either party in a bilateral arrangement from exploiting the other's locked-in position [78]. Together, these two functions make ACM the institutional anchor that gives hybrid governance arrangements their enforceability in practice.

6.3. Analytical observations from the regulatory framework

Five analytical observations follow from the regulatory framework described in Sections 6.1 and 6.2. Each identifies a specific mechanism by which the legal environment constrains or distorts the governance structures that TCE predicts to be efficient. Figure 6.3 maps each observation against the six services and shows where multiple constraints apply to the same service simultaneously. The observations are the author's own analytical derivation from the framework examined in Sections 6.1 and 6.2. Together, they form the analytical bridge to Section 6.4.

	Balancing	Voltage control	Congestion management	Synthetic inertia	System strength	Black start
O1 - Non-storage asset asymmetry						
O2 - Investment horizon						
O3 - Non-trading condition						
O4 - Procurement exemption route						
O5 - FINC scope exclusion						
Constraint count	2	2	2	4	4	4

Figure 6.3: Regulatory constraints mapped against the six system services. Observations O1 through O5 are shown as rows; shading indicates where a constraint applies. Balancing, voltage control, and congestion management each face two constraints; synthetic inertia, system strength, and black start each face four, making them the most governance-constrained services under the Energy Act 2026. (Author's own)

O1 – Non-storage asset asymmetry

TenneT already owns synchronous condensers, coils, and capacitors for stability purposes and faces no ownership barrier for those assets. A BESS performing the same function at the same node requires prior ACM approval under Article 3.32 or 3.33. The framework discriminates between functionally equivalent assets based on technology rather than function, a distinction with no grounding in the service requirements it governs. The practical consequence is a regulatory bias toward the more expensive option: TenneT can deploy a synchronous condenser freely, but must obtain prior approval to deploy

a BESS that could provide the same service at lower cost.

O2 – Investment horizon mismatch

An Article 3.33 exemption is reviewed at least every five years and must be withdrawn if market parties can provide the service, with an eighteen-month wind-down period. A financial risk exists: TenneT may have invested in an asset it can no longer use. However, this risk is partially mitigable because TenneT could sell or transfer the asset to a market party at termination. The more acute risk is operational: if the exemption is withdrawn before an adequate market replacement exists, TenneT faces a service continuity gap that it cannot close within eighteen months. For stability services with no standardised product definition and no established market, finding and contracting a replacement provider within that window is not realistic. The FINC route under Article 3.32 does not carry this review cycle and is therefore analytically preferable for stability services.

O3 – Non-trading condition

Article 3.33(2) prohibits TenneT from using an owned BESS to buy or sell electricity. This removes market participation as a tool for state of charge management and cost recovery, requiring either larger installed capacity or higher operating costs. The constraint is most acute for synthetic inertia, where the service requires only a small bidirectional headroom, leaving most of the battery's capacity idle and commercially unusable.

O4 – Procurement-level exemption route

Articles 3.28(3) and 3.29(2) allow ACM to exempt TenneT from the market procurement obligation without requiring asset ownership. TenneT needs only to demonstrate that market-based procurement is not economically efficient or, under Article 3.29(2), would cause market distortions or more congestion. This route is legally lighter than Article 3.33 because TenneT does not own the asset: the private BESS operator retains commercial use of the battery's capacity outside the service obligation, improving the commercial viability of the arrangement. It is not currently used for stability services but is legally available and provides the foundation for the interim arrangements identified in Section 6.4 where FINC recognition cannot yet be obtained.

O5 – FINC scope exclusion

The Energy Act 2026 defines a fully integrated network component as an asset used exclusively for safe and reliable system management, explicitly not for balancing or congestion management [76]. The FINC route is therefore permanently closed for congestion management, regardless of node severity or governance problem. Where Articles 3.29(2) and 3.33 are insufficient, TenneT has no further legal recourse for congestion management. For the stability services, the FINC definition maps directly onto the service requirements and remains the most legally robust ownership route available. Section 6.4 examines the consequences of this exclusion for chronically congested nodes where the available pathways cannot be made fully effective.

6.4. Legal feasibility analysis

This section assesses the legal feasibility of each governance prediction from Chapter 5 against the regulatory framework established in Sections 6.1 and 6.2. Two questions are addressed in sequence for each service. First, does the Energy Act 2026 permit the governance structure that TCE predicts is efficient? Second, if not, what is the best feasible alternative within the legal boundaries?

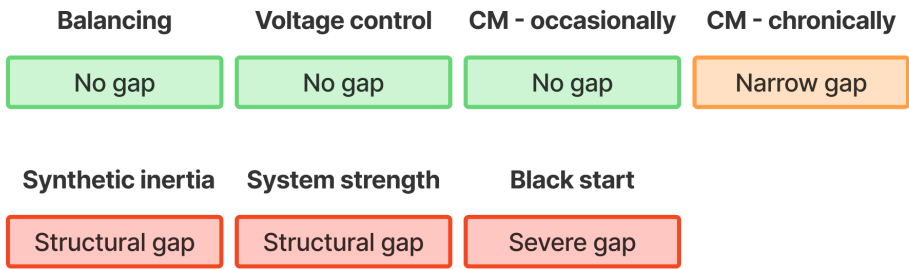


Figure 6.4: Governance gap severity across the six system services. Balancing, voltage control, and occasionally congested nodes have no gap or a narrow gap. Chronically congested nodes face a narrow gap. Synthetic inertia and system strength face a structural gap; black start faces the most severe gap. (Author’s own)

Balancing

Chapter 5 predicts market governance for balancing services, and the Energy Act 2026 is fully aligned with this prediction. Balancing services are governed under Articles 3.26 and 3.27 of the Energy Act 2026, which require market-based procurement of balancing capacity and energy through transparent and non-discriminatory procedures. ENTSO-E product standardisation keeps asset specificity low across all transactions, bilateral lock-in never arises, and TenneT already procures FCR, aFRR, and mFRR through competitive platforms shared with neighbouring TSOs. None of the observations from Section 6.3 applies, and there is no governance gap.

Voltage control

Voltage control is predicted to require bilateral hybrid governance in Chapter 5. The Energy Act 2026 permits this. Long-term bilateral contracts for stability services are procured under Article 3.28, and no procurement exception is required if TenneT uses transparent, non-discriminatory, and market-based procedures. In practice, the pool of providers at any given voltage-stressed node is limited, so the competitive tender that initiates the arrangement quickly gives way to a bilateral relationship once the investment is made. The fundamental transformation then takes hold. Both parties are locked in: the provider cannot easily relocate, and TenneT cannot easily replace it. This creates a hold-up risk, where the provider could exploit its local monopoly position to renegotiate terms after the investment is committed. In the Dutch institutional environment, ACM oversight under Article 24 of the Competition Act constrains this risk [78]. Article 24 prohibits the abuse of a dominant position and prevents the provider from extracting prices above a fair, cost-reflective level. The Energy Act 2026, therefore, permits exactly the bilateral arrangement that the lock-in dynamic requires, and there is no governance gap for voltage control.

Congestion management

Chapter 5 predicts hybrid governance for congestion management, depending on how often congestion occurs at a specific node. At nodes where congestion occurs only occasionally, a trilateral hybrid arrangement is sufficient: the asset retains sufficient commercial freedom for the fundamental transformation not to have fully taken hold. At nodes where congestion is chronic, a bilateral hybrid arrangement is needed. The difference between the two comes down to how committed the asset becomes to TenneT over time. At chronically congested nodes, the asset is activated so frequently that it effectively becomes dedicated to TenneT. This is the fundamental transformation in practice: what began as a competitive arrangement collapses into a bilateral dependency, and neither party can exit without significant loss. Figure 6.5 shows the governance logic and legal instruments for both node types.

Congestion management covers two different service types, both governed under Article 3.29. Preventive redispatching means TenneT sees congestion hours in advance and calls on flexible assets to prevent it. Curative N-1 security means a portion of an asset’s capacity is kept on standby at all times, ready to respond the moment an unexpected failure occurs. The difference matters for governance: for preventive redispatching, TenneT calls on the asset when it anticipates congestion, and the BESS op-

erator knows in advance whether it will be needed. For curative N-1 security, a defined capacity block is reserved and must remain available at all times, but whether it is actually called upon depends on whether a contingency occurs. No formal contractual instrument for curative N-1 security currently exists in the Netherlands. TenneT currently relies on bilateral agreements negotiated on a case-by-case basis, without a standardised framework.

At occasionally congested nodes, a capacity management contract under Article 3.29(1) is sufficient. The term trilateral hybrid governance does not appear in the Energy Act 2026. It is an analytical term from Williamson: a contract between two parties in which a third party provides oversight to keep both sides honest. In the Dutch context, ACM plays that role. ACM oversight under the Competition Act prevents the provider from exploiting its position, and ACM's power to grant or withdraw exemptions under Article 3.29(2) gives the arrangement its institutional anchor. No governance gap exists at nodes that are occasionally congested.

At chronically congested nodes, two structural problems prevent the framework from delivering the governance structure that TCE predicts. The first is that the bilateral contract required by this situation is legally available under Article 3.29(2), but TenneT has no legal tool to compel a BESS operator to enter one. The BESS operator retains the right to decline precisely where TenneT most needs commitment.

The second problem is circular. Congestion leads to multi-year waiting lists, preventing new BESS operators from connecting to the grid. Those same BESS operators could relieve the congestion if they were connected. TenneT, therefore, cannot easily demonstrate market failure under Article 3.29(2), because BESS operators are willing in principle but structurally excluded by the very problem the service is meant to solve. This circularity strengthens the case for invoking Article 3.29(2) on the ground that market-based procurement cannot deliver the service, rather than on the ground of economic inefficiency alone.

Observation O5 closes the FINC route for congestion management regardless of node severity, making Article 3.29(2) the most relevant legal pathway. The governance gap is not a legal gap but an effectiveness gap: the right governance structure exists in the law, but the framework does not give TenneT the tools to make it work where it is needed most.

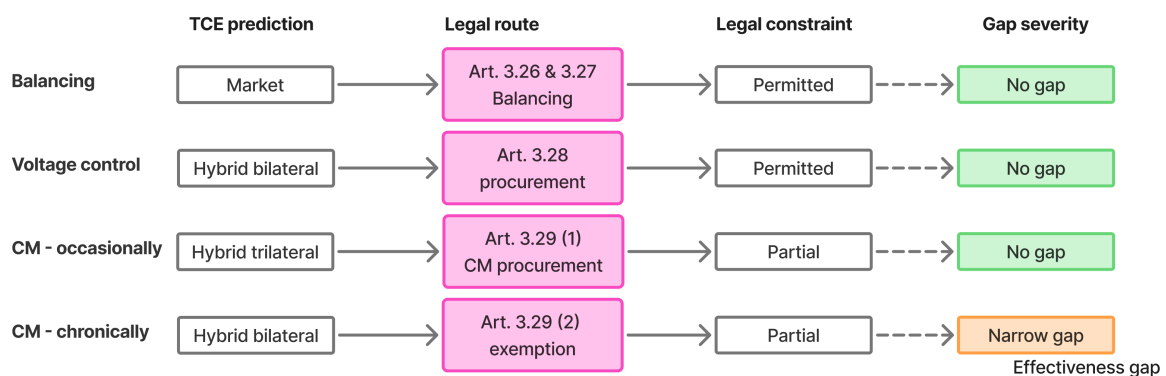


Figure 6.5: Legal feasibility assessment for balancing, voltage control, and congestion management. Each row maps the TCE prediction to the applicable legal route and resulting gap severity. Balancing and voltage control are fully permitted; occasionally congested nodes face no gap; chronically congested nodes face a narrow effectiveness gap under Art. 3.29(2). (Author's own)

Synthetic inertia

Chapter 5 predicts hierarchy for synthetic inertia, driven by governance problems that no contractual arrangement can resolve. The Energy Act 2026 prohibits BESS ownership by default, creating a structural governance gap. Two legal routes to hierarchy are available and are assessed in turn.

The FINC route under Article 3.32 is the most robust legal pathway to hierarchy for synthetic inertia. The FINC definition maps directly onto synthetic inertia: the asset must be used exclusively for safe and

reliable system management, which is precisely what synthetic inertia provides. However, the route faces two practical barriers. The first is procedural: ACM has never granted FINC recognition to a BESS, no published guidance exists on what evidence is required, and TenneT has not yet initiated the process. The second is evidentiary. To obtain FINC recognition, TenneT must in practice demonstrate that the market cannot provide the service. Synthetic inertia has never been procured competitively and has no established market product. This creates a circular problem: the market cannot be tested before the product is defined, and the product cannot be defined before standardisation exists. Until that standardisation is in place, the evidentiary requirement cannot be satisfied.

The alternative ownership route is the ACM exemption under Article 3.33, but it is structurally unattractive for one decisive reason: the five-year review cycle under O2. If the exemption is withdrawn before an adequate market replacement exists, TenneT faces a service continuity gap it cannot close within eighteen months. For a stability service with no established market, that risk is acute.

Both ownership routes carry the non-trading constraint: neither Article 3.33 nor the FINC route permits the owned BESS to participate in commercial markets. For synthetic inertia, this means most of the battery's capacity sits idle regardless of which route is pursued. The decisive advantage of FINC over Article 3.33 is therefore not commercial freedom but the absence of a review cycle and the associated service continuity risk.

Observation O1 further sharpens the governance gap. TenneT already owns synchronous condensers for inertia provision and can deploy them without any prior approval. A BESS that could provide the same service at a lower cost would require a multi-year approval process before TenneT could own it. The framework, therefore, creates a regulatory bias toward the more expensive option.

Where neither the FINC route nor the ACM exemption is immediately achievable, the best feasible interim arrangement is a procurement-level exemption under Article 3.28(3) combined with a long-term bilateral contract. Unlike voltage control, where a market-based tender under Article 3.28(1) naturally produces a bilateral outcome, synthetic inertia has no standardised product definition that would allow TenneT to run a compliant market procedure. Article 3.28(3) is therefore needed: ACM may exempt TenneT from the market procurement obligation where market-based procurement is not economically efficient, which is precisely the case here. This arrangement is preferable to Article 3.33 for one decisive reason: TenneT does not own the asset. The BESS operator retains commercial use of the battery's idle capacity through frequency response markets, balancing services, or wholesale energy trading, making the arrangement commercially viable and aligning incentives more effectively than either ownership route. The bilateral contract does not fully resolve the verification problems identified above, but it avoids both the service continuity risk of Article 3.33 and the procedural and evidentiary barriers of the FINC route during the transition period.

The governance gap for synthetic inertia is structural and threefold: a legal gap because ownership is prohibited by default, a procedural gap because no ACM guidance or precedent exists, and an evidentiary gap because market failure cannot be demonstrated for a service with no existing market. The gap is closable in principle through the FINC route, but requires published ACM guidance, a defined application procedure, and a standardised product definition.

System strength

Chapter 5 predicts hierarchy for system strength on the same grounds as synthetic inertia, and the legal routes follow the same logic: FINC recognition under Article 3.32 is the most robust route, Article 3.33 is structurally unattractive due to O2 and O3, and Article 3.28(3) combined with a long-term bilateral contract provides the best feasible interim arrangement for the dynamic stability component. These are not restated here. Two features distinguish system strength from synthetic inertia.

System strength has two components: dynamic voltage stability, which a BESS can contribute to through grid-forming control, and short-circuit current, which a BESS cannot provide. Short-circuit current is the surge of current that flows when a fault occurs, needed to trigger protective equipment and isolate the fault. No governance structure can require a BESS to deliver a capability its physics cannot support. The only solution for the short-circuit component is a synchronous condenser, which TenneT can already own without prior approval.

The second distinguishing feature is the verification problem. For synthetic inertia, performance can be partially observed during normal frequency disturbances. For system strength, fault-current capability can only be confirmed during a real fault event, which may never occur over the asset's operational lifetime. The governance hazard is therefore more severe: TenneT may never be able to verify that the asset delivers what it was contracted to provide.

Observation O1 applies with additional force. A synchronous condenser provides both components of system strength simultaneously without any regulatory barrier. A BESS can only provide the dynamic stability component and requires prior ACM approval to do so. The asset TenneT can deploy freely is technically superior to the one subject to regulatory barriers.

The best feasible arrangement is therefore a hybrid asset mix. FINC recognition allows TenneT to own a BESS for the dynamic stability component. Synchronous condensers cover the short-circuit current component. Together, they provide the full system strength capability that neither asset can deliver alone.

The governance gap for system strength is twofold. There is a legal gap in the dynamic stability component that the FINC route can, in principle, close. There is a technical gap in the short-circuit component that no governance structure can resolve.

Black start

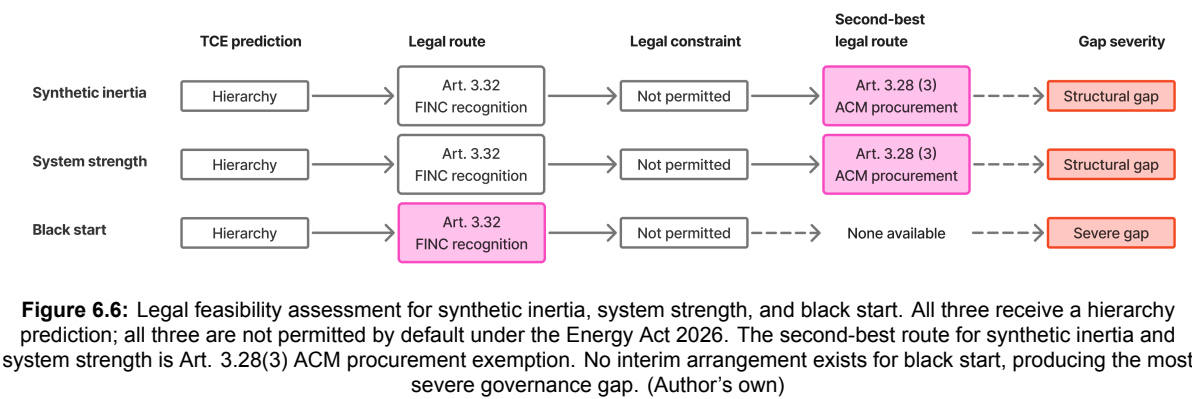
Chapter 5 predicts hierarchy for black start. The legal position follows the same general structure as synthetic inertia and system strength, with one critical difference that makes the governance gap the most severe in this analysis.

That difference is the state of charge requirement. The entire battery reserve must be held in permanent readiness at all times, leaving no capacity for commercial use. This is not a governance problem that better contract design can solve: it is a physical incompatibility between the service obligation and commercial operation. No BESS operator can justify the investment on availability payments alone when commercial revenue is permanently excluded, making a hybrid contract with a private BESS operator unviable.

FINC recognition under Article 3.32 is therefore the only arrangement that can provide the certainty of delivery required by a critical restoration function. Article 3.33 is unattractive due to the five-year review cycle under O2: a service continuity gap in black start capability means the grid cannot be restored after a system collapse, making the review risk unacceptable. The non-trading condition under O3 adds no further constraint because the service already excludes commercial use regardless of ownership form. There is no interim alternative.

Current Dutch practice confirms this conclusion. TenneT's most recent black start tender, awarded in January 2026, was won by a combined cycle gas turbine, not a standalone BESS. The battery in the winning configuration plays a supporting role, assisting turbine start-up rather than providing black start independently [79]. Standalone BESS has not yet demonstrated the capability to fulfil a primary black start obligation in the Dutch system. The Network Code on Emergency and Restoration explicitly acknowledges that market-based procurement cannot always guarantee delivery of restoration services, preserving the legal space for non-market arrangements where contractual governance is insufficient.

The governance gap for black start is structural and the most severe in this analysis. FINC recognition is the only arrangement that can work, and no interim exists while the procedural and evidentiary barriers are being resolved.



6.5. European Union practices

Three analytical observations emerge from the EU comparison and frame the country cases that follow. First, no TSO operating under the same Article 54 framework has fully closed the governance gap for stability services. Second, institutional sequencing matters: the TSOs that have made the most progress moved from pilot arrangements under TSO ownership or regulatory obligation toward competitive procurement only after product definitions and verification protocols were sufficiently developed.

Germany

Germany has developed two distinct governance arrangements that together constitute the most relevant EU reference point for the Dutch gaps identified in Section 6.4. For curative network security, TenneT DE and TransnetBW, the German TSOs, deployed a 250 MW BESS at Kupferzell, the Network Booster, as a regulated network component under the German equivalent of the FINC route. The asset sits permanently fully charged, is activated extremely rarely, and does not participate in energy markets. This constitutes hierarchy governance and is the closest EU analogue to the FINC route under the Dutch Energy Act 2026. The boundary it illustrates is directly relevant to the Dutch context: assets that sit ready but rarely activate qualify for network component classification; assets dispatched regularly for congestion relief do not [80].

For synthetic inertia, the four German TSOs launched the Momentanreserve market on 22 January 2026, the first standardised hybrid governance arrangement for synthetic inertia in the EU. Grid-forming BESSs are procured through fixed-price contracts of two to ten years, must meet defined technical requirements, and are certified upfront through a testing procedure. Ongoing availability is monitored retrospectively through synchronisation data. This is the most significant EU reference point for the Dutch evidentiary gap: standardised hybrid governance for synthetic inertia is legally achievable under Article 54 [81]. The gap is not irresolvable in principle, but it required standardised product definitions and verification protocols that the Dutch framework has not yet established.

Italy

Terna, the Italian TSO, has transitioned to the MACSE framework, a market-based auction system for long-term storage capacity contracts of up to 15 years [82]. BESS has become the dominant new asset class for fast frequency response and synthetic inertia procurement, while synchronous condensers remain in use for local voltage issues where site specificity is acute. The MACSE framework represents market-based governance with contract durations long enough to partially approximate the safeguards of bilateral hybrid governance. It is relevant to the Dutch context as an example of how standardised product definitions and long contract durations can reduce the governance gap for synthetic inertia without requiring TSO ownership, provided that product definitions and verification protocols are sufficiently developed to make contractual monitoring tractable.

France

RTE, the French TSO, illustrates the pilot-to-procure sequencing logic most directly. Storage was deployed under TSO ownership through the RINGO pilot to prove the technical case and establish operational rules before procurement shifted toward competitive market arrangements as product definitions matured [83]. For the Netherlands, this suggests that FINC recognition for synthetic inertia and system strength need not be a permanent arrangement: once standardisation improves, procurement can shift toward competitive bilateral contracts of the kind that the German Momentanreserve market has begun to establish.

Belgium

Elia, The Belgium TSO, manages congestion primarily through redispatching and counter-trading. Belgium's nuclear fleet currently provides approximately 42 per cent of electricity generation, meaning the urgency on stability services is substantially lower than in systems with higher shares of inverter-based generation [84]. Ongoing technical consultations on grid-forming BESS requirements place Belgium at an early stage of the pilot-to-procure transition, having not yet met the preconditions, standardised product definitions, and testing protocols that Germany met before launching the Momentanreserve market [85].

Spain

REE, the Spanish TSO, organises stability services through regulatory obligations and bilateral contracts, with pumped hydro and synchronous condensers as the dominant asset types. Storage under system-operator control in island grids illustrates the same pilot-to-procure logic. Where markets are thin and alternative providers are absent, non-market arrangements create the operational experience that may eventually support competitive procurement [86].

European Union comparison

The EU comparison points to a single conclusion for the Netherlands. The governance gap for stability services is not unique to the Dutch regulatory framework, and it is not permanent. Germany demonstrates that standardised hybrid governance for synthetic inertia is achievable under Article 54 once product definitions and verification protocols exist. France demonstrates that FINC recognition need not be the end state: TSO ownership during a pilot phase can create the conditions for competitive procurement to follow. The Netherlands is at the beginning of that transition, not at its limit.

Table 6.1: EU approaches to stability services and congestion management

Country	Instrument	Governance	Stage	Lesson for NL
Germany	Network Booster; Momentanreserve	Hierarchy; Hybrid	Advanced	Standardisation + verification enable hybrid inertia markets
Italy	MACSE auctions	Market / hybrid	Transition	Long-term contracts can approximate hybrid safeguards
France	RINGO pilot → procurement	Pilot → hybrid	Transition	Pilot-to-procure sequencing is critical for market design
Belgium	Redispatch; BESS consultation	Market / early hybrid	Early	Preconditions for inertia markets (standards, testing) not yet met
Spain	Bilateral; regulatory obligation	Hybrid / hierarchy	Mixed	Non-market governance justified in constrained local systems

7

The System Services Governance Framework

TenneT must procure system services reliably and at the lowest total cost. The preceding chapters established two independent answers to that question. Chapter 5 derived a governance prediction for each service from its transaction characteristics alone: which arrangement minimises the combined cost of delivering the service and organising the relationship around it. Chapter 6 tested those predictions against the Energy Act 2026 and EU unbundling rules: which arrangements the law actually permits, and where the efficient form is legally unavailable, what the closest feasible alternative is. The two analyses do not always point in the same direction. That gap between efficiency and legal availability is the governance problem this chapter addresses.

The System Services Governance Framework (SSGF) integrates both analyses into a single structured decision tool. It answers three questions in sequence for any given system service: which governance structure minimises total costs, whether that form is legally available under the Energy Act 2026, and what the appropriate interim arrangement is if it is not yet achievable. The framework does not introduce new analytical content. It translates the findings of Chapters 5 and 6 into a structured decision tool that a TenneT practitioner can apply in a service design process or a regulatory proceeding, and that ACM can audit against statutory criteria.

Five limitations apply throughout. Cost comparisons at Gate 4 are directional and qualitative: they establish the direction of the cost advantage, not its magnitude. The legal feasibility check identifies what the regulatory framework permits in principle and does not constitute legal advice or predict ACM decisions in specific cases. The framework assumes that the identified service must be delivered and does not assess whether alternative technical solutions could meet the same system need at a lower cost. Foregone revenue is included in the Gate 4 cost comparison as a cost specific to direct TenneT ownership, arising from the Article 3.33(2) prohibition on the commercial use of an owned asset. The forward-looking assumption is that grid connection queues will have cleared by the planning horizon of 2030 to 2035; where that assumption does not hold, the liquidity assessment at Gate 1 and the market failure demonstration in the legal feasibility check would need to be reassessed.

Market governance, meaning competitive tendering, is the default starting point of the SSGF. This is not an analytical preference: it is a legal requirement under the Energy Act 2026, and any departure from it must be actively justified to ACM.

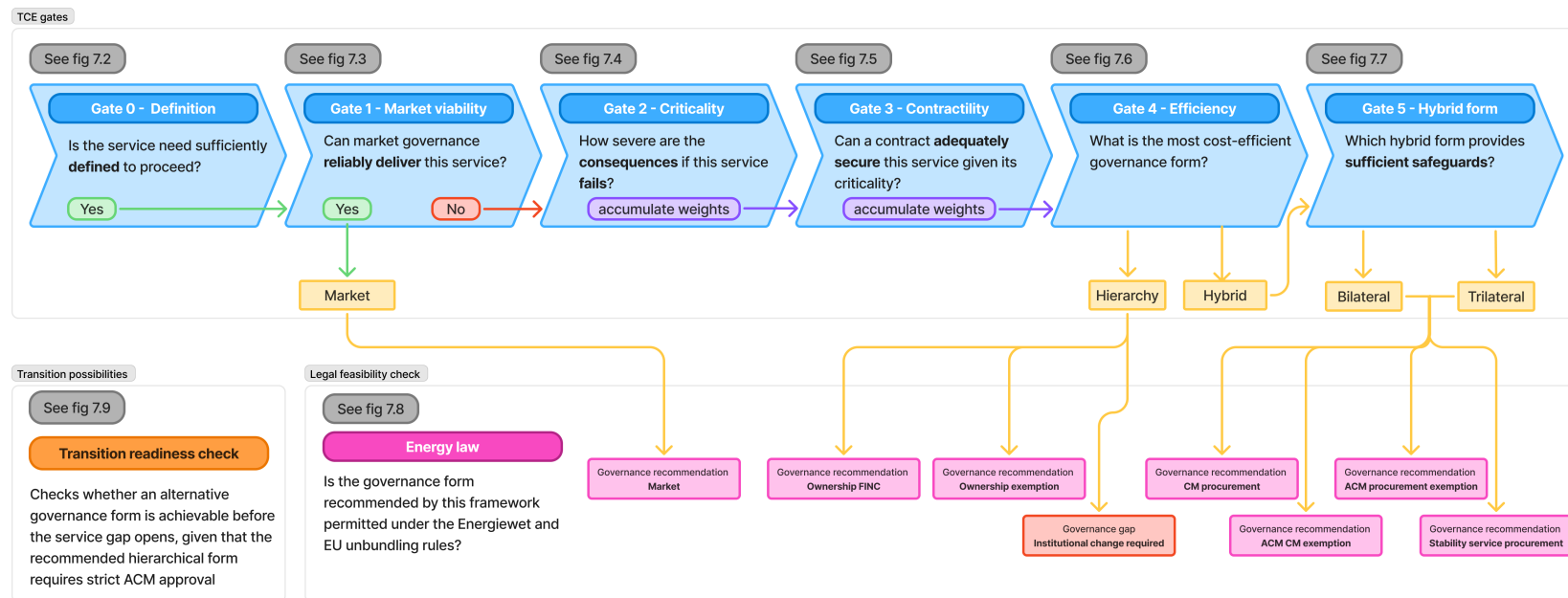


Figure 7.1: The System Services Governance Framework: the transaction cost gate sequence (Gates 0–5), the legal feasibility check, and the transition readiness check, with all possible governance outputs. Market governance is the default; each gate departs from it only where a specific criterion is not met. (Author's own)

7.1. Framework Architecture

The SSGF consists of three sequential components. The gate sequence asks what is economically efficient. The legal feasibility check asks what is legally permitted. The transition readiness check asks whether the legally permitted arrangement can be put in place before the service gap opens. Keeping these questions separate prevents the legal analysis from narrowing the efficiency finding before it has been reached.

The gate sequence consists of six gates that progressively narrow the governance solution space from the market default toward more control-intensive forms. Gate 0 determines whether the service is sufficiently well-defined to proceed. Gates 1 through 5 each apply a specific analytical criterion. The sequence terminates as soon as a conclusive governance direction is reached and routes directly to the legal feasibility check.

The legal feasibility check tests the gate sequence output against the Energy Act 2026 and EU unbundling rules. It identifies the applicable legal pathway and produces either a governance recommendation or a governance gap finding, including the closest feasible alternative where no pathway is immediately available.

The transition readiness check activates only where direct TenneT ownership is recommended and ACM approval is required. It assesses whether the approval timeline is compatible with the service delivery deadline and, if not, identifies the most appropriate interim arrangement that is legally available without prior ACM approval.

Figure 7.1 illustrates the full framework.

Gates 0 and 1 establish whether the service is defined precisely enough and whether competitive tendering can deliver it; Gates 2 and 3 assess how severe the consequences of failure are and whether a contract can adequately guard against them; Gate 4 determines which governance structure minimises total costs; and Gate 5 selects the appropriate contractual form where long-term contracting is the answer.

Gate 0: Service Definition

Gate 0 is a definitional prerequisite, not a scoring gate. If the service cannot be precisely specified here, the transaction characteristics assessed at later gates will be incomplete and the governance recommendation will be unreliable.

Four criteria must be confirmed before proceeding: the service and asset type must be named; the reason the service is needed at this specific location must be stated; the key operational constraints must be specified; and the primary service must be designated where more than one service is under consideration. Where multiple services are identified, a multi-service flag is raised and carried forward to Gate 4.

One constraint requires particular attention. A battery's availability cannot be determined from its state of charge at a single point in time. The recent operating trajectory matters too: prior cycles limit how quickly the asset can move from one state to another, and two services that appear compatible on a snapshot assessment may conflict when the full operational window is considered.

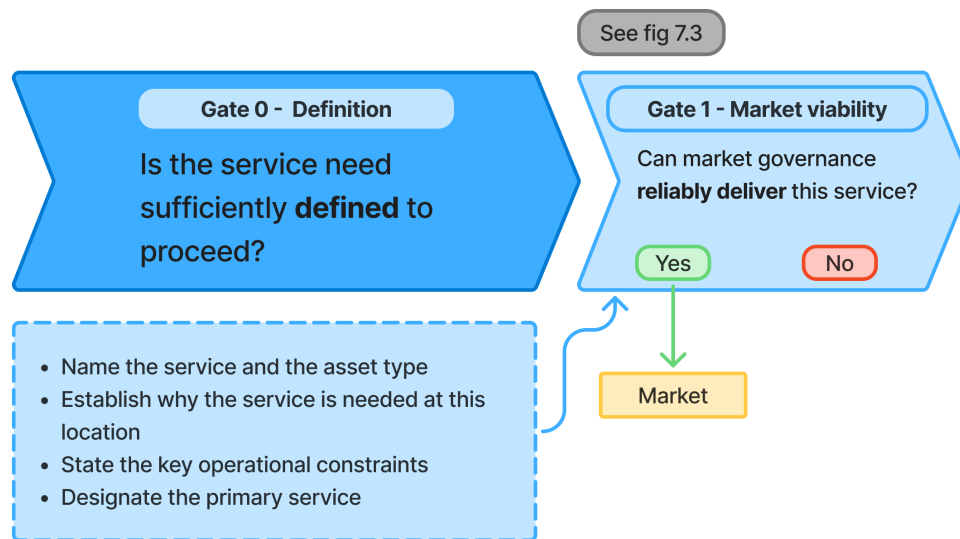


Figure 7.2: Gate 0: Service definition checklist and connection to Gate 1. A positive finding on all four criteria is required before the gate sequence proceeds. (Author's own)

Gate 1: Market Viability

Gate 1 asks whether competitive tendering can reliably deliver the service. According to Williamson, market governance works when three conditions are simultaneously met: price signals can communicate the value of the service, genuine competition exists among providers, and switching between providers remains possible without significant cost. Where all three hold, market governance minimises total costs and no further governance analysis is needed [20]. The gate therefore tests each condition in sequence. First, the service must be sufficiently standardised for price signals to communicate its value: without a product definition, TenneT cannot compare offers or verify delivery. Second, enough providers must exist at the relevant location to create genuine competitive pressure: without it, the provider that wins the tender faces no constraint on its subsequent behaviour. Third, the assets must not be so specific to this transaction that switching providers becomes costly after the tender: where switching is expensive, the competitive discipline that market governance relies on disappears.

If all three conditions are satisfied, competitive tendering is recommended and the analysis routes to the legal feasibility check. If any condition fails, the analysis proceeds to Gate 2. Where the service is location-bound, the liquidity check applies specifically to the relevant node, and the degree of location-boundedness carries forward to Gate 4 as a modifier on transaction costs.

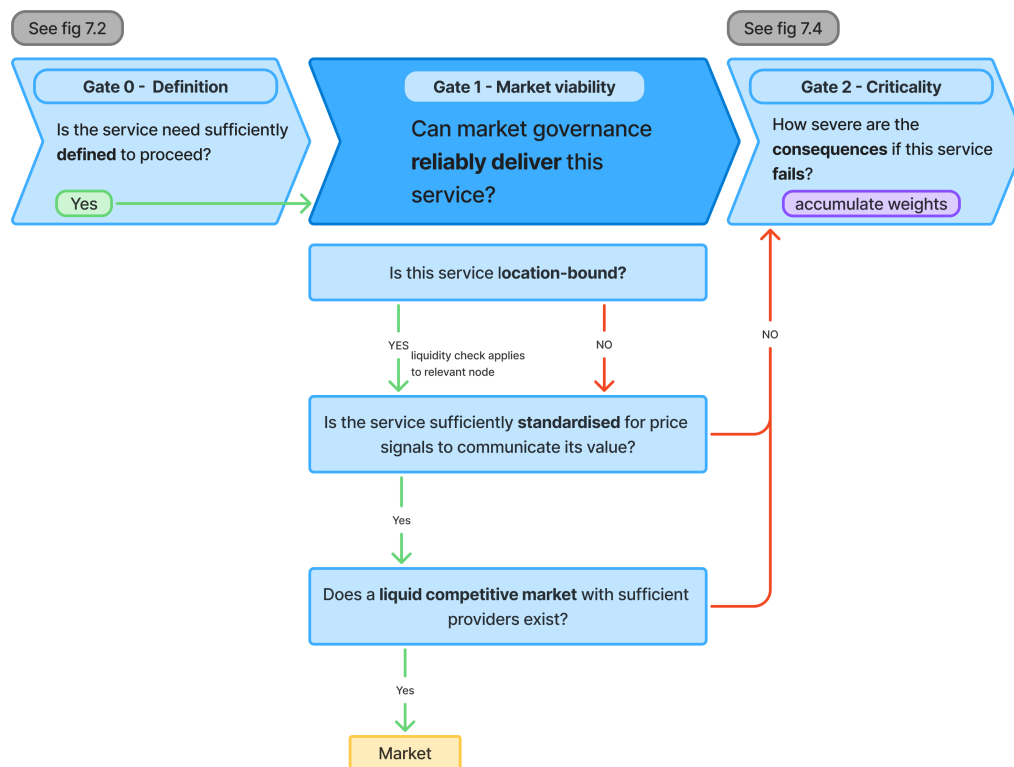


Figure 7.3: Gate 1: Market viability assessment. The gate tests location-boundedness, standardisation, and market liquidity in sequence. A negative finding at any step routes the analysis to Gate 2. (Author's own)

Gate 2: Criticality

Gate 2 asks how severe the consequences are if the service fails. The gate is grounded in the alignment framework of Künneke, Ménard and Groenewegen [34], which introduces the concept of critical functions: tasks whose failure threatens the integrity of the system as a whole. For critical functions, the standard TCE logic of minimising expected costs is insufficient. A governance structure that accepts a small probability of non-delivery may be cost-efficient on average. But if non-delivery triggers an immediate and irreversible system collapse, that small probability carries consequences that no cost estimate fully captures. The alignment framework therefore requires that governance of critical functions provides certainty of delivery, not merely expected cost efficiency. Gate 2 operationalises this by scoring how critical the service is, so that the subsequent gates can apply a proportionally higher standard.

Gate 2 produces no governance output of its own. It produces an accumulated score that tightens the requirements at the subsequent gates in two ways. At Gate 3, a high score raises the contractibility threshold: where criticality is high, any residual verification or commitment gap adds weight towards direct TenneT ownership, because the consequences of that gap occurring are too severe to accept even a small residual probability of governance failure. At Gate 4, a high combined score raises the cost-comparison threshold: direct TenneT ownership requires less of a cost advantage to be selected, because the expected cost of governance failure under a less control-intensive form must be added to the comparison, and that cost rises with the severity and irreversibility of non-delivery.

Two questions are scored. The first asks how severe and irreversible the consequences of non-delivery are: slow and compensable consequences add no weight (0); rapid but correctable consequences add

one weight (+1); immediate and irreversible consequences add two weights (+2). The second asks how technically dependent the service is on this specific asset: no interdependency adds no weight (0); interdependency where alternatives exist adds one weight (+1); interdependency without alternatives adds two weights (+2). The maximum accumulated score from Gate 2 is four. Where degraded delivery, as distinct from complete non-delivery, itself threatens system integrity, this is recorded as a qualitative weight towards hierarchy alongside the two scored questions.

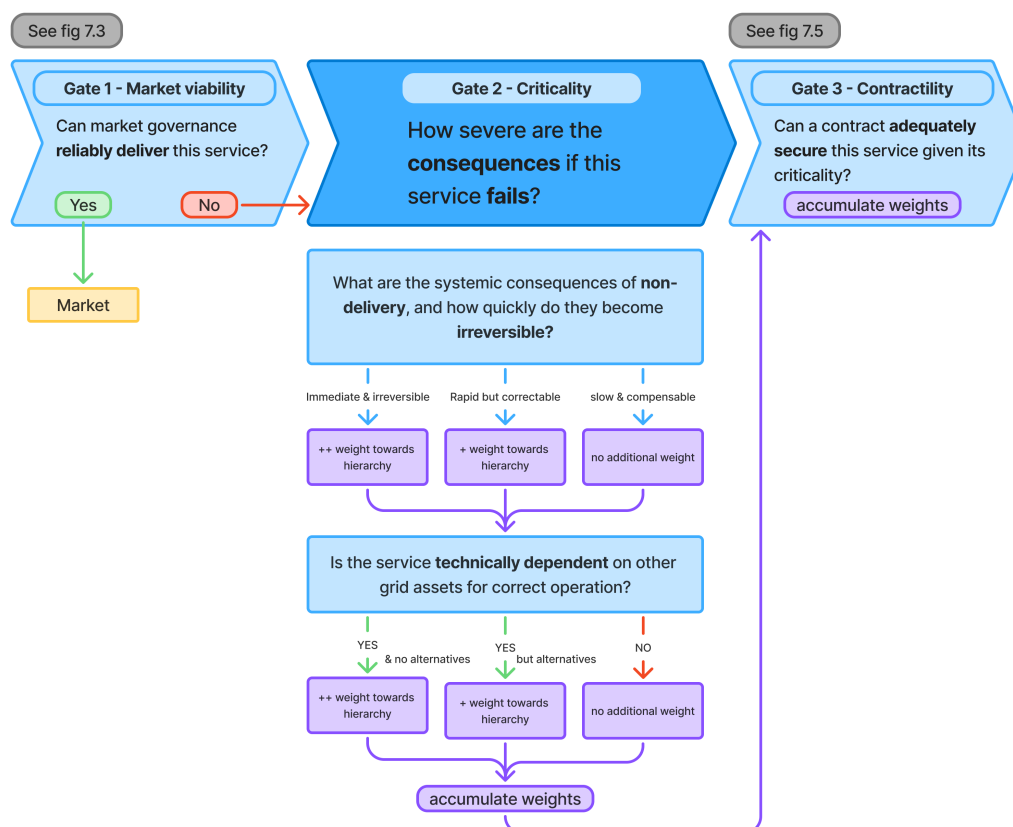


Figure 7.4: Gate 2: Criticality assessment. The gate scores the severity and irreversibility of non-delivery and the degree of technical interdependency. The accumulated weights carry forward to Gates 3 and 4. (Author's own)

Gate 3: Contractability

Gate 3 asks whether a contract can adequately secure the service given its criticality. It is grounded in Williamson's analysis of information asymmetry and credible commitments [19]. Like Gate 2, it produces weights only, not governance output.

The Gate 2 score sets the contractability threshold. A score of zero to two means partial contractability is sufficient: where the consequences of non-delivery are manageable, a contract that addresses the most significant monitoring and commitment gaps can adequately secure the service. A score of three to four means full contractability is required: where failure is immediate and irreversible, even a small residual gap creates an unacceptable probability of governance failure, and any such gap adds weight towards direct TenneT ownership.

Williamson identifies two conditions that determine whether a contract can adequately govern a transaction. The first is verifiability: TenneT must be able to observe whether the service is actually being

delivered. Without this, the BESS operator can reduce availability to pursue commercial revenues without being detected, and the contract cannot be enforced. The second is credible commitment: the BESS operator must have made a sufficiently large irreversible investment that walking away is genuinely costly. An BESS operator who has committed substantial capital to a specific location loses most of that value if it exits the relationship. That sunk cost is what makes the commitment credible. Where that investment is absent, the contract must compensate through other means such as availability penalties. These two conditions form the basis of the two scored questions at this gate.

Two questions are scored. The first asks whether service delivery can be adequately verified in real time; if not, one weight (+1) is added. The second asks whether the BESS operator has sufficient asset-specific investment to constitute a credible commitment to availability; if not, one weight (+1) is added. The maximum additional weight from Gate 3 is two, producing a combined maximum of six from Gates 2 and 3, which carries forward to Gate 4.

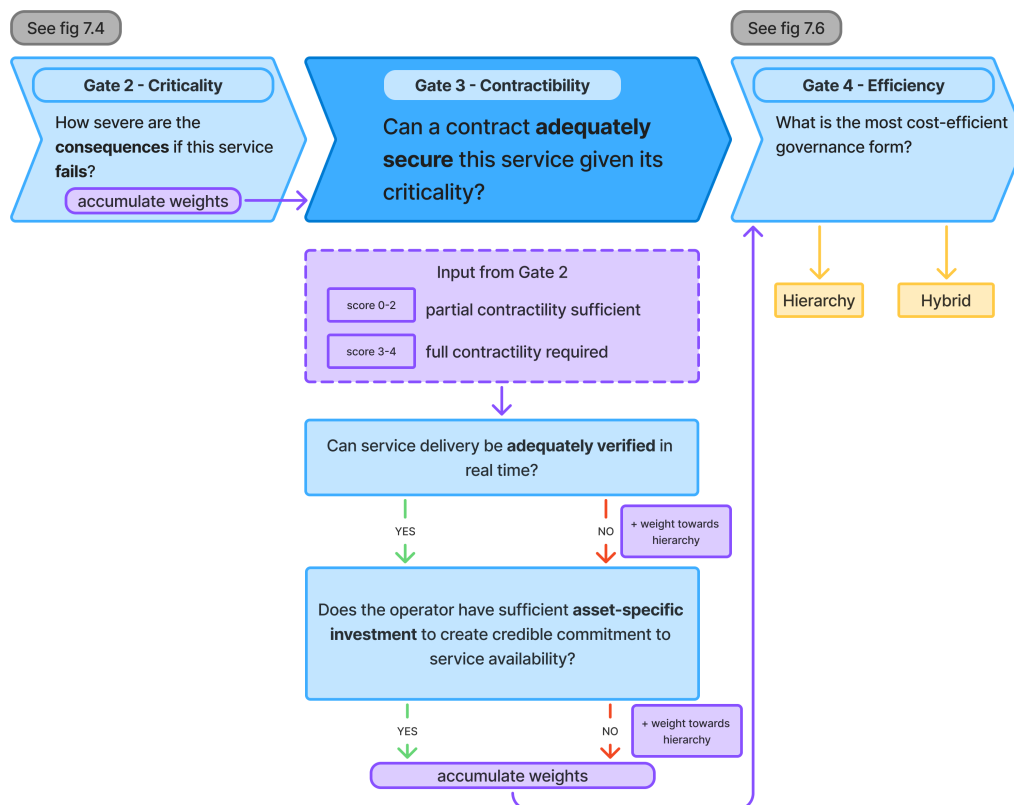


Figure 7.5: Gate 3: Contractability assessment. The Gate 2 score sets the contractability threshold. The gate then tests whether delivery can be verified in real time and whether the BESS operator's investment creates a credible commitment to availability. The accumulated weights carry forward to Gate 4. (Author's own)

Gate 4: Efficiency

Gate 4 determines the most cost-efficient governance structure by operationalising Williamson's comparative cost logic [19]. The gate proceeds in four steps.

The first step establishes the availability type and identifies the key cost drivers. Where a service requires continuous availability with a minimum SoC headroom obligation, $C_{\text{foregone revenue}}$ is higher than for event-triggered services, because under Article 3.33(2) TenneT may not use an owned asset com-

mercially and the revenue from idle capacity is foregone. Partially offsetting this, TenneT's regulated status gives it a lower cost of capital than a private BESS operator: because TenneT's financial returns are guaranteed by regulation rather than subject to market risk, lenders and investors accept a lower return, which reduces the financing cost of the asset relative to private ownership. This reduces $C_{\text{production}}(h)$ relative to $C_{\text{production}}(hy)$. The magnitude of this advantage is asset- and market-condition-specific and must be estimated for the service under analysis.

The non-trading condition under Article 3.33(2) is the only point at which the legal framework directly enters the efficiency analysis. It creates a cost that is specific to direct TenneT ownership and has no equivalent under hybrid governance, which is why foregone revenue is included in the hierarchy formula but not the hybrid formula.

The second step selects the cost formula based on the Gate 0 flag.

Single service:

$$C_{\text{total}}(\text{hierarchy}) = C_{\text{production}}(h) + C_{\text{transaction}}(h) + C_{\text{foregone revenue}}(h), \quad (7.1)$$

$$C_{\text{total}}(\text{hybrid}) = C_{\text{production}}(hy) + C_{\text{transaction}}(hy). \quad (7.2)$$

Multiple services:

$$C_{\text{total}}(\text{hierarchy}) = \sum_i C_{\text{production}}(i) + \sum_i C_{\text{transaction}}(i) + \sum_i C_{\text{foregone revenue}}(i), \quad (7.3)$$

$$C_{\text{total}}(\text{hybrid}) = \sum_i C_{\text{production}}(i) + \sum_i C_{\text{transaction}}(i) + C_{\text{coordination}}(n). \quad (7.4)$$

The third step applies the combined Gate 2 and 3 score as a threshold modulator. A score of four to six means a raised threshold applies: hierarchy requires less of a cost advantage to be selected, because governance hazards are severe enough that the expected cost of governance failure under a less control-intensive form must be added to the comparison. That expected cost rises with the severity and irreversibility of non-delivery established at Gate 2 [34].

The fourth step compares total costs. Where hierarchy minimises C_{total} , hierarchy is recommended and the analysis routes to the legal feasibility check. Where it does not, the analysis proceeds to Gate 5.

Three limitations apply to the cost comparison.

1. First, $C_{\text{foregone revenue}}$ is systematically difficult to estimate: the full optionality value of market participation is not captured in any single cost estimate, and the reference measure differs depending on the actor and the market conditions assumed.
2. Second, every output of the cost comparison is assumption-dependent; small changes in input assumptions can alter the result, and the practitioner should document the assumptions explicitly.
3. Third, effectiveness and efficiency cannot be fully separated: the governance structure with the lowest estimated total cost is not always technically optimal, and where technical optimality is a binding constraint, it takes precedence over the cost comparison result.

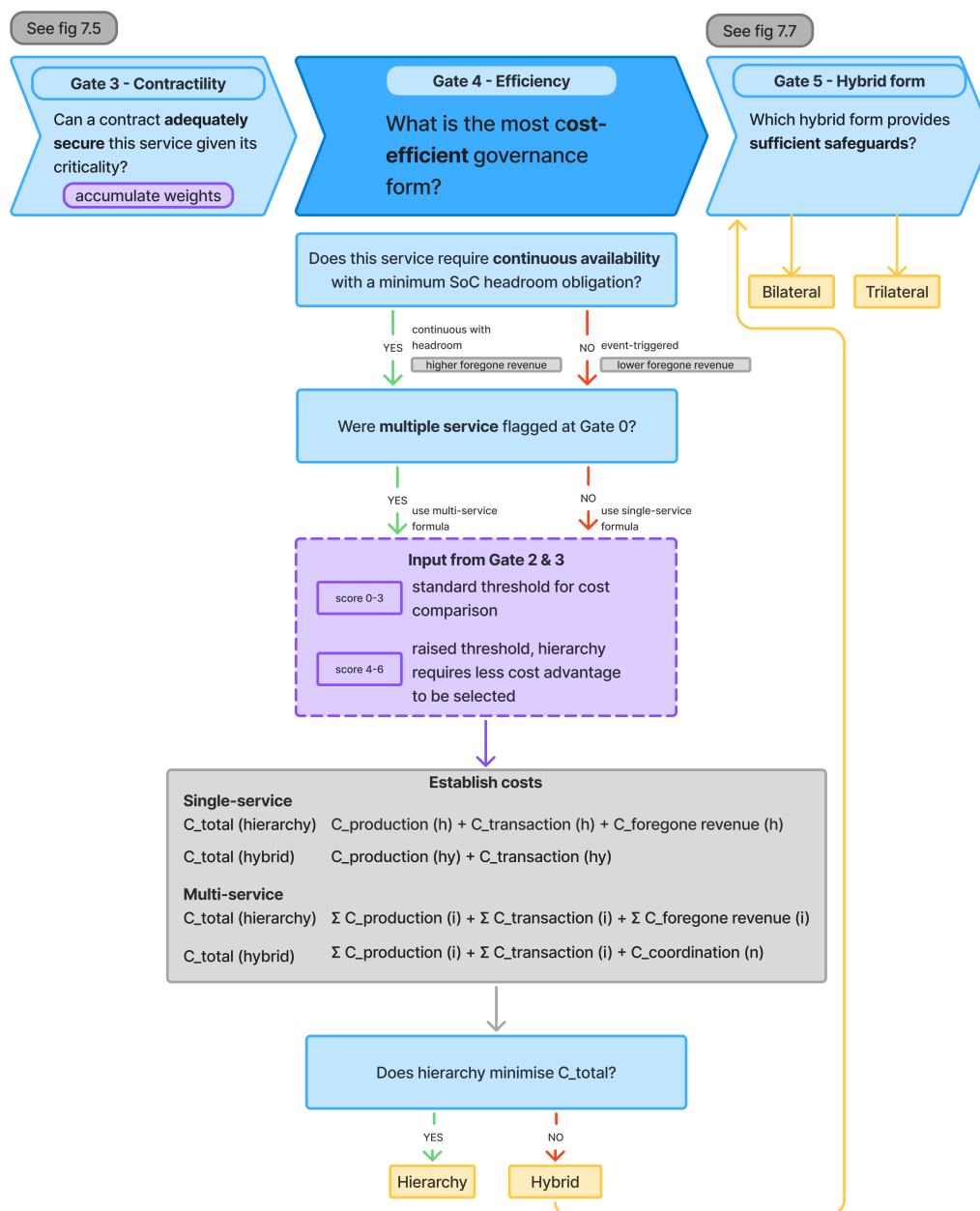


Figure 7.6: Gate 4: Efficiency assessment. The gate establishes the availability type, selects the cost formula based on the Gate 0 flag, applies the combined Gate 2 and 3 score as a threshold modulator, and compares total costs to determine whether direct TenneT ownership or long-term contracting minimises total costs. (Author's own)

Gate 5: Hybrid Form

Gate 5 asks which hybrid form provides sufficient safeguards, grounded in Williamson's distinction between trilateral and bilateral hybrid governance [19] and Ménard's typology [31].

The distinction between them follows from how deeply the two parties have become dependent on each other. Before the investment is made, multiple providers compete for the service, and TenneT

can choose freely. Once a provider has committed capital to a specific location and has been activated repeatedly, that changes. The provider cannot easily relocate, and TenneT cannot quickly replace it. What began as a competitive arrangement has collapsed into a relationship where neither party can exit without significant loss. Williamson calls this the fundamental transformation [19]. It is this mutual dependence, not the contract itself, that determines which hybrid form is appropriate.

Where service activation is frequent, the fundamental transformation takes hold quickly. Each activation ties the provider more deeply to this specific relationship, because the asset is being used predominantly for TenneT rather than for commercial markets. TenneT, in turn, cannot easily replace a provider that has demonstrated reliable performance at that node. Because neither party can exit without significant loss, mutual dependence itself becomes the primary governance mechanism, and the arrangement must be governed by the contract's own terms rather than by third-party oversight. A bilateral form is therefore recommended directly.

Where activation is occasional, the relationship has not yet generated that depth of mutual dependence. Neither party is deeply locked in, and a third party with formal legal standing must keep both sides honest. In the Dutch context, ACM performs this role through its statutory authority under the Competition Act, which prevents either party from exploiting the other's position. A trilateral form is recommended where ACM can effectively safeguard the arrangement; otherwise, a bilateral form remains appropriate.

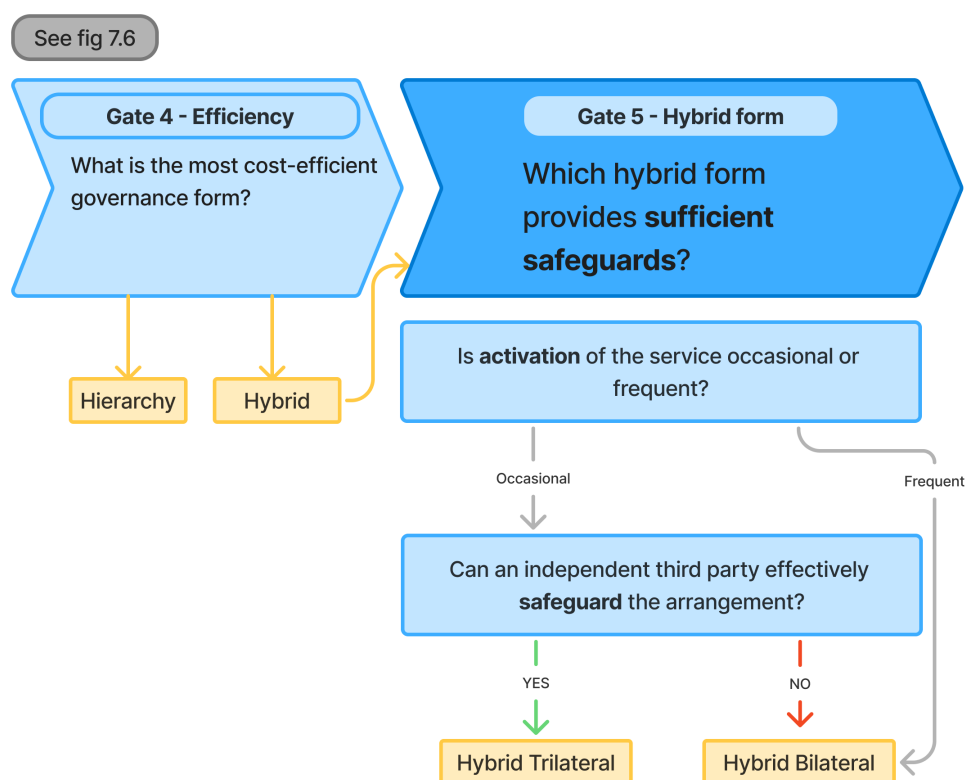


Figure 7.7: Gate 5: Hybrid form selection. Where activation is frequent, bilateral governance is recommended directly. Where activation is occasional, the gate tests whether an independent third party can effectively safeguard the arrangement, determining whether a trilateral or bilateral form is appropriate. (Author's own)

7.2. Legal Feasibility Check

The legal feasibility check tests the gate sequence output against the Energy Act 2026 and EU unbundling rules. It does not reopen the efficiency question; it asks only whether the recommended governance structure is legally available and, if not, what the closest feasible alternative is.

Where market governance is recommended, no further legal action is required. Article 3.28(1) and Articles 3.26 and 3.27 mandate competitive procurement as the default, and the recommendation is fully aligned with the law.

Where hybrid governance is recommended, the check asks whether a standard competitive procedure can deliver the required bilateral or trilateral commitment. If yes, Article 3.28(1) applies for stability services and Article 3.29(1) for congestion management, without ACM exemption. If a standard procedure cannot deliver the required commitment, TenneT must demonstrate to ACM that market-based procurement is not economically efficient. Where that demonstration succeeds, Article 3.28(3) applies for stability services and Article 3.29(2) for congestion management. Where it cannot be demonstrated, a governance gap exists and institutional change is required.

Where direct TenneT ownership is recommended, two routes are available. FINC recognition under Articles 3.31(a) and 3.32 is the most robust pathway: it simultaneously resolves the ownership problem and removes the market procurement obligation, and carries no review cycle. It is permanently unavailable for congestion management and balancing. Where FINC recognition cannot be obtained, Article 3.33 requires TenneT to demonstrate both that market procurement is economically inefficient and that market parties cannot deliver at reasonable cost or within a reasonable timeframe. The non-trading condition under Article 3.33(2) applies if the exemption is granted, and the five-year review cycle makes this route structurally less attractive for long-lived assets. ACM will not grant approval on cost grounds alone; demonstrated market failure is required.

One qualification applies to all direct ownership recommendations. Even under FINC recognition or an Article 3.33 exemption, unbundling rules prevent TenneT from using the asset commercially. Direct ownership in this framework therefore means full operational control, but not the full commercial control that pure hierarchy in transaction cost theory implies.

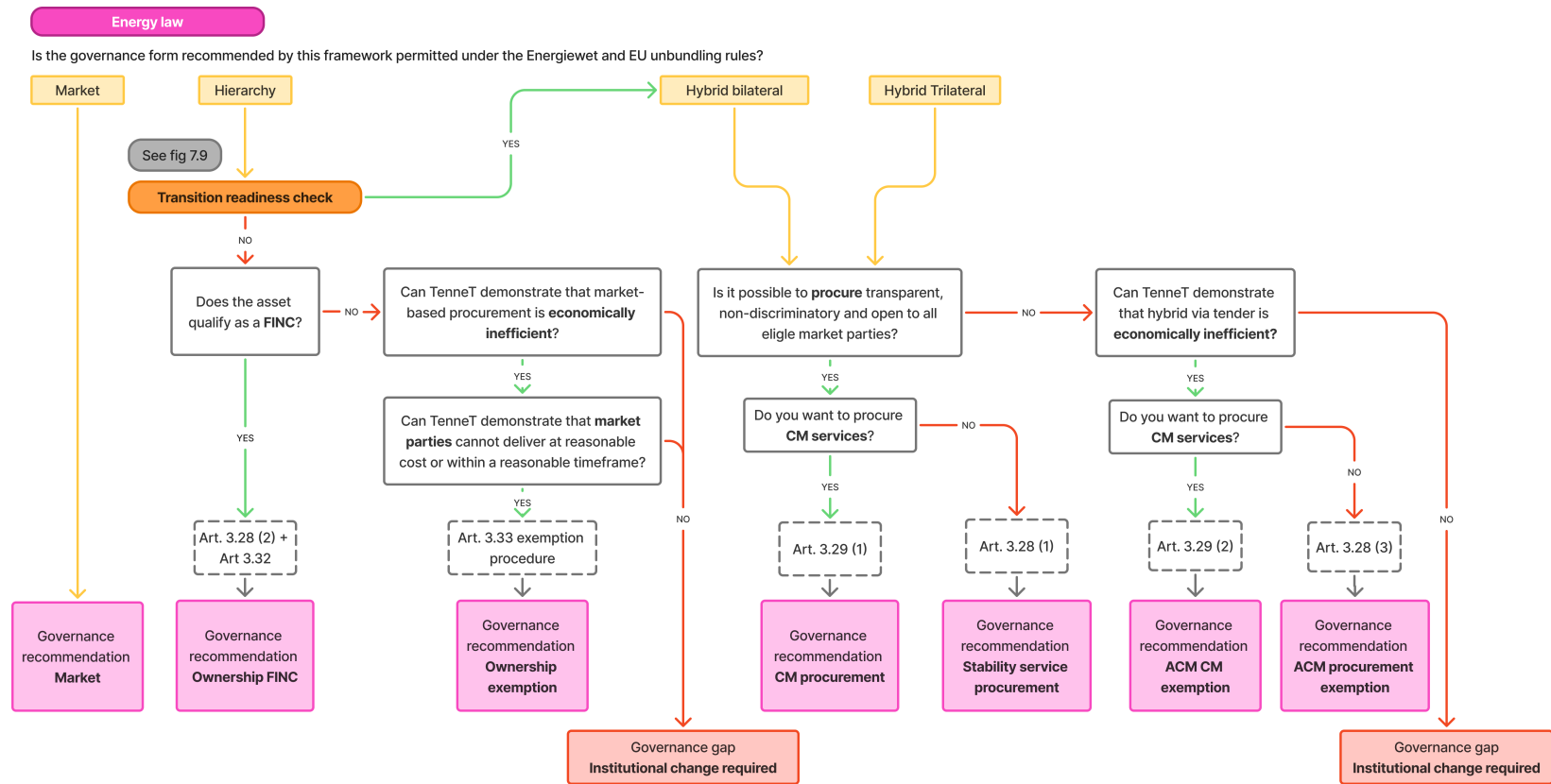


Figure 7.8: Legal feasibility check. The check tests whether the governance structure recommended by the gate sequence is permitted under the Energy Act 2026 and EU unbundling rules, identifies the applicable legal pathway, and flags where no pathway is available and institutional change is required. (Author's own)

7.3. Transition Readiness Check

The transition readiness check activates only where direct TenneT ownership is recommended and ACM approval is required. This is the most demanding legal pathway available under the Energy Act 2026, and the check exists precisely because the approval timeline may not be compatible with the urgency of the service gap. It asks whether the approval timeline is compatible with the service delivery deadline and, if not, identifies the most appropriate interim arrangement.

For non-frequency ancillary services, the most robust interim arrangement is an Article 3.28(3) exemption combined with a long-term bilateral contract. This retains private ownership, avoids the non-trading restriction of Article 3.33(2), and preserves the BESS operator's commercial revenue from capacity not required for the service obligation. Where no interim arrangement can provide adequate certainty of delivery, the governance gap is structural and institutional change is required.

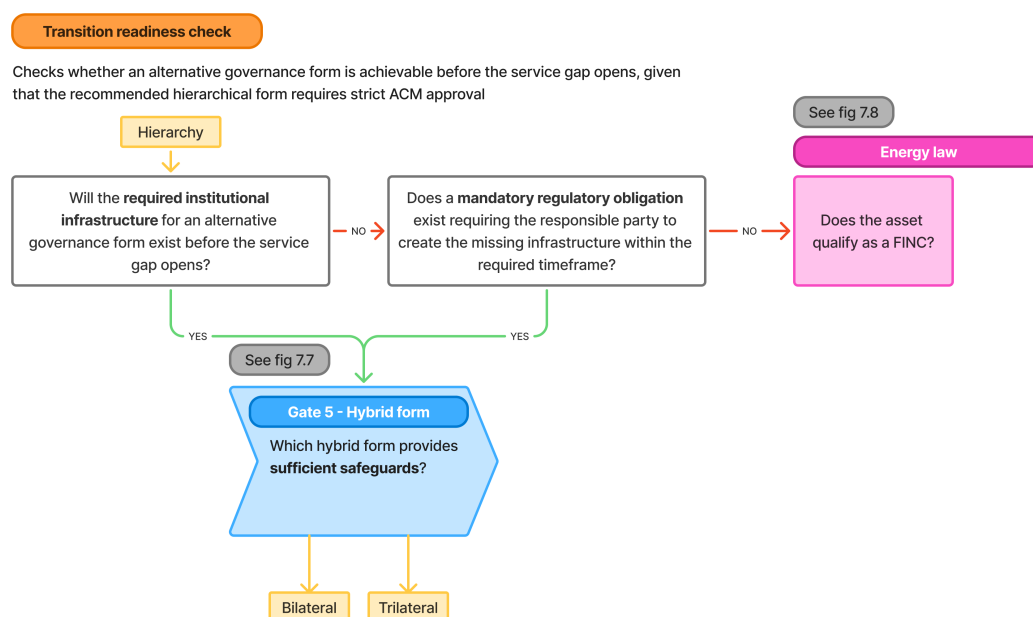


Figure 7.9: Transition readiness check. Where direct TenneT ownership requires ACM approval that cannot be obtained before the service gap opens, the check identifies whether an interim governance structure is achievable, routing to Gate 5 where one exists and flagging a structural governance gap where it does not. (Author's own)

7.4. Expert Interview Validation

The SSGF was evaluated through semi-structured interviews with four TenneT practitioners after the framework was fully developed: one regulatory expert and three market design experts responsible for service procurement and governance arrangements relevant to the services analysed. The interviews assessed whether the gate structure, criteria, and cost logic reflect the operational realities of BESS governance in the Dutch transmission system. Where experts identified gaps or misalignments, these were addressed in the framework.

Two observations apply across the framework as a whole. Expert 1 and Expert 2 noted that market governance must be explicitly stated as the default starting point, reflected in the introduction above. Expert 4 and Expert 1 flagged a terminological gap between TCE and TenneT practice: bilateral contracts, as understood operationally at TenneT, are a contractual instrument, a specific agreement between two parties, whereas hybrid bilateral governance in TCE terms is a governance structure that combines

that contractual instrument with the mutual lock-in and dependencies that arise after the fundamental transformation. A bilateral contract can exist without the fundamental transformation having taken place; hybrid bilateral governance cannot. This distinction is made explicit in Chapter 9.

Three gate-level changes were made following the interviews. Expert 1 identified state-of-charge path dependency as an operational constraint requiring explicit recognition at Gate 0; this criterion was added to the checklist. Expert 1 further proposed incorporating the quality of delivery as a qualitative weight at Gate 2, alongside the two scored questions. A service can be technically present but delivered at insufficient quality to prevent a system integrity problem, and the two scored questions do not capture that risk. This is therefore included as a qualitative weight in the Gate 2 assessment: where degraded delivery itself threatens system integrity, it adds weight towards direct TenneT ownership alongside the scored dimensions. At Gate 4, the experts identified three key limitations: foregone revenue is systematically difficult to estimate, the reference measure varies across actors, and effectiveness and efficiency cannot be fully separated in practice. These limitations are reflected in the Gate 4 section.

Two framework-level observations bear on the interpretation of all recommendations on hierarchy. Expert 1 noted that under the Energy Act 2026, any TSO ownership construction retains a hybrid element for the energy dimension due to unbundling rules, meaning that hierarchy in the strict TCE sense has not yet been achieved for BESS in the Dutch regulatory context. Expert 2 added that ACM will not approve TSO ownership on cost grounds alone; demonstrated market failure is required. Both observations are reflected in the legal feasibility and transition readiness checks.

Case Study: Utrecht Lage Weide 150 kV

This chapter applies the SSGF to three cases at the Utrecht Lage Weide 150 kV node, testing whether the framework produces governance recommendations that are coherent, internally consistent, and responsive to the operational realities of the Dutch transmission system. Section 8.1 describes the case study design and location. Section 8.2 presents the findings for each case. Section 8.3 compares the results across cases. Section 8.4 conducts a sensitivity analysis. Section 8.5 synthesises the findings.

The case study is hypothetical: it does not describe a procurement decision TenneT has taken, but asks what governance arrangement the SSGF would recommend if TenneT were to address the service gaps at ULW150 through a BESS deployment

8.1. Case study design and location

The case study applies the SSGF to the Utrecht Lage Weide 150 kV node (ULW150) in the central Netherlands. The node sits within the Flevopolder, Gelderland and Utrecht (FGU) 150 kV network, operated by TenneT. Figure 8.1 shows the spatial configuration of the network.

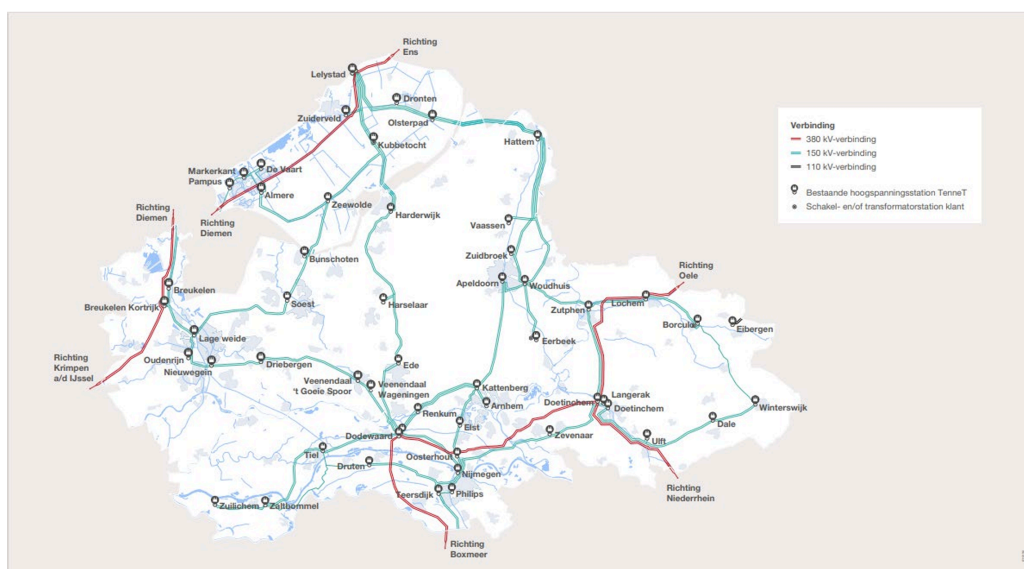


Figure 8.1: Spatial configuration of the Flevopolder, Gelderland and Utrecht (FGU) 150 kV network. The Utrecht Lage Weide–Soest connection is the most critically loaded element in the network and forms the basis of the case study in this chapter. [87]

Of all the connections in the FGU network, the Utrecht Lage Weide–Soest 150 kV connection is the most critically loaded. Congestion arises because Utrecht cannot import enough power through this connection during peak demand moments. The structural solution is the construction of a new 150 kV station, Utrecht Noord. In June 2025, TenneT announced a four-year delay until it comes into service, now expected in 2033–2035 [87]. Until that relief arrives, the congestion problem at ULW150 must be managed through other means.

Current situation

TenneT currently manages congestion at ULW150 preventively. Rather than allowing power to travel into Utrecht through the constrained connection, TenneT dispatches local generation to meet demand from behind the bottleneck, reducing the need for imports and keeping flows on the Utrecht Lage Weide–Soest connection within safe limits [88].

The primary resource for this purpose is the Eneco combined heat and power fleet at Utrecht. Three units operate at or adjacent to ULW150: Lage Weide 6 (248 MW), Merwedekanaal 11 (103 MW), and Merwedekanaal 12 (225 MW). These are combined heat and power plants whose primary product is heat: they supply the district heating network serving households and buildings in Utrecht and Nieuwegein, and electricity generation is a by-product of that heat production. They were not originally contracted as grid assets. Eneco had planned to retire the fleet from 2028 as part of its sustainability transition. TenneT approached Eneco bilaterally when the planned retirement threatened to worsen congestion in the region. No competitive tender was run. TenneT pays Eneco a fee to keep the fleet available beyond its planned retirement date, including on days when there is no heat demand and the fleet would otherwise be offline. A contract signed in July 2025 secures their availability until the end of 2029, with an option to extend until the end of 2034 [9] [88].

In Williamson's TCE terms, the Eneco arrangement is a hybrid bilateral contract: a long-term bilateral agreement between TenneT and a single provider at a specific node, without a competitive market underlying it. The fundamental transformation has fully taken hold. The fleet does not have genuine commercial freedom in the electricity market. In winter, it must run regardless of electricity prices because of the heat supply obligation to the district heating network. In summer, it would normally be offline, but the TenneT contract forces it to remain available for grid purposes even when there is no heat demand [9]. In both seasons, the fleet's operation is dictated by obligations rather than commercial choice. TenneT cannot replace the fleet before the structural solution arrives in 2033, and Eneco cannot exit without losing the TenneT payment that compensates for running the fleet outside heating season. Neither party can exit without significant loss.

As a passive by-product of being online, the Eneco fleet also contributes synchronous inertia to the Utrecht sub-grid. The rotating masses of the gas turbines naturally resist frequency changes, slowing the rate at which frequency deviates following a sudden generation loss. This inertia contribution is not procured or paid for separately. TenneT does not hold a contract for inertia at this node; the service arises incidentally from the congestion management arrangement.

Why the current arrangement must change

The Eneco fleet faces two pressures that make the current arrangement unsustainable beyond 2029. The first is technical: the units are approaching the end of their operational lifetime and were already scheduled for retirement before TenneT intervened. The second is sustainability: Eneco has stated that continued operation of fossil-fuelled generation conflicts with its sustainability ambitions, and the arrangement is explicitly a temporary compromise [9]. TenneT has acknowledged that the fleet will be deployed to a minimum, only at peak moments where it is strictly necessary.

When the fleet closes, two service gaps open simultaneously at the same node. The preventive congestion management capability is lost at the node TenneT already identifies as its most critically loaded. The inertia contribution disappears with no replacement planned for the 2030–2033 window [89]. Both gaps share the same location, trigger event, and opening date.

The BESS alternative and its assumptions

A BESS connected at ULW150 is examined here as a potential replacement for the preventive generation capacity lost when the Eneco fleet closes. Unlike a gas turbine, a BESS can provide both grid services and respond within milliseconds, making it technically suited for the curative approach described below.

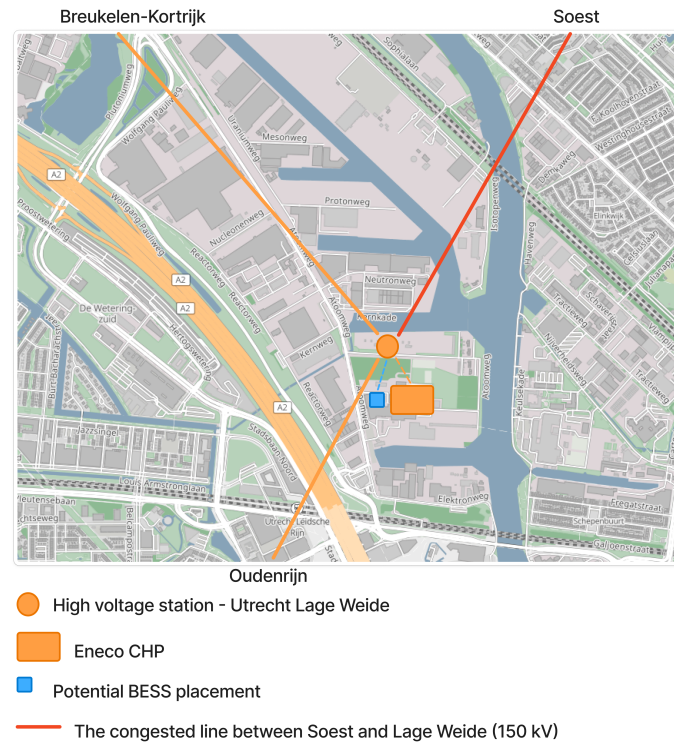


Figure 8.2: Hypothetical location of the potential BESS at the Utrecht Lage Weide 150 kV node, relative to the existing high-voltage station and the Eneco CHP fleet. The red line indicates the constrained Utrecht Lage Weide–Soest interconnector. (map from [90])

The FGU 150 kV network is operated by TenneT under mandatory N-1 security. The N-1 criterion, known in Dutch as the *enkelvoudige storingsreserve*, requires that any network with a voltage level of 110 kV or higher be designed and operated so that electricity transport is guaranteed if a single network element fails unexpectedly. The criterion applies both during normal operation and during periods when part of the network is out of service for maintenance [91].

TenneT is actively exploring curative N-1 approaches to increase grid utilisation in congested regions of the Netherlands [60]. Rather than dispatching local generation to reduce import need, TenneT could allow the Utrecht Lage Weide–Soest connection to operate closer to its thermal limit, importing more renewable energy from outside Utrecht. If the connection then trips, the BESS would immediately inject power locally to prevent the parallel path from overloading. This is a curative N-1 response, not a preventive redispatch. It increases grid utilisation and reduces reliance on local fossil-fuel generation, but brings the grid closer to its physical limits and requires fast, reliable BESS response.

Unlike the Eneco fleet, a BESS has no heat supply obligation constraining its dispatch. Outside contracted hours, the BESS operator retains genuine commercial freedom to participate in energy arbitrage and balancing markets. This means the mutual lock-in that disciplines the Eneco arrangement arises naturally from the fleet's operational constraints, whereas for a BESS it must be created through the contract itself, through availability penalties, long contract duration, and state-of-charge obligations that make exit genuinely costly.

Four assumptions underpin the case study analysis. First, the BESS operates under a day-ahead

reservation mechanism: TenneT reserves capacity the day before a constrained window and activates the BESS if a contingency occurs; outside reserved hours, the BESS operator retains full commercial freedom. Second, for synthetic inertia, the BESS operates in grid-forming mode continuously when online; inertia is not activated on demand but is always present, and the headroom obligation leaves the majority of battery capacity available for commercial use. Third, no standardised product definition exists for either service at the time of analysis; both must be specified within the contract itself. Fourth, the BESS is sized to cover both services simultaneously, with state-of-charge management designed to meet both obligations without one undermining the other.

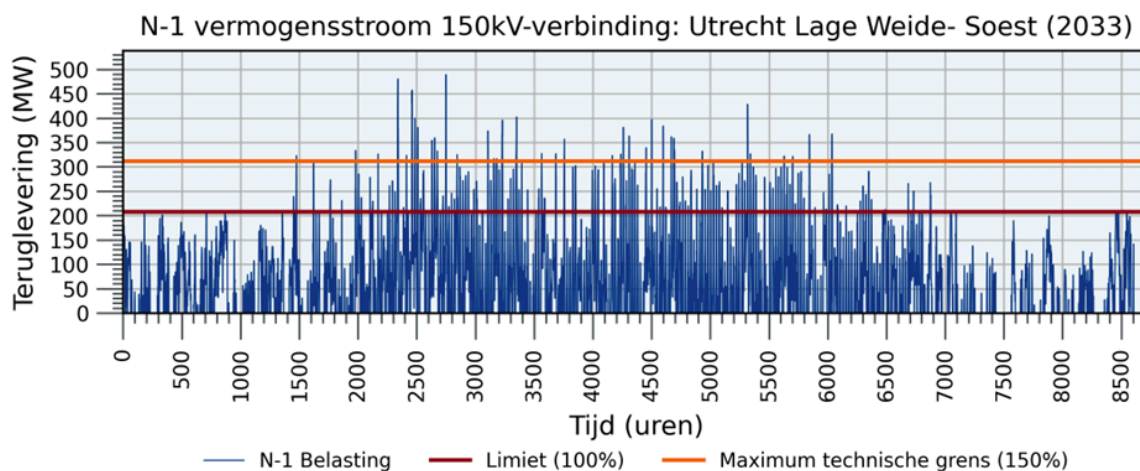


Figure 8.3: N-1 power flow of the 150 kV Utrecht Lage Weide–Soest interconnector required to facilitate transmission capacity in 2033. The profile illustrates the frequency and magnitude of congestion events that a curative BESS would need to address following a contingency on this connection. [87]

8.2. Case findings

Each case is analysed by walking through the SSGF gate sequence established in Chapter 7, from Gate 0 through Gate 5, and then conducting the legal feasibility check. The gates are applied in strict sequence; a conclusive finding at any gate routes directly to the legal feasibility check without revisiting earlier gates.

Case A: Synthetic inertia

Current situation and what changes

The Eneco fleet currently provides synchronous inertia to the Utrecht sub-grid as a passive by-product of being online, as described in Section 8.1. TenneT does not pay for this separately. When the fleet closes in 2030, that contribution disappears. The three units together contribute approximately 3,168 MWs of synchronous inertia [7], and no replacement is planned for the 2030–2033 window [89].

A grid-forming BESS can replicate this function through synthetic inertia: by operating in grid-forming mode, it responds to frequency deviations using its internal dynamics rather than waiting for an external signal. Unlike the inertia contribution of the Eneco fleet, which arose free of charge as a by-product of the congestion management arrangement, synthetic inertia from a BESS must be explicitly contracted, specified, and monitored.

Gate 1: Can competitive tendering deliver this service?

Competitive tendering requires a standardised product definition: TenneT must be able to specify what it is buying, compare offers from different providers, and verify after the contract is signed whether the service is being delivered as specified. None of these conditions are currently met for synthetic inertia. No product definition exists in the Dutch Grid Code or any applicable EU network code. There is no established market, no standard measurement methodology, and no telemetry protocol against

which TenneT could verify delivery in real time [7, 92]. Competitive tendering is therefore ruled out, not because providers are unwilling, but because the service itself is not yet defined precisely enough to be tendered.

Gate 2: How severe are the consequences if this service fails?

Gate 2 scores two dimensions: how severe and irreversible the consequences of non-delivery are, and how technically dependent the system is on this specific asset.

If synthetic inertia is absent when a large generator trips, frequency drops faster than protection systems can respond. At a rate of change of frequency above 2 Hz per second, generators begin disconnecting themselves to avoid damage, which can trigger a cascade of further disconnections and a grid collapse [57]. The consequences are therefore potentially irreversible. However, the 2030 timeframe provides some room: if a governance framework is established now, alternatives can emerge before the gap opens. The consequences are rapid but not yet certain to be irreversible. One weight is added (+1).

The inertia contribution at ULW150 is not unique: other assets in the wider synchronous area also contribute inertia, so the system is not completely dependent on this single node. Alternatives exist at the system level, even if they are not guaranteed to be sufficient. One weight is added (+1).

Gate 3: Can a contract adequately secure this service?

Gate 3 scores two dimensions: whether TenneT can adequately verify that the service is being delivered, and whether the BESS operator has made a sufficiently large irreversible investment to make walking away genuinely costly.

For synthetic inertia, verification is structurally incomplete. TenneT can inspect the converter's control parameters before the contract starts and run periodic compliance tests, but it cannot observe in real time whether the asset is actually providing inertia between those checks. The BESS operator could reduce its actual availability to pursue commercial revenues without TenneT detecting it until the next inspection. Verification is therefore inadequate. One weight is added (+1). Credible commitment is weak. A grid-forming BESS retains its full commercial value outside this relationship: switching to another service requires only a software parameter change at low cost. The BESS operator has not made an irreversible investment that would make exit genuinely costly. If a better commercial opportunity arises, walking away remains a genuine option, and no contractual penalty fully substitutes for that missing lock-in. One weight is added (+1).

Combined score from Gates 2 and 3: 4, raising the threshold at Gate 4.

Gate 4: Which governance structure minimises total costs?

Gate 4 compares total costs across governance structures in four steps.

The first step establishes the availability type. Synthetic inertia requires continuous availability with a minimum bidirectional state-of-charge headroom obligation. This means the foregone revenue cost under direct TenneT ownership is higher than for event-triggered services, because the non-trading condition under Article 3.33(2) of the Energy Act 2026 prohibits TenneT from using an owned asset commercially, and the idle capacity above the headroom obligation cannot be redirected to energy or balancing markets.

The second step selects the cost formula. Because only one service is being analysed, the single-service formula applies:

$$C_{\text{total}}(\text{hierarchy}) = C_{\text{production}}(h) + C_{\text{transaction}}(h) + C_{\text{foregone revenue}}(h) \quad (8.1)$$

$$C_{\text{total}}(\text{hybrid}) = C_{\text{production}}(hy) + C_{\text{transaction}}(hy) \quad (8.2)$$

The third step applies the threshold modulator. The combined score from Gates 2 and 3 is 4, raising the threshold: direct TenneT ownership requires less of a cost advantage to be selected than under standard conditions.

The fourth step compares total costs. A private BESS operator retains full access to commercial markets for the capacity not required by the headroom obligation. The foregone revenue cost under direct ownership is therefore substantial, and even with the raised threshold, it is not offset by the production cost advantage that TenneT's lower cost of capital provides. Direct TenneT ownership does not minimise total costs.

The analysis therefore proceeds to Gate 5 to determine which hybrid form provides sufficient safeguards.

Gate 5: Which contractual form?

Gate 5 asks whether the service is activated frequently or occasionally, and whether a third party can effectively safeguard the arrangement.

Synthetic inertia does not activate on demand: the BESS must operate in grid-forming mode and maintain bidirectional state-of-charge headroom at every moment it is online, regardless of whether a frequency disturbance occurs. This continuous dependency means the relationship functions more like a frequently activated service than an occasional one. TenneT depends on the BESS operator being correctly configured and available at every moment, not just when called upon.

Frequent or continuous obligations point directly to bilateral governance, in which the contract terms and the ongoing mutual dependence between the parties provide the governance structure without requiring a third-party safeguard. A bilateral form is therefore recommended.

Legal feasibility

The legal feasibility check asks two questions: whether the recommended governance structure is legally available, and if not, what the closest feasible alternative is.

The first question is whether TenneT can procure the service through a transparent, non-discriminatory procedure open to all eligible market parties. The answer is no: no standardised product definition exists, which means TenneT cannot specify what it is buying, compare offers on a common basis, or verify delivery against a standard. A compliant competitive procedure cannot be run.

Because the service is not congestion management, the check routes to Article 3.28(3). The second question is whether TenneT can demonstrate to ACM that hybrid governance via a competitive tender is economically inefficient. Given that no market product currently exists for synthetic inertia and no standardised measurement methodology is available, that demonstration is straightforward. The applicable legal pathway is therefore Article 3.28(3), subject to ACM approval.

TenneT should begin ACM engagement no later than 2027 to ensure the exemption is in place before the service gap opens in 2030.

Governance recommendation: Hybrid Bilateral via Article 3.28(3), subject to ACM approval.

In TenneT's procurement practice, the Article 3.28(3) exemption means TenneT does not run a legally mandated competitive tender. Instead, it issues a request for proposals to BESS operators who can connect at or near ULW150, with the service specifications written into the procurement documents. The location requirement means only a small number of BESS operators can physically offer the service, so genuine competition is limited from the outset. Once an BESS operator is selected and invests in a grid connection at the site, the fundamental transformation takes hold: the BESS operator cannot easily relocate and TenneT cannot easily replace it. Both parties become dependent on each other, and the contract that follows must reflect that dependency. It is a bespoke bilateral agreement, not a standard market arrangement, and its terms must be defined by TenneT because no standard product definition exists. ACM must approve the arrangement before it can take effect.

What can be kept and what must change

The current arrangement provides passive inertia, free of charge, as a by-product of the Eneco contract. That model cannot be replicated with a BESS. Three things must change. First, the service must be defined: TenneT needs a contractual specification of what synthetic inertia means for a grid-forming BESS, including the required virtual inertia constant, the droop settings that determine how the asset responds to frequency deviations, and the headroom obligation. Second, a monitoring regime must

be established: because real-time verification is not possible, the contract must require parameter inspections before operation and periodic compliance tests triggered by frequency events or scheduled simulations. Third, the commercial model must be carefully designed: unlike the Eneco fleet, whose commercial freedom is constrained by its heat-supply obligation, a BESS operator has genuine market options. Availability penalties must be high enough to make non-compliance commercially unattractive, and the contract must specify escalating sanctions rather than immediate termination, to preserve the long-term relationship that bilateral governance depends on.

Contractual requirements

The governance hazards identified at Gates 2 and 3 translate directly into six contractual obligations, structured around Ostrom's design principles, that the bilateral agreement must satisfy to be durable and enforceable.

Principle 1 — Clearly defined boundaries. The contract must precisely specify what TenneT is procuring. In the absence of a formal product definition in the Dutch Grid Code, the contract itself must define the service: the required virtual inertia constant, the control parameters that determine how the asset responds to frequency deviations, and the headroom the operator must maintain in both charging and discharging directions at all times. Without this precision, neither party can know whether the obligation is being met.

Principle 2 — Congruence. The availability obligation must reflect the always-on character of synthetic inertia. The asset must operate in grid-forming mode continuously when online, not only during frequency events. This is a fundamentally different obligation from a dispatchable service, and the contract must make that distinction explicit so the operator cannot claim compliance by being available on request rather than continuously present.

Principle 4 — Monitoring. Because real-time verification of synthetic inertia is not possible, the contract must establish a monitoring regime that works within that constraint. TenneT must be able to inspect control parameters before operation begins and at regular intervals thereafter. Compliance tests, triggered either by actual frequency events or by scheduled simulations, provide the evidence base for enforcement. Without this regime, TenneT has no means of detecting underperformance between events.

Principle 5 — Graduated sanctions. Because the operator retains strong commercial outside options and faces no natural lock-in, monetary availability penalties must substitute for the mutual dependence that would otherwise discipline the relationship. These penalties must escalate with the duration and severity of non-compliance rather than triggering immediate termination, because immediate termination would leave TenneT without a provider and create a service gap precisely when it is most exposed.

Principle 6 — Conflict resolution. The contract must include a clearly defined procedure for resolving disputes. Given the novelty of the service and the absence of regulatory precedent, disagreements about parameter compliance, performance attribution during frequency events, and the interaction between the inertia obligation and commercial dispatch decisions are foreseeable. An agreed resolution procedure prevents those disagreements from escalating into litigation that neither party can afford during an active service period.

Principle 7 — Recognition. The contract is contingent on ACM approval under Article 3.28(3). ACM's recognition of the arrangement as a legitimate departure from competitive procurement is not a mere formality; it is the legal foundation conferring enforceability on the contract within the Dutch regulatory framework.

Case B: N-1 Curative Congestion Management

Case B follows the same gate structure as Case A. Where the analysis reaches the same conclusion for the same reason, this is noted briefly rather than repeated in full.

Current situation and what changes

TenneT currently manages congestion at ULW150 preventively: the Eneco fleet generates electricity locally, so less power needs to travel into Utrecht via the constrained connection. When the fleet closes

in 2030, that preventive capability disappears. A BESS would enable a fundamentally different operational model. Rather than reducing import need, TenneT could allow the Utrecht Lage Weide–Soest connection to carry more power during normal operation. If the connection then trips, the BESS would immediately inject power locally to prevent the parallel path from overloading. This is a curative N-1 response: a dedicated capacity block is reserved and held on standby, ready to activate within seconds of a contingency occurring. TenneT's 2033 analysis projects that following a trip of the connection, the N-1 load on the remaining parallel path exceeds the security limit in approximately 65 percent of congestion window hours [87].

No formal product definition for N-1 curative congestion management by a BESS currently exists in the Netherlands. Unlike a gas turbine, which can always generate when instructed, a BESS can inject power only if it has sufficient stored energy at the time of activation. The state-of-charge trajectory in the hours before a congestion window opens is therefore as important as the state of charge at dispatch.

Gate 1: Can competitive tendering deliver this service?

No. The N-1 curative product has no formal specification in the Dutch Grid Code, and the service is strictly location-bound: an asset at any other node provides zero relief for a constraint on this specific connection [87]. Competitive tendering is ruled out on both grounds simultaneously.

Gate 2: How severe are the consequences if this service fails?

Gate 2 scores two dimensions: how severe and irreversible the consequences of non-delivery are, and how technically dependent the system is on this specific asset.

The curative approach deliberately allows the connection to operate beyond the N-1 secure state, relying on the BESS as the sole backup. If the BESS fails to respond, the parallel path is exposed to thermal overloading with no corrective action available, and sustained overloading can cause irreversible damage within minutes. Two weights are added (++). No technical interdependency with other grid assets adds further weight. Accumulated score from Gate 2: 2.

Gate 3: Can a contract adequately secure this service?

Unlike synthetic inertia, power flows are directly measurable in real time. When the BESS is activated, TenneT can immediately observe whether the required injection is delivered. No verification weight is added. Credible commitment is weak for the same reason as Case A: the operator retains full commercial value outside this relationship and can redirect the asset at low cost. One weight is added (+1). Combined score from Gates 2 and 3: 3, raising the threshold at Gate 4.

Gate 4: Which governance structure minimises total costs?

The single-service cost formula applies. Under direct TenneT ownership, the non-trading condition forfeits all commercial revenues. Under a hybrid bilateral contract, the operator forfeits commercial participation only during the approximately 65 percent of congestion window hours when capacity is reserved; outside those hours, the operator retains full commercial freedom. The foregone revenue cost of direct ownership is substantially higher, and hybrid governance minimises total costs. The analysis proceeds to Gate 5 to determine which hybrid form provides sufficient safeguards.

Gate 5: Which contractual form?

Activation is frequent: the BESS is called upon in approximately 65 percent of congestion window hours. Repeated activation ties the operator deeply to this specific relationship, creating the mutual dependence that makes bilateral governance both necessary and self-sustaining. A bilateral form is recommended directly.

Legal feasibility

The legal feasibility check asks two questions: whether the recommended governance structure is legally available, and if not, what the closest feasible alternative is.

The first question is whether TenneT can procure the service through a transparent, non-discriminatory procedure open to all eligible market parties. The answer is no on two grounds: no standardised product definition exists for N-1 curative congestion management by a BESS, and the pool of viable providers at this node is too limited to support genuine competition.

Because this is a congestion management service, the check routes to Article 3.29(2). The second question is whether TenneT can demonstrate to ACM that market-based procurement is not economically efficient or would cause market distortions. Both grounds apply: the absence of a product definition makes competitive procurement structurally impossible, and the location constraint means only one or two providers can realistically offer the service at this node, thereby creating conditions for market distortion. TenneT has operational experience with bilateral congestion management at ULW150 through the Eneco contract, but a BESS-based arrangement requires a separate ACM assessment under Article 3.29(2) because storage assets are governed under different rules than generation assets. This assessment has not yet been sought.

Governance recommendation: Hybrid Bilateral via Article 3.29(2), subject to ACM approval.

In TenneT's procurement practice, the Article 3.29(2) exemption means TenneT does not need to run a legally mandated competitive tender. It issues a request for proposals to battery storage operators who can connect at or near ULW150, specifying the required response time, the power the BESS must deliver after a contingency, and the state-of-charge level that must be maintained during reserved hours. Once a provider is selected and commits to the standby obligation, the relationship becomes bilateral for the same reasons as Case A: the provider cannot easily relocate and TenneT cannot easily replace it.

Contractual requirements

The bilateral contract structure and the day-ahead reservation mechanism of the current Eneco arrangement can, in principle, be retained. What changes is both the technology and the operational purpose: the Eneco fleet is reserved to generate preventively when congestion is forecast, whereas the BESS is reserved to stand by and activate only after a contingency occurs. A gas turbine can always generate when instructed; a BESS can only inject power if it has sufficient stored energy at the moment of activation. This introduces a state-of-charge obligation that does not exist in the current arrangement.

Principle 1 — Clearly defined boundaries. The contract must specify which contingency events trigger activation, the required response time in seconds, and the power ramp profile.

Principle 2 — Congruence. The state-of-charge reservation obligation must reflect the seasonal and time-of-day congestion pattern: full reservation during constrained hours, with commercial freedom retained outside those windows.

Principle 4 — Monitoring. Because power flows are directly measurable in real time, the contract can rely on continuous monitoring of the connection. The operator's state of charge must be verifiable through telemetry before each congestion window opens.

Principle 5 — Graduated sanctions. Non-response following a confirmed contingency event constitutes a verifiable breach. Penalties must escalate with repeated non-availability and be set at a level that makes non-compliance commercially unattractive, given the operator's alternative market options.

Principle 6 — Conflict resolution. The contract must include a dispute resolution procedure for disagreements about activation instructions, state-of-charge obligations, and power flow attribution.

Principle 7 — Recognition. The contract is contingent on ACM approval under Article 3.29(2). TenneT must initiate the exemption procedure sufficiently in advance of the service gap opening in 2030.

Case C: Multi-Service Configuration

Current situation and what changes

Cases A and B separately establish the governance requirements for synthetic inertia and N-1 curative congestion management. Case C asks whether a single BESS can provide both services simultaneously, and whether combining them changes the governance recommendation. The Eneco fleet provides both functions today without explicit coordination, because inertia arises passively and gas turbines have no state-of-charge constraint. A BESS must coordinate both obligations actively within a single asset and a single contract. The key question is whether the two services are sufficiently compat-

ible to be governed together, or whether combining them would create conflicts that require separate arrangements.

Gate 0: Are both services sufficiently defined?

Both services have been defined in Cases A and B. The multi-service flag is raised. State-of-charge compatibility is confirmed as partial but directionally consistent. The Gate 4 multi-service cost formula applies.

Gate 1: Can competitive tendering deliver these services?

No. Neither service has a standardised product definition, and the combined asset is strictly location-bound. Competitive tendering is ruled out on the same grounds as Cases A and B.

Gate 2: How severe are the consequences if this service fails?

Gate 2 scores two dimensions: how severe and irreversible the consequences of non-delivery are, and how technically dependent the system is on this specific asset.

The N-1 curative consequence dominates: non-delivery exposes the parallel path to thermal overloading with no corrective action available. Two weights are added (++). The inertia contribution adds a systemic dimension but does not create complete interdependency without alternatives at this node alone. No further weight is added. Accumulated score from Gate 2: 2.

Gate 3: Can a contract adequately secure both services?

Gate 3 scores two dimensions: whether TenneT can adequately verify that the service is being delivered, and whether the operator has made a sufficiently large irreversible investment to make walking away genuinely costly.

The multi-service configuration introduces a verification asymmetry. The congestion management component can be verified in real time through power flow monitoring. The synthetic inertia component cannot. The combined contract is therefore only as verifiable as its weakest component. One verification weight is added (+1). Credible commitment is weak for the same reasons as Cases A and B. One commitment weight is added (+1). Combined score from Gates 2 and 3: 4, raising the threshold at Gate 4.

Gate 4: Which governance structure minimises total costs?

Gate 4 compares total costs across governance structures in four steps.

The first step establishes the availability type. Both services require continuous or reserved availability, meaning the foregone revenue cost under direct TenneT ownership is high across both obligations simultaneously.

The second step selects the cost formula. Because multiple services were flagged at Gate 0, the multi-service formula applies:

$$C_{\text{total}}(\text{hierarchy}) = \sum_i C_{\text{production}}(i) + \sum_i C_{\text{transaction}}(i) + \sum_i C_{\text{foregone revenue}}(i) \quad (8.3)$$

$$C_{\text{total}}(\text{hybrid}) = \sum_i C_{\text{production}}(i) + \sum_i C_{\text{transaction}}(i) + C_{\text{coordination}}(n) \quad (8.4)$$

The third step applies the threshold modulator. The combined score from Gates 2 and 3 is 4, raising the threshold: direct TenneT ownership requires less of a cost advantage to be selected than under standard conditions.

The fourth step compares total costs. Under direct TenneT ownership, the non-trading condition forfeits all commercial revenues across both service obligations. Both services push the battery toward the same operational range during solar peak hours: synthetic inertia requires a mid-range state of charge to maintain headroom in both directions, and congestion management requires sufficient stored energy to inject power after a contingency. The two constraints point in the same direction rather than

pulling against each other, so combining the services does not require significantly more reserved capacity than congestion management alone would. Sharing production costs across two services further strengthens the hybrid case: the same asset, grid connection, and monitoring infrastructure serve both obligations. Even with the raised threshold, direct TenneT ownership does not minimise total costs. The analysis proceeds to Gate 5 to determine which hybrid form provides sufficient safeguards.

Gate 5: Which contractual form?

The N-1 curative component dominates the activation frequency classification. Curative activations occur in approximately 65 percent of congestion window hours, creating the repeated interaction that drives the bilateral form directly. The always-on inertia headroom obligation reinforces this: the operator must maintain continuous availability for both services simultaneously. A bilateral form is therefore recommended directly.

Legal feasibility

The legal path follows Case B, anchored in the congestion management framework with synthetic inertia as an additional contractual obligation. The first question is whether a transparent, non-discriminatory procedure can deliver the required commitment. The answer is no on both service counts. The check routes to Article 3.29(2) for the congestion management component and Article 3.28(3) for the inertia component. Both require ACM approval. The multi-service configuration does not require a new legal instrument; it requires a single contract addressing both obligations under the existing exemption routes. TenneT must initiate ACM engagement no later than 2027.

Governance recommendation: Hybrid Bilateral via Article 3.28(3) and Article 3.29(2), subject to ACM approval.

In TenneT's procurement practice, TenneT issues a single request for proposals covering both service obligations simultaneously. The procurement documents must specify the synthetic inertia parameters, the curative standby requirements, and the state-of-charge management protocol that governs how the operator meets both obligations at the same time. Because the asset must be at this specific node and capable of providing both services, the pool of viable respondents is smaller than for either service alone. Once a provider is selected and invests in a grid connection at the site, the fundamental transformation takes hold on two dimensions: the provider cannot easily relocate, and TenneT cannot easily replace it for either service independently. The bilateral relationship that follows is more deeply locked in than in Cases A or B alone, because exit would leave two simultaneous service gaps rather than one.

Contractual requirements

The bilateral contract structure and location-specific procurement approach from the Eneco precedent can be kept. What changes is the complexity: two simultaneous obligations with a shared state-of-charge budget must be governed within a single contract. The contractual requirements follow Ostrom's design principles.

Principle 1 — Clearly defined boundaries. The contract must specify the obligations for both services separately: the virtual inertia constant, control parameters, and headroom obligation for synthetic inertia; and the contingency events, response time, and power ramp profile for N-1 curative congestion management. The boundaries between the two obligations must be unambiguous.

Principle 2 — Congruence. The state-of-charge management protocol must reflect the partial compatibility established at Gate 0. Both services require operation within a low-to-mid state-of-charge range during solar peak hours. The contract must specify how the operator allocates the shared state-of-charge budget between the two obligations and what TenneT can instruct if commercial dispatch has depleted that budget below the required threshold before a congestion window opens.

Principle 4 — Monitoring. Two distinct monitoring regimes must operate within a single contract. The inertia component requires parameter inspections and periodic compliance tests. The congestion management component relies on continuous real-time power flow monitoring. The contract must specify which regime applies to each obligation and how compliance is assessed when both are active simultaneously.

Principle 5 — Graduated sanctions. Sanctions must be defined separately for each service. Non-availability for inertia and non-response for congestion management are different failures with different system consequences. Escalating penalties must apply to both, calibrated to the severity of each failure type.

Principle 6 — Conflict resolution. The contract must include a dispute resolution procedure covering both service components, including disagreements about state-of-charge management, parameter compliance, and simultaneous activation events where the two obligations interact.

Principle 7 — Recognition. The contract requires ACM approval under Article 3.28(3) and Article 3.29(2). TenneT must initiate the exemption procedure no later than 2027, presenting a single application that addresses both service obligations and demonstrates that market-based procurement cannot deliver the combined arrangement at this specific node.

8.3. Sensitivity analysis

All three cases produce a hybrid bilateral recommendation under current conditions. The sensitivity analysis asks what would need to change for that recommendation to shift toward direct TenneT ownership on one side, or toward competitive tendering on the other.

When would direct TenneT ownership be selected?

Two conditions must change simultaneously. The first is the commercial viability of the hybrid arrangement. More congestion means more activations, which generates more activation payments to the operator. However, it also means fewer hours of commercial freedom outside reserved windows. At 65 percent constrained hours, the operator retains 35 percent of hours for commercial trading, and those revenues make the overall investment viable. If constrained hours were to rise toward 90 percent, commercial freedom would effectively disappear. Even if TenneT increased activation payments to compensate, it would need to cover nearly all lost market revenues, making the arrangement financially equivalent to direct ownership. At that point, no market party would accept a hybrid contract at a commercially viable price, and direct TenneT ownership would emerge by necessity.

The second condition is asset specificity. Currently, a grid-forming BESS retains its full commercial value outside this arrangement: redirecting it to another service requires only a software change at negligible cost. The operator therefore faces no genuine lock-in. If the combined service obligation were to become so technically demanding and location-specific that the asset had no viable alternative use, the operator's exit option would disappear. Exit would then be genuinely costly, credible commitment would arise naturally, and direct ownership would become more competitive on cost grounds. Neither condition alone is sufficient to shift the recommendation.

Table G.1 shows that direct TenneT ownership is selected only when both apply simultaneously. Under current projections, the baseline sits well within the hybrid zone, but worsening congestion could push Cases B and C toward necessity-driven direct ownership before structural network relief arrives in 2033.

When would competitive tendering be selected?

Three preconditions must be met before competitive tendering becomes viable for Cases A and C. First, a standardised product definition for synthetic inertia must exist: without it, TenneT cannot specify what it is buying, compare offers, or verify delivery. Second, a standardised measurement and verification methodology must be established: even with a product definition, TenneT must be able to attribute the inertia contribution of a specific asset during frequency events. Third, a sufficient pool of providers must exist at or near ULW150: location-bound services require genuine competition at the relevant node. The German Momentanreserve market, launched in January 2026, demonstrates that all three preconditions are achievable once standardisation is sufficiently developed.

For Case B, competitive tendering is closer to being achievable. Power flows are already measurable in real time, so the verification precondition is already met. What is missing is a standardised product definition and a liquid pool of providers at this specific node.

Table 8.1: Sensitivity analysis: conditions under which governance recommendation shifts

Scenario	Case A	Case B	Case C
Baseline	Hybrid	Hybrid	Hybrid
High congestion (> 90%)	Hybrid	Hierarchy*	Hierarchy*
High asset specificity	Hybrid	Hybrid	Hybrid
Both combined	Hierarchy	Hierarchy	Hierarchy
Standardised product definitions	Market	Hybrid	Market

*Hierarchy by necessity — no private operator will accept a hybrid contract at a commercially viable price.

The hybrid bilateral recommendation is therefore not a permanent outcome. It reflects the current absence of standardisation and the current level of congestion, not a structural preference for bilateral contracting. As product definitions and verification protocols develop, the governance frontier shifts toward competitive tendering. As congestion worsens and commercial freedom shrinks, the shift toward direct ownership intensifies.

8.4. Synthesis

All three cases produce the same governance recommendation: hybrid bilateral. That convergence is not coincidental. It reflects two structural features of the current Dutch regulatory and market context that apply regardless of which service is examined.

The first is the non-trading condition under Article 3.33(2) of the Energy Act 2026. As long as TenneT cannot use an owned asset commercially, direct ownership carries a cost disadvantage that the raised thresholds from Gates 2 and 3 cannot overcome. The idle battery capacity that would sit unused under direct TenneT ownership represents substantial foregone revenue that a private operator can capture. This single institutional constraint is the primary reason hierarchy is not selected in any of the three cases under current conditions.

The second is the absence of standardised product definitions. Neither synthetic inertia nor N-1 curative congestion management has a formal specification in the Dutch Grid Code or any applicable EU network code. Without product definitions, competitive tendering is structurally impossible, and bilateral contracting requires an ACM exemption in both cases. The hybrid bilateral recommendation is therefore not a governance preference: it is the only form that is both economically viable and legally achievable under current conditions.

Together, these two features define the boundary within which TenneT currently operates. The sensitivity analysis shows that hierarchy becomes viable only when the hybrid business case collapses due to extreme congestion and asset specificity increases simultaneously. Competitive tendering becomes viable only once standardised product definitions, verification methodologies, and a sufficient pool of providers are in place at the relevant node. The current baseline sits between these two boundaries, squarely in the hybrid zone.

The policy implication is direct. TenneT and ACM face two parallel tasks before 2027. The first is to develop product definitions for both services: without these, neither competitive tendering nor bilateral contracting can be operationalised efficiently. The second is to begin the ACM engagement process for the Article 3.28(3) and Article 3.29(2) exemptions required by the hybrid bilateral arrangements. The Eneco contract provides operational experience for the congestion management framework. Neither task requires waiting for the other: both can proceed in parallel.

9

Discussion

This chapter interprets the thesis's findings, places them within the broader theoretical and regulatory literature, and reflects on their implications for the governance of BESS-based system services in the Dutch electricity system.

The chapter is structured as follows. Section 9.1 addresses each sub-question in turn and presents the answer to the main research question. Section 9.2 states the scientific and societal contributions. Section 9.3 identifies the limitations that bound the validity and transferability of the findings. Section 9.4 proposes directions for future research.

9.1. Interpretation of results

Governance follows the transaction, not the asset

Subquestion 1

What are the transactions involved for BESS providing system services, what are their characteristics, and what governance structure does TCE predict as efficient?

Every BESS service arrangement decomposes into eight transactions. Three are generic: land acquisition (T1), grid connection (T2), and termination (T8). Five are service-specific: the availability obligation (T3), dispatch and control rights (T4), market participation and state-of-charge conflict (T5), telemetry and information rights (T6), and performance maintenance (T7). The generic transactions pose no governance challenge because, before any service-specific investment is made, neither party is committed to the other, and the asset retains its full commercial value. A standard competitive tender is sufficient. All governance complexity is service-specific.

The analysis produces three distinct governance outcomes. These correspond to the three governance structures TCE identifies: market, hybrid, and hierarchy. Balancing services receive a market prediction. In the Dutch electricity system, market governance means auction-based procurement: providers bid capacity into a competitive platform, TenneT selects based on price, and no ongoing relationship between buyer and seller is required. Voltage control and congestion management receive a hybrid prediction. Hybrid governance means long-term bilateral contracting. TenneT and a private BESS operator enter a multi-year agreement that combines formal performance obligations with relational mechanisms to manage unforeseen circumstances. Both parties remain legally independent but are bound to each other for the duration of the contract. Once the investment is committed at a specific location, the fundamental transformation takes hold: neither party can easily exit, and that mutual dependency becomes the primary governance mechanism. Synthetic inertia, system strength, and black start receive hierarchical predictions. Hierarchy means direct TSO ownership and operation: TenneT

owns and operates the asset itself, rather than contracting with an independent BESS operator for its output.

The first interpretive observation is that governance follows the transaction, not the asset. This is the foundational logic of TCE: the transaction is the unit of analysis, not the technology that delivers it [93]. In the traditional electricity system, that principle was invisible because every asset had a single purpose, and governance followed naturally from it. A BESS breaks this pattern: the same physical asset can provide almost all system services, sometimes multiple simultaneously. What determines the governance structure is not the technology but what the service requires. Künneke, Ménard and Groenewegen establish why: the technical properties of a network infrastructure are themselves derived from the expected service it is designed to provide [34]. Transaction characteristics, how location-specific the investment must be, how difficult performance is to verify, and how often the service is activated, follow from those technical properties. Those characteristics differ across services, and the governance prediction follows from them. The asset is the same. The transaction is not.

The second observation is that hierarchy does not come from a single diagnosis. All three stability services end up at direct TSO ownership, but for different reasons, and those reasons point to different solutions.

For synthetic inertia, the problem is visibility. TenneT cannot verify whether the BESS operator is keeping the battery ready between disturbance events. Williamson identifies this as the most costly form of uncertainty: where a party can exploit gaps in monitoring without detection, no contract can close the resulting governance hazard [20]. For system strength, location dependency compounds this: the BESS operator is locked in once the investment is made, the quasi-rent is large, and fault performance can only be confirmed during a real fault that may never occur [4]. For black start, the problem is entirely different. The service requires the entire battery reserve to be in permanent readiness, thereby permanently excluding commercial use. Williamson argues that where ex-post governance costs exceed what any contractual arrangement can deliver, hierarchy is the only viable response [19]. An asset that must stay fully charged at all times is more efficiently owned by the party that does not need it to generate commercial returns.

All three services share a governance prediction. They do not share a cause. Moving any of them away from direct TSO ownership, therefore, requires a different intervention for each.

The third and most significant observation is that standardisation functions as a governance shifter. The TCE analysis in Chapter 5 takes transaction characteristics as given inputs. But those inputs are not fixed by the physics of the service. They are shaped by regulatory choices made at Layer 2: whether a standardised product definition exists, how performance is measured, and what qualification criteria providers must meet. Where ENTSO-E has established uniform specifications, as with balancing, every provider can be compared and replaced, asset specificity stays low, and competitive tendering is feasible. Where those specifications do not exist, as with synthetic inertia and system strength, the same technical complexity produces transaction characteristics that no contract can manage, and hierarchy follows. A TSO can in principle develop its own national product definition without waiting for ENTSO-E, but doing so requires significant resources and produces a standard that cannot attract providers from other member states. For location-bound services that limitation is less decisive, but the resource cost remains real and the resulting standard lacks the legitimacy and enforceability of a EU network code.

This means the hierarchy prediction is not a permanent technical consequence. It holds only as long as the regulatory choice not to standardise remains in place. The EU comparison makes this visible. Germany demonstrates that standardised hybrid governance for synthetic inertia is achievable once product definitions exist [81]. France demonstrates that TSO ownership as a transitional phase can create the conditions for competitive procurement to follow [83]. Same technical service, different regulatory choices, different governance outcomes. Every TSO is navigating the same underlying problem, but arriving at different governance outcomes depending on how far their regulatory framework has developed. North (1990) treats Layer 2 as the set of rules that determines what governance structures are legally permissible [22]. This thesis shows that Layer 2 also determines what is economically efficient. Product definitions are simultaneously governance design decisions. This finding cannot be derived from TCE alone. It requires TCE, the alignment framework of Künneke, Ménard, and Groenewegen, and North's institutional environment analysis together [19] [34] [22].

TenneT's decision to deploy three synchronous condensers to provide inertia independently confirms the analysis [94]. The TCE framework predicts hierarchy for synthetic inertia from transaction characteristics alone, without prior knowledge of the deployment. TenneT reached the same conclusion in practice: where performance cannot be verified and no market product exists, the safest option is to own the asset directly. The regulatory framework reinforces this choice. Under the current Energy Act 2026, TenneT can deploy a synchronous condenser without any prior approval, while a BESS performing the same function at the same node requires a multi-year ACM process. This regulatory asymmetry creates a bias toward the more expensive asset, not the more efficient one.

With that baseline in place, the question changes. It is no longer a question of whether TenneT should own stability assets. It is what needs to happen before contracting becomes a viable alternative. The answer is standardisation. If ENTSO-E were to develop product definitions and verification protocols for synthetic inertia and system strength, the governance prediction would shift: first toward long-term bilateral contracting, and eventually toward competitive procurement as the market matures. That transition does not happen automatically. It requires a regulatory decision, and the ministry responsible for energy policy is the actor positioned to push for it at the EU level.

Three gaps, three different problems

Subquestion 2

Does the Energy Act 2026 permit the TCE-predicted governance structure, and if not, what is the best feasible alternative within the legal boundaries?

The Energy Act 2026 [18] aligns with the TCE prediction for two of the six services but not for the other four. The four misalignments are not random: the more complex the transaction characteristics of a service, the harder it is for a legal framework designed for competitive markets to accommodate the governance structure that would work best. But they are not the same kind of problem, and that distinction matters because each requires a different intervention.

For balancing and voltage control, the law permits exactly what TCE predicts. The Energy Act 2026 requires auction-based procurement for balancing under Articles 3.26 and 3.27, which is precisely the market governance TCE predicts. For voltage control, Article 3.28 permits long-term bilateral contracting. Once a BESS operator has invested at a specific location, neither party can easily exit: the BESS operator cannot relocate, and TenneT cannot easily replace it. This creates a risk that one party exploits the other's locked-in position to renegotiate terms. ACM oversight under the Competition Act prevents this by prohibiting the abuse of a dominant position, ensuring neither party can extract more than a fair, cost-reflective return [78]. There is no governance gap for either service.

For congestion management, the law provides the right instrument but the market environment prevents it from firing. Article 3.29(2) allows ACM to exempt TenneT from the market procurement obligation where market-based procurement is not economically efficient or would cause market distortions. But TenneT cannot easily use it, because the evidentiary requirement creates a circular problem: congestion creates grid connection waiting lists that slow the entry of new BESS operators, and those same BESS operators could relieve the congestion if they were connected. Although BESS operators that contribute to congestion relief can receive connection priority, the process remains slow and uncertain in practice [95]. TenneT, therefore, cannot straightforwardly demonstrate market failure, because BESS operators are willing in principle but face structural barriers created by the very problem the service is meant to solve. This is not a legal gap but an effectiveness gap: the instrument exists, but the market conditions that would allow it to function do not yet reliably exist. Closing it requires a market structure intervention, not legal reform.

For synthetic inertia and system strength, hierarchy is legally possible through the FINC route under Article 3.32, but the route is untested in practice: ACM has never granted recognition to a BESS, no published guidance exists, and no application procedure has been defined. This creates a second problem on top of the procedural one: the market cannot be tested before the product is defined, and the product cannot be defined before standardisation exists.

The procedural barrier is not the only problem. Even if FINC recognition were obtainable, the efficiency case for direct TSO ownership is weaker than it appears. Both services require only a small bidirectional headroom, leaving most of the battery's capacity commercially free. Under private ownership, that capacity generates revenue through balancing, energy arbitrage, and other services. Under direct TenneT ownership, the non-trading condition prohibits that use entirely. To make direct ownership efficient, TenneT would need to stack multiple regulated services on the same asset so that the idle capacity serves a productive purpose within the regulated framework. Without stacking, most of the battery does nothing. Hybrid governance is therefore more commercially viable than FINC for these services when assessed on a standalone basis, as long as verification can be made workable through bilateral contract design. If TenneT were to stack multiple regulated services on the same asset under direct ownership, the idle capacity would serve a productive purpose and the efficiency gap would narrow. But stacking regulated services is not the same as commercial freedom: TenneT directs the asset within the regulated framework, while a private BESS operator can respond to market price signals and pursue the highest-value use at any moment.

For black start, the situation is structurally different and FINC is the most logically justified governance structure. The service requires the entire battery reserve to be available at all times, making commercial use structurally impossible regardless of ownership form. The small headroom argument does not apply: there is no commercially free capacity to exploit. Because commercial revenue is permanently excluded, no private BESS operator would invest in the asset voluntarily. That is precisely why FINC is appropriate: the non-trading condition adds no further constraint beyond what the service already imposes. Germany has already granted the equivalent of FINC recognition to a BESS for curative network security under the same EU framework, demonstrating that the legal pathway is workable in practice [80]. TenneT's most recent black start tender, awarded in January 2026, confirms this independently: it was won by a combined cycle gas turbine with a battery in a supporting role [79]. A standalone BESS cannot fulfil the primary obligation. If TenneT pursues FINC recognition for any service, black start is where the case is clearest and the commercial distortion is smallest.

The EU comparison confirms that the governance gaps are not unique to the Dutch framework and are not permanent. Germany demonstrates that standardised hybrid governance for synthetic inertia is achievable under Article 54 of Directive 2019/944: the Momentanreserve market, launched in January 2026, procures grid-forming batteries through fixed-price bilateral contracts with defined technical requirements and a standardised verification protocol [81]. France demonstrates that the hierarchy-to-hybrid transition is viable: TSO ownership during the RINGO pilot created the operational experience and product knowledge that enabled competitive procurement to follow as definitions matured [83]. Both countries reached that point by first developing product definitions and verification protocols. The Netherlands has not yet done so. It is at the beginning of that transition, not at its limit.

Three interventions follow from the three types of misalignment. For black start, TenneT should pursue FINC recognition: it is the clearest case, the commercial distortion is minimal, and establishing a precedent creates the procedural foundation for the other services. For synthetic inertia and system strength, the path runs from synchronous condensers as the immediate baseline under existing ownership rights, through hybrid bilateral contracting for BESS as an interim arrangement, toward competitive tendering as standardisation develops. For congestion management, the grid connection waiting list must be addressed as a precondition for Article 3.29(2) to function: the legal instrument cannot fire as long as the market structure that should activate it remains broken.

A single rule keeps all three cases out of hierarchy

Subquestion 3

What governance framework can be derived from the TCE analysis and the regulatory analysis to guide governance decisions for BESS providing system services, and what recommendations does it produce when applied to the Dutch transmission system?

The System Services Governance Framework integrates the TCE efficiency analysis from Chapter 5 and the legal feasibility analysis from Chapter 6 into a single structured decision tool. It consists of three

sequential components: a six-gate sequence that determines which governance structure minimises total costs, a legal feasibility check that tests that output against the Energy Act 2026 and EU unbundling rules, and a transition readiness check that identifies the best interim arrangement where the efficient form cannot yet be obtained. Market governance is the legal default under the Energy Act 2026, and every departure from it must be actively justified to ACM. The gate sequence keeps the efficiency question and the legal question separate, so that the legal framework does not narrow the efficiency finding before it has been reached.

Applied to three cases at the Utrecht Lage Weide 150 kV node, the framework produces a hybrid bilateral recommendation in all three cases: synthetic inertia via Article 3.28(3), N-1 curative congestion management via Article 3.29(2), and a combined multi-service arrangement via both exemption routes simultaneously, each subject to ACM approval. That convergence is not coincidental. It reflects the current regulatory and market conditions, not a structural preference for bilateral contracting. Each case arrives at the same output through a different causal path, and those differences matter because the conditions that would shift each case away from hybrid are not the same.

A single institutional rule is keeping all three cases out of hierarchy. The non-trading condition under Article 3.33(2) of the Energy Act 2026 prohibits TenneT from using an owned asset for commercial purposes. Under direct ownership, all commercially free battery capacity is permanently lost. That foregone revenue cost is substantial enough that even where Gates 2 and 3 raise the threshold in favour of hierarchy, direct ownership does not minimise total costs in any of the three cases. This applies even in the multi-service configuration, where two services are stacked on the same asset. The non-trading condition makes sense from a competition policy perspective: without it, TenneT could use a publicly regulated asset to compete against private BESS operators in commercial markets. But its consequence for governance efficiency must be explicitly acknowledged. It is the single institutional rule that makes hybrid the only viable option under current conditions, not a considered judgment that hybrid is the most efficient governance structure in principle.

The hybrid bilateral recommendation is not the endpoint. It reflects current conditions and can shift in either direction as those conditions change. Two variables determine where the recommendation sits on the governance continuum. The first is standardisation. Without product definitions and verification protocols, competitive tendering is structurally impossible and bilateral contracting requires an ACM exemption under Article 3.28(3) that has never been granted for a BESS. Once those preconditions exist, the governance frontier shifts toward market, as the EU comparison in SQ2 demonstrates. The second variable is commercial freedom. The hybrid business case depends on the BESS operator retaining enough freedom outside contracted hours to generate independent revenue. Congestion is the primary threat: as constrained hours rise, the window for commercial trading shrinks, and beyond a certain point, no private BESS operator will accept a hybrid contract at a commercially viable price. Direct ownership then emerges by necessity, not by efficiency. The hybrid recommendation is not a stable equilibrium. It is a conditional outcome that reflects where the Dutch system currently sits between two shifting boundaries.

From efficiency to permission

Main Research Question

What is the efficient governance structure for battery energy storage providing system services in the Dutch electricity system, does the Energy Act 2026 permit it, and where it does not, what is the best feasible alternative?

The Energy Act 2026 permits the TCE-predicted governance structure fully for two services, balancing and voltage control, partially for one, congestion management, and not by default for three, synthetic inertia, system strength, and black start. The resulting gaps are structural rather than incidental, but they are not the same kind of problem: congestion management faces an effectiveness gap; synthetic inertia and system strength face procedural and evidentiary barriers; and black start faces a structural incompatibility between the service obligation and private investment logic. Each gap, therefore, requires a different intervention. The System Services Governance Framework operationalises both the

efficiency prediction and the legal feasibility check into a single, reproducible procedure, providing TenneT and ACM with a theoretically grounded tool for navigating those gaps and identifying the most feasible arrangement when the efficient form is not yet legally achievable.

9.2. Scientific and societal contribution

Scientific contribution

This thesis makes four contributions to the scientific literature on critical network infrastructure governance within New Institutional Economics.

The first is methodological. The eight-transaction decomposition provides a replicable analytical template for governance analysis in regulated infrastructure. It shows that governance challenges concentrate in service-specific transactions rather than generic ones, and that the most severe transaction drives the overall governance prediction. The gate sequence translates this logic into a structured procedure that produces a concrete governance recommendation for a defined context, rather than a theoretical ranking of governance structures.

The second is theoretical. Prior applications of TCE to network infrastructure, including Joskow's coal contract analysis and the alignment framework of Künneke, Ménard and Groenewegen, treat the institutional environment at Layer 2 as a constraint on what governance arrangements are legally permissible at Layer 3. This thesis shows that Layer 2 also shapes what is economically efficient at Layer 3. Product definitions, measurement protocols, and qualification criteria are regulatory choices that determine transaction characteristics. Standardisation is therefore an institutional precondition for discriminating alignment, not a technical given. Regulatory decisions about product standards are simultaneously governance design decisions. This reframes asset specificity as a partially endogenous variable and extends the standard reading of Williamson's four-layer model.

The third is integrative. The finding that standardisation functions as a governance shifter cannot be derived from TCE alone, from the alignment framework alone, or from North's institutional environment analysis alone. It requires all three together. This thesis demonstrates that combining these frameworks produces analytical results that no single framework can reach independently, and provides a worked example of how that combination operates in a technically complex, legally constrained context.

The fourth is generalisability. The framework is not specific to BESS or to the Dutch electricity system. The gate sequence derives recommendations from transaction characteristics and legal constraints. Those inputs change across asset classes and jurisdictions, but the analytical logic does not. Any new asset class providing system services in a regulatory environment that follows the Clean Energy Package structure can be assessed through the same procedure.

Societal contribution

This thesis contributes to regulatory and procurement practice in the Dutch electricity system at two levels.

At the practitioner level, the SSGF provides TenneT with a structured decision tool for evaluating governance arrangements for BESS-based system services. It fills a methodological gap at a moment when procurement decisions will shape market structure for a decade or more. The gate sequence translates theoretical governance predictions into a procedure that a TenneT practitioner can apply in a service design process and that ACM can audit against statutory criteria. The minimum contractual requirements derived from Ostrom's design principles specify the conditions a hybrid bilateral arrangement must satisfy to be durable and enforceable, and can be incorporated into TenneT's standard framework agreements in the near term.

At the regulatory level, the thesis provides ACM, TenneT, and the Ministry of Economic Affairs and Climate Policy with an analytically grounded account of where the current framework produces governance gaps, why each gap is a different kind of problem, and what type of intervention each requires. For practitioners navigating procurement decisions under the Energy Act 2026, this provides a theoretically coherent basis for regulatory exemption applications, product definition processes, and legislative

review at the EU level.

9.3. Limitations

Eight limitations bound the validity of the findings and the transferability of the framework.

The first is methodological. Transaction characterisation and gate scoring are qualitative throughout, producing directional governance recommendations rather than measured efficiency differentials. Where transaction characteristics fall at the boundary between governance categories, the recommendation is sensitive to the researcher's judgment. The expert interview sample is limited to four TenneT practitioners, meaning the framework has only been validated from the buyer's perspective, not from that of a BESS operator.

The second concerns the completeness of the transaction decomposition. The eight-transaction structure is a starting point, not a fixed list. Additional transactions may be relevant for services or asset classes not examined here, and future applications of the framework should assess whether the decomposition requires extension.

The third is a scope limitation on asset choice. The thesis assumes that a BESS is the appropriate asset for each service and asks how it should be governed. It does not assess whether alternative technologies would be more efficient for some services. For synthetic inertia and system strength in particular, the case for expanding the synchronous condenser fleet rather than deploying BESS is not evaluated. This limits the conclusions for those services.

The fourth concerns political feasibility. The analysis derives governance predictions from transaction characteristics and legal feasibility. It does not account for political constraints: ministerial priorities, coalition dynamics, the political acceptability of TSO ownership expansion, or the interests of incumbent market parties. The framework identifies what is economically efficient and legally available, not what is politically achievable. Real governance outcomes will be shaped by the political context that the framework cannot capture.

The fifth is a forward-looking assumption. The case study and hybrid recommendations rest on the assumption that grid connection queues clear before the service gap opens in 2030. This is treated as a given rather than analysed. If the assumption fails, the hybrid recommendations for congestion management and the case study findings no longer hold under current market conditions.

The sixth is a single-party perspective. The analysis is conducted from TenneT's perspective throughout. A BESS operator's perspective might produce different governance preferences around contract duration, penalty structures, and revenue certainty. The framework optimises for TenneT's procurement problem, not for bilateral efficiency.

The seventh is the exclusion of implicit social worth. TCE captures transaction and production costs but not the welfare value of system reliability to end users. The social cost of a governance failure may substantially exceed the private costs the framework measures, and the broader societal value of a privately owned BESS through market participation is equally absent from the cost comparison. The recommendations are therefore conservative in both directions.

The eighth is a boundary condition of TCE itself. Williamson's model assumes opportunistic behaviour in the presence of information asymmetry and asset specificity. In practice, long-term relationships between TenneT and BESS operators may be governed substantially by trust and relational norms that reduce the hazards TCE predicts. The framework identifies the governance structure that is robust under adversarial conditions, not necessarily the form that experienced parties operating in good faith would find optimal.

9.4. Future research

Five directions for future research follow directly from the findings and limitations of this thesis, each targeting a specific gap the analysis leaves open.

The most immediate extension is quantitative. A cost comparison that calibrates the directional Gate 4

findings numerically would allow the sensitivity analysis to be conducted with greater precision, so that threshold statements about when the governance recommendation shifts between market, hybrid, and hierarchy are empirically grounded rather than analytically assumed.

The second direction addresses the single-party perspective. A study from the perspective of BESS operators would complement the procurement-side analysis. BESS operator willingness to enter long-term bilateral contracts is a critical feasibility condition for the hybrid recommendations, and this thesis does not assess it.

The third direction follows from the black start argument. An in-depth governance analysis of synthetic inertia, system strength, and black start under the assumption that FINC recognition has been granted would address what TSO ownership of a BESS requires in terms of operational design and regulatory oversight. Black start is the natural starting point, and the German and French cases provide directly applicable reference points.

The fourth direction targets the most acute governance gap. Regulatory design research addressing the circularity problem at chronically congested nodes would examine how to resolve the grid connection waiting list as a precondition for Article 3.29(2) to function. Priority connection rights, pre-qualification mechanisms, and TSO-sponsored pilot connections are candidate instruments.

The fifth direction extends the analytical scope. A welfare economics extension incorporating the social value of system reliability would allow the governance recommendations to be evaluated against a socially optimal benchmark. For stability services, the social cost of a governance failure may substantially exceed the private costs the framework currently measures.

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Conclusion & recommendation

This thesis examines how battery energy storage systems providing system services in the Dutch electricity system should be governed, and whether the Energy Act 2026 permits the governance structures that transaction cost economics identifies as efficient. Three findings stand out.

The first is that governance follows the transaction, not the asset. In the traditional electricity system, every asset had one purpose and governance followed naturally from that. A battery breaks this pattern: the same physical asset can provide almost all system services, sometimes multiple at the same time. What determines the governance structure is not the technology but what the service requires, because the transaction characteristics, how location-specific the investment must be, how difficult performance is to verify, and how often the service is activated, differ across services. This has a direct implication for TenneT: service design must precede procurement design, not follow from it.

The second and most significant finding is that standardisation functions as a governance shifter. Transaction cost economics takes transaction characteristics as given inputs. This thesis shows those inputs are not fixed by the physics of the service. They are shaped by whether standardised product definitions exist. Where European network codes define what a service looks like, how it is measured, and what a provider must demonstrate, competitive tendering becomes feasible. Where those definitions do not exist, the same technical complexity makes contracting impossible and direct ownership follows. Standardisation decisions are therefore simultaneously governance design decisions. Layer 2 does not only constrain what governance structures are legally permissible: it shapes what is economically efficient. It requires combining transaction cost economics, the alignment framework of Künneke, Ménard and Groenewegen, and North's institutional environment analysis. This has a direct implication for ENTSO-E: developing product definitions is not only a technical coordination task. It determines which governance structures are economically feasible across all connected transmission systems.

The third finding is that the governance gaps produced by the Energy Act 2026 do not all have the same cause. The law aligns for two services, but for the remaining four, three distinct gaps emerge. Congestion management faces an effectiveness gap: the legal instrument exists but the market structure prevents it from firing. Synthetic inertia and system strength face a procedural and evidentiary barrier: the FINC route is available in law but untested in practice. Black start faces a structural incompatibility: the service requires the entire battery reserve in permanent readiness, making private investment commercially unviable. Each gap requires a different intervention, and treating them as a single problem leads to the wrong response for each. This has a direct implication for ACM: published guidance on each type of gap is a precondition for TenneT to navigate them, not an optional regulatory convenience.

The System Services Governance Framework translates these findings into a structured decision tool. Applied to three cases at Utrecht Lage Weide 150 kV, all three produce a recommendation for long-term bilateral contracting. That recommendation is not permanent. It reflects current conditions: a legal rule that makes direct ownership expensive and the absence of product definitions that makes competitive tendering impossible. As those conditions change, the governance recommendation changes with them.

Recommendations

TenneT

For TenneT, the most important shift is analytical. Market-based procurement should not be assumed as the default for every service. Each service has different transaction characteristics that determine which governance structure minimises total costs. Where direct ownership is more efficient, TenneT should pursue FINC recognition rather than paying a premium for conventional assets that perform the same function. Black start is the clearest starting point: the case for FINC is straightforward, establishing a precedent creates the foundation for synthetic inertia and system strength to follow.

ACM

For ACM, the priority is to provide TenneT with clearer guidance on what constitutes an adequate market failure demonstration under Articles 3.28(3), 3.29(2), and 3.33. Without that guidance, regulatory uncertainty prevents TenneT from pursuing available exception routes even where the legal basis is clear. More broadly, ACM should reconsider how it approaches TSO ownership of storage assets. ACM's mandate is to protect competitive markets, but the electricity system of 2026 is fundamentally different from the one that liberalisation was designed for. Germany and France have granted TSO ownership of storage assets for stability services and found that it supports rather than undermines system reliability. Direct TSO ownership for critical stability services is not a step back from liberalisation: it is a pragmatic response to a system that market procurement alone cannot stabilise.

Ministry of Economic Affairs and Climate Policy and European Commission / ENTSO-E / ACER

The priority is product standardisation. National definitions alone cannot create the market conditions that efficient procurement requires. ENTSO-E network codes covering synthetic inertia and system strength would reduce transaction characteristics that currently make contractual governance impossible, shifting governance prediction from hierarchy toward hybrid and, eventually, toward competitive tendering. The ownership prohibition in Article 54 of Directive 2019/944 should also be reviewed: the criterion for TSO ownership exceptions should be function-based rather than technology-based, removing the regulatory bias toward more expensive assets that perform the same function.

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Reflection

Looking back at this thesis, the process turned out to be very different from what I expected. I thought writing a thesis was a straight line from start to finish. It was not. It was messy, circular, and at times frustrating, but also more rewarding than I had anticipated.

The beginning was the hardest part. The topic is complex, and everyone at TenneT seemed to have a different opinion on what the real problem was. I knew the topic mattered. I just did not know yet what I wanted to say about it. The midterm was the turning point. Choosing Transaction Cost Economics gave the thesis a clear foundation, but the period immediately afterwards was, paradoxically, the hardest. I knew a lot had to change, but I did not yet know how. Looking back, I think I could have handled that uncertainty better by accepting earlier that not knowing the answer at the start is simply part of how complex problems get solved. Research is not a journey from A to B. The days that felt unproductive were often the ones that shaped the most important parts of the thesis. The thinking was happening even when the writing was not.

Working with TenneT practitioners confronted me with something I had not anticipated: the gap between theory and professional experience. Williamson's model assumes that parties will exploit every gap in a contract whenever it benefits them. When I raised this with practitioners, the response was consistent: they did not recognise that picture. They told me counterparties would simply deliver, and that a breach-of-contract claim with a substantial fine was the backstop. That tension stuck with me. It does not mean the theory is wrong, but it does mean that the professional environment in which a theory is applied matters enormously. Going forward I will be more deliberate about testing theoretical assumptions against the operational context early in the process, not only after the analysis is complete.

The regulatory chapter was a different kind of challenge. Reading and interpreting legislation requires a precision I had not practised before, and I relied heavily on asking for help and checking my interpretations carefully. It made me appreciate how much expertise sits behind what looks like a straightforward legal framework.

One of the things I will take forward is a better understanding of scope. This thesis covers six services, eight transactions, a full regulatory analysis, a governance framework, and a case study. That ambition made the work rich but also demanding. Knowing when to go deep on fewer things rather than broad across many is a skill I am still developing, and one I will be more deliberate about next time.

Beyond the research itself, doing my graduation internship at TenneT was the perfect way to end my studies. TenneT is an organisation where everything I learned during the master's, the interaction between technology, institutions, policy, and markets, comes together in practice. I am leaving with a much better understanding of what it means to work on difficult problems within a large institution, with greater tolerance for uncertainty, and with deep appreciation for everyone who gave their time and knowledge along the way.

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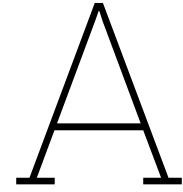
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AI Statement

This thesis was written with the assistance of artificial intelligence tools. Claude (Anthropic) was used as a writing assistant throughout the drafting and revision process: it helped structure arguments, improve sentence clarity, and refine the academic tone of the text. NotebookLM (Google) was used to support the literature review process by organising and summarising academic sources. Grammarly (Grammarly, Inc.) was used to check grammar and spelling throughout the thesis. All analytical content, governance predictions, legal interpretations, and conclusions are the author's own work. The author takes full responsibility for the content, interpretation, and conclusions of this thesis.



Literature review methodology

The literature review conducted for this thesis serves two purposes. The first is to establish the theoretical foundation for the governance analysis: identifying the relevant bodies of work in transaction cost economics, new institutional economics, and network infrastructure governance that inform the analytical framework developed in Chapter 2. The second is to survey the technical and regulatory literature on battery energy storage systems and system services in the Dutch and European electricity system, providing the empirical grounding for the analysis in Chapters 3 and 6.

A systematic, multi-step approach was used for the theoretical literature. Search strings were constructed using keywords drawn from the core research domains of the thesis, including transaction cost economics, governance, energy storage, system services, and Dutch and European energy regulation. These strings were applied to the Google Scholar and Scopus databases, with no fixed publication date restriction for foundational theoretical works, and a focus on literature published from 2019 onwards for regulatory and technical sources, reflecting the introduction of the Clean Energy Package as the relevant regulatory baseline. Papers were screened by title and abstract for suitability. The snowballing technique was applied to identify additional relevant sources cited in the selected papers.

Technical and regulatory sources cited in Chapters 3 and 6 were selected based on direct relevance to the specific system services and legal instruments analysed. These include grid codes, regulatory documents, industry reports, and engineering literature, and are cited individually where analytically relevant rather than compiled through a systematic search procedure. The selected literature for the theoretical framework is presented in Table A.1.

Table A.1: Overview of selected literature

Author	Title	Year	[Ref]
Ménard and Shirley North	Introduction: Handbook of New Institutional Economics	2025	[21]
	Institutions, Institutional Change and Economic Performance	1990	[22]
Williamson	The Institutions and Governance of Economic Development and Reform	1995	[23]
Coase	The Nature of the Firm	1937	[24]
Williamson	The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting	1985	[19]
Simon	A Behavioral Model of Rational Choice	1955	[25]
Williamson	The New Institutional Economics: Taking Stock, Looking Ahead	2000	[26]
Demsetz	Toward a Theory of Property Rights	1967	[27]
Hart	A Natural-Resource-Based View of the Firm	1995	[28]

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Author	Title	Year	[Ref]
Williamson	Transaction Cost Economics: How It Works; Where It is Headed	1990	[96]
Williamson	Transaction Cost Economics	1989	[29]
Williamson	Transaction-Cost Economics: The Governance of Contractual Relations	1979	[30]
Williamson	Comparative Economic Organization: The Analysis of Discrete Structural Alternatives	1991	[20]
Ménard	The Economics of Hybrid Organizations	2004	[31]
Klein, Crawford, and Alchian	Vertical Integration, Appropriable Rents, and the Competitive Contracting Process	1978	[33]
Künneke, Ménard, and Groenewegen	Network Infrastructures: Technology Meets Institutions	2021	[34]
Joskow	Vertical Integration and Long-term Contracts: The Case of Coal-burning Electric Generating Plants	1985	[35]
Ostrom	Governing the Commons: The Evolution of Institutions for Collective Action	1990	[38]
Cox, Arnold, and Villamayor Tomás	A Review of Design Principles for Community-Based Natural Resource Management	2010	[39]

B

Transaction Cost Analysis Scoring Framework

This appendix documents the scoring framework applied in Chapter 5 to assess the transaction characteristics of each system service. For each dimension, a general rubric defines what low, moderate, and high scores mean in the context of this thesis, and a set of transaction-specific key questions grounds that rubric in the concrete governance problems that each transaction presents. The rubric and key questions together ensure that scores are assigned consistently across all six services and all eight transactions, and that each score reflects a transaction-specific analytical judgement rather than a generic assessment.

The dimensions covered are site specificity, dedicated asset specificity, temporal specificity, physical asset specificity, and human asset specificity under asset specificity, followed by primary uncertainty, secondary uncertainty, and tertiary uncertainty under uncertainty, and frequency. Where a dimension is not analytically applicable to a specific transaction, this is noted explicitly alongside the rubric and the transaction is excluded from the scoring for that dimension.

Site Specificity

Site specificity measures how difficult it is for TenneT to find an equivalent alternative provider or location if the contracted operator exits. It captures geographic and network-topological lock-in.

General Rubric

Score	Definition	Distinguishing indicator
Low	Multiple equivalent alternatives exist at other locations or nodes	Service is location-agnostic; any grid-connected BESS can substitute
Moderate	Some alternatives exist but with meaningful geographic or network constraints	Alternative nodes exist but involve non-trivial search, tendering, or re-routing costs
High	No viable alternative exists; TenneT is locked into this location or node	Service is strictly local (e.g. reactive power, fault current, restoration sequence); no equivalent substitute at another location

key question of Transaction

Site specificity is not applicable to transactions T4–T7 (dispatch, SoC management, telemetry, and degradation governance).

Transaction	key question
T1 — Land acquisition	Is the land or site required for the BESS uniquely positioned for the intended service, such that TenneT cannot replicate the arrangement at another location at comparable cost?
T2 — Grid connection	Is the grid connection point uniquely required for service delivery, or could an equivalent connection at another node serve TenneT equally well?
T3 — Availability obligation	If the contracted operator exits, how easily can TenneT find an equivalent provider at the same or a comparable location?
T8 — Termination	Does termination of this contract leave TenneT without a viable alternative at this location, or can the service be re-contracted elsewhere without material loss of service quality?

Dedicated Asset Specificity

Dedicated asset specificity measures how much the service commitment reduces the operator's freedom to use the asset for other purposes or buyers. It captures commercial lock-in created by the service obligation.

General Rubric

Score	Definition	Distinguishing indicator
Low	Obligation imposes minimal constraints; the operator retains full or near-full commercial freedom	Asset can freely participate in other markets or services alongside the primary obligation
Moderate	Obligation constrains but does not eliminate commercial freedom; other services or markets remain accessible	SoC window or availability window restricts but does not structurally exclude commercial participation
High	Obligation structurally excludes or severely limits commercial use of the asset throughout the contract	Asset must remain fully charged, continuously available, or in a mode that is incompatible with commercial optimization

key question of Transaction

Transaction	key question
T3 — Availability obligation	How much does committing to this availability obligation reduce the operator's freedom to sell the asset's capacity to other buyers or in other markets?
T4 — Dispatch and control rights	How much do the dispatch and control arrangements — beyond the availability obligation itself — reduce the operator's commercial freedom in practice?
T5 — Market participation / SoC conflict	How much does the SoC obligation associated with this service reduce the operator's ability to trade freely in commercial energy markets?
T6 — Telemetry and information rights	How much does complying with the telemetry obligation reduce the operator's freedom to use the asset commercially?
T7 — Degradation and cycling rights	How much does the service obligation structurally constrain the operator's ability to optimise charge/discharge cycles for commercial purposes?

Temporal Specificity

Temporal specificity measures whether TenneT's service value is entirely dependent on the operator's availability at one specific, unpredictable moment. It captures the irreversible value loss if the operator is unavailable at exactly the right time.

General Rubric

Score	Definition	Distinguishing indicator
Low	Service value does not hinge on a single critical moment; defined response windows or advance notice exist	TenneT can plan around the activation; non-availability at a given instant does not cause irreversible value loss
Moderate	A short response window creates time pressure, but the service is not millisecond-critical	Some preparation is possible but the window is narrow enough that late availability causes material value loss
High	Service value is entirely dependent on availability at one unpredictable, unforeseeable moment	No advance warning; non-availability at the exact triggering instant causes complete and irreversible service failure

key question of Transaction

Temporal specificity is not applicable to transactions T1–T2 (site acquisition and grid connection) and T4, T6–T8 (dispatch, telemetry, degradation, and termination), as these are not single-moment transactions.

Transaction	key question
T3 — Availability obligation	Is the value of the availability obligation entirely dependent on the operator being available at one specific, unpredictable moment, or does TenneT have advance warning of when availability will be needed?
T5 — Market participation / SoC conflict	Is the SoC requirement time-critical in the sense that a single instant of incorrect SoC — with no advance warning — would cause complete service failure?

Physical Asset Specificity

Physical asset specificity measures whether the physical configuration of the asset is so tailored to the service that it has little or no value outside this specific relationship. It captures lock-in created by bespoke hardware or software configuration.

General Rubric

Score	Definition	Distinguishing indicator
Low	Standard configuration applicable across multiple services and counterparties	Hardware and software settings are generic or becoming standard across the industry
Moderate	Some service-specific configuration required, but residual value exists in other relationships	Configuration is tailored but transferable with moderate adaptation cost
High	Bespoke configuration with little or no value outside this specific service relationship	Hardware or software is so uniquely specified that redeployment for another service or buyer is technically or commercially impractical

key question of Transaction

Physical asset specificity is not applicable to transactions T1–T2 (land and grid connection), T3 (pre-deployment contracting stage), T5 (SoC management), and T7–T8 (degradation and termination governance), as these are not driven by physical asset configuration.

Transaction	key question
T4 — Dispatch and control rights	Is the physical and software configuration required to enable dispatch and autonomous response so service-specific that TenneT could not redeploy the asset for another service without material cost?
T6 — Telemetry and information rights	Is the telemetry hardware and software configuration so service-specific — for example, bespoke phasor measurement or fault-current sensors — that it has little value outside this relationship?

Human Asset Specificity

Human asset specificity measures whether the operator accumulates knowledge or skills in the course of performing the service that TenneT cannot easily replace if the operator exits. It captures lock-in created by experiential or relational knowledge.

General Rubric

Score	Definition	Distinguishing indicator
Low	Knowledge is standardised and transferable; a replacement operator could be onboarded without material loss	Skills required are available in the market; no irreplaceable relationship-specific expertise is accumulated
Moderate	Some accumulated knowledge is service-specific but could be reconstructed with meaningful transition effort	Replacement is possible but involves a non-trivial learning curve or knowledge transfer period
High	Operator accumulates irreplaceable knowledge; exit would leave TenneT without expertise it cannot quickly source	Deep operational familiarity with grid conditions, asset behaviour, or restoration procedures is not easily replicated

key question of Transaction

Human asset specificity is not applicable to transactions T1–T2 (site and grid connection), T3 (pre-deployment contracting stage), and T5 (SoC management), as these do not generate service-specific human knowledge.

Transaction	key question
T4 — Dispatch and control rights	Does configuring and operating the dispatch and control parameters over time accumulate operator knowledge that TenneT could not easily source from a replacement operator?
T6 — Telemetry and information rights	Does operating the telemetry system and interpreting its data streams accumulate operator knowledge that would be difficult to replicate if the operator exits?
T7 — Degradation and cycling rights	Does managing degradation and cycling in the context of this specific service obligation accumulate operator knowledge that TenneT cannot easily replace?
T8 — Termination	Does the operator hold knowledge about asset condition, grid interface settings, or restoration data at termination that TenneT cannot independently reconstruct?

Primary Uncertainty

Primary uncertainty measures what external factors — regulatory, technical, or operational — neither TenneT nor the operator can anticipate or control at the relevant transaction stage. This dimension is never not applicable.

General Rubric

Score	Definition	Distinguishing indicator
Low	Regulatory framework is stable and well-defined; external factors are foreseeable and bounded	Both parties can write a reasonably complete contract without significant gaps caused by external uncertainty
Moderate	Some regulatory or operational uncertainty exists but is partially foreseeable or manageable	Key parameters are known but some external contingencies require contractual adaptation clauses
High	No established framework; timing, magnitude, or regulatory trajectory is fundamentally unpredictable	Neither party can write a complete contract; the service is governed by an incomplete agreement with significant residual risk

key question of Transaction

Transaction	key question
T3 — Availability obligation	What regulatory, technical, or market developments could neither party anticipate at the point of contracting availability, potentially making the agreed terms incomplete or unworkable?
T4 — Dispatch and control rights	What external factors could disrupt the agreed dispatch and control arrangements in ways neither party could foresee when the operational protocols were established?
T5 — Market participation / SoC conflict	What external factors — such as market rule changes, grid code updates, or technology shifts — could alter the SoC obligations or commercial constraints in unforeseeable ways?
T6 — Telemetry and information rights	What external factors — such as cybersecurity incidents, data standard changes, or regulatory requirements — could disrupt the telemetry arrangement in ways neither party could anticipate?
T7 — Degradation and cycling rights	What external factors — such as new battery chemistry standards, warranty rule changes, or grid code revisions — could alter the degradation risk allocation in unforeseeable ways?
T8 — Termination	What external factors — such as regulatory changes, asset condition surprises, or grid evolution — could make the termination arrangement incomplete or disputed?

Secondary Uncertainty

Secondary uncertainty measures what information the operator holds — about asset capability, SoC, or readiness — that TenneT needs but cannot directly observe. All analysis is conducted from TenneT's perspective as the uninformed party.

General Rubric

Score	Definition	Distinguishing indicator
Low	Standard protocols or monitoring tools allow TenneT to adequately verify the relevant information	The information gap is minimal; TenneT can independently confirm what the operator reports
Moderate	Some information gap exists but is partially bridgeable through monitoring, advance notice, or audits	TenneT cannot continuously verify but can check periodically with acceptable residual uncertainty
High	A persistent information advantage for the operator exists that TenneT cannot bridge with available tools	Capability, SoC, or readiness cannot be verified except during rare real-world events; TenneT is structurally dependent on the operator's self-reporting

key question of Transaction

Secondary uncertainty is not applicable to transaction T1 (land acquisition) and T3 (pre-deployment contracting stage), as these do not generate a service-relevant information asymmetry.

Transaction	key question
T2 — Grid connection	Does the operator hold information about the grid connection's technical capability or limitations that TenneT cannot independently verify at the point of connection?
T4 — Dispatch and control rights	What does the operator know about actual dispatch readiness — control parameters, firmware settings, response configuration — that TenneT cannot continuously observe between verifications?
T5 — Market participation / SoC conflict	What does the operator know about the actual state of charge at the critical moment of activation that TenneT cannot independently guarantee through telemetry alone?
T6 — Telemetry and information rights	Does the operator hold information about data quality, sensor calibration, or reporting gaps in the telemetry system that TenneT cannot independently audit?
T7 — Degradation and cycling rights	Does the operator hold information about actual battery degradation, cycling history, or remaining useful life that TenneT cannot independently verify?
T8 — Termination	Does the operator hold information about asset condition, configuration, or residual capability at termination that TenneT cannot independently assess?

Tertiary Uncertainty

Tertiary uncertainty measures whether the operator has a persistent incentive to exploit the information gap identified under secondary uncertainty — i.e., whether the information asymmetry creates a real and ongoing opportunism risk for TenneT.

General Rubric

Score	Definition	Distinguishing indicator
Low	No persistent financial incentive to exploit the information gap, or non-compliance is immediately detectable	Market mechanisms, penalties, or real-time monitoring constrain opportunistic behaviour effectively
Moderate	Some incentive exists but commercial activity is observable, limiting the scope and duration of exploitation	Opportunism is possible but detectable with some delay; the financial upside is limited by monitoring or penalties
High	Persistent and material financial incentive to exploit the information gap; detection is structurally difficult	The operator can derive ongoing commercial benefit from the information advantage with low risk of timely detection by TenneT

key question of Transaction

Tertiary uncertainty is not applicable to transactions T1 (land acquisition), T2 (grid connection), and T3 (pre-deployment contracting stage), as these do not create a persistent exploitation incentive structure.

Transaction	key question
T4 — Dispatch and control rights	Does the operator have a persistent financial incentive to misrepresent or under-deliver on dispatch readiness, and can TenneT detect this in time to prevent harm?
T5 — Market participation / SoC conflict	Does the operator have a persistent financial incentive to deplete SoC commercially — knowing that unforeseeable activation events provide cover — and can TenneT detect and penalise this reliably?
T6 — Telemetry and information rights	Does the operator have a persistent financial incentive to manipulate, delay, or suppress telemetry data in ways that benefit the operator at TenneT's expense?
T7 — Degradation and cycling rights	Does the operator have a persistent financial incentive to shift cycling costs onto TenneT — for example, by accelerating degradation through commercial use while attributing it to service obligations?
T8 — Termination	Does the operator have a financial incentive at termination to misrepresent asset condition, retain configuration knowledge, or otherwise exploit the information gap to TenneT's detriment?

Frequency

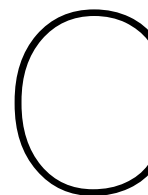
Frequency measures how often the governance interaction for the relevant transaction actually recurs between TenneT and the operator. High frequency reduces per-interaction governance cost and supports market or bilateral arrangements; low frequency increases the relative weight of safeguards.

General Rubric

Score	Definition	Distinguishing indicator
Low	Transaction occurs once or very rarely — at contract formation, periodic review, or exceptional events	Governance interaction is not repeated in the ordinary course of contract performance
Moderate	Transaction recurs periodically — on a weekly, monthly, or seasonal basis	Interaction repeats at intervals but is not a continuous or daily feature of the relationship
High	Transaction recurs continuously or very frequently — daily, intra-day, or in real time	Governance interaction is a permanent and ongoing feature of contract performance

key question of Transaction

Transaction	key question
T3 — Availability obligation	How often does TenneT need to re-contract, renegotiate, or renew the availability obligation — at the level of the obligation itself, not its activation?
T4 — Dispatch and control rights	How often does TenneT actively exercise its dispatch or control right — by issuing a signal, configuring a parameter, or triggering a response?
T5 — Market participation / SoC conflict	How often does the tension between the operator's commercial SoC management and the service obligation actively materialise and require governance attention?
T6 — Telemetry and information rights	How often does the telemetry data exchange between operator and TenneT actually occur?
T7 — Degradation and cycling rights	How often do TenneT and the operator need to interact over the governance of degradation risk and cycling rights?



Transaction-Level TCE Analysis of BESS System Services

This appendix presents the full transaction-level scoring for each of the six system services analysed in Chapter 5. For each service, the five service-specific transactions (T3 through T7) are assessed across the dimensions of asset specificity, uncertainty, and frequency. The generic transactions (T1, T2, and T8) are presented in the opening table and apply to all six services regardless of the specific service provided.

Each cell contains a score, low, moderate, or high, and a brief justification grounding that score in the transaction-specific characteristics of the service. Scores marked N/A indicate that the dimension is not analytically applicable to that transaction, as specified in the scoring framework in Appendix X. The governance recommendation in the final row of each table reflects the dominant hazard across all scored dimensions for that transaction: where one dimension produces a severe hazard, it drives the governance recommendation regardless of how the other dimensions score.

The tables in this appendix are the evidentiary basis for the governance predictions summarised in Chapter 5 and tested against the legal framework in Chapter 6. Readers who wish to understand the scoring rationale for a specific transaction should consult the corresponding key question in the scoring framework appendix alongside the relevant cell in these tables.

General Transactions

Level 1 Transaction Analysis — General BESS Transactions			
	T1 — Land acquisition	T2 — Grid connection	T8 — Residual rights & termination
Site Specificity	Low Land itself is generally substitutable at the acquisition stage	Mod The connection point matters technically but alternatives at nearby nodes may exist	Mod Termination leaves TSO without a provider at this location
Dedicated Asset Specificity	Low Land does not yet commit the asset to any specific service	Low Grid connection does not yet commit the asset to a specific service	Low Termination ends the commitment; operator regains full commercial freedom
Temporal Specificity	N/A	N/A	N/A
Physical Asset Specificity	N/A	N/A	N/A
Human Asset Specificity	N/A	N/A	Mod Operator may hold knowledge that takes time to reconstruct with a replacement operator
Asset Specificity Score	Low	Mod	Mod
Primary Uncertainty	Mod Permitting, zoning, and environmental regulations introduce uncertainty	Mod Connection requirements, capacity availability, and technical standards	Mod Regulatory changes, asset condition surprises, or grid evolution could make termination terms incomplete
Secondary Uncertainty	N/A	Low TSO knows a lot about grid connections	Mod Operator holds information about actual asset condition and configuration at termination
Tertiary Uncertainty	N/A	N/A	Mod Operator has some incentive to misrepresent asset condition
Uncertainty Score	Mod	Mod	Mod
Frequency	Low One-time transaction	Low One-time transaction	Low One-time transaction
Governance Recommendation	Mod	Mod	Mod

Table C.1: Transaction analysis for general BESS transactions

Synthetic inertia

Level 2 Transaction Analysis — Synthetic Inertia					
	T3 — Availability obligation	T4 — Dispatch & control rights	T5 — Market participation & SoC conflict	T6 — Telemetry & information rights	T7 — Degradation & cycling rights
Site Specificity	Mod System-wide effect, alternatives at other locations are viable	N/A	N/A	N/A	N/A
Dedicated Asset Specificity	Mod Commercial freedom is constrained but not eliminated	Low GFM parameters locked; all other settings free	Mod SoC window must be maintained but commercial activities possible	Low Telemetry required but does not restrict commercial use	Mod SoC window constraints cycling but commercial cycling possible
Temporal Specificity	High Autonomous millisecond response	N/A	High SoC must be correct at every moment	N/A	N/A
Physical Asset Specificity	N/A	Low GFM becoming standard	N/A	High Measurement methodology not standardised	N/A
Human Asset Specificity	N/A	Low Parameters documented and transferable	N/A	Low Parameters documented and transferable	Low Parameters documented and transferable
Asset Specificity Score	High	Low	High	High	Mod
Primary Uncertainty	High No regulatory framework; unpredictable frequency events	Low Technical parameters well-defined	Low Behavioural SoC issue	Low Telemetry well-defined	Low Degradation driven by cycling
Secondary Uncertainty	High Rare activation; performance not observable	High TSO cannot observe parameter settings	High SoC not continuously observable	Low Fully captured at T5	Low Operator responsibility
Tertiary Uncertainty	High Incentive to appear available while optimising commercially	High Operator can alter settings undetected	High Incentive to prioritise market revenues	Low Fully captured at T5	Low Operator responsibility
Uncertainty Score	High	High	High	Low	Low
Frequency	Low Contracted once per contract period	Low Configured once; autonomous thereafter	High Continuous constraint	High Continuous data stream	Low
Governance Recommendation	High	Mod	High	High	Mod

Table C.2: Transaction analysis for synthetic inertia services

Congestion Management

Level 2 Transaction Analysis — Congestion Management (node-dependent)					
	T3 — Availability obligation	T4 — Dispatch & control rights	T5 — Market participation & SoC conflict	T6 — Telemetry & information rights	T7 — Degradation & cycling rights (congestion-specific)
Site Specificity	Mod (occasional) / High (chronic) Asset value tied to specific congested node; wrong side of bottleneck = zero value	N/A	N/A	N/A	N/A
Dedicated Asset Specificity	Mod (chronic) / Low (occasional) Occasional: activations are rare, operator has significant commercial freedom. Chronic: near-daily activations, constrain commercial freedom	Low Dispatch settings locked; all other settings free	Mod (chronic) / Low (occasional) Near-daily activities constrain commercial freedom	Low Telemetry required but does not restrict commercial use	Mod (chronic) / Low (occasional) Near-daily deep cycles constraint / rare activations
Temporal Specificity	Low Advance notice hours before activation	N/A	Low Hours in advance notice allow SoC correction	N/A	N/A
Physical Asset Specificity	N/A	Low Standard inverter sufficient	N/A	Low Standard equipment	N/A
Human Asset Specificity	N/A	Low Parameters documented and transferable to new operator	N/A	Low Parameters documented and transferable to new operator	Low Parameters documented and transferable to new operator
Asset Specificity Score	Mod (occasional) / High (chronic)	Low	Low (occasional) / Mod (chronic)	Low	Low (occasional) / Mod (chronic)
Primary Uncertainty	Mod Congestion patterns partly foreseeable day-ahead but depends on unpredictable vRES output	Low Technical parameters well-defined	Low SoC conflict is a behavioural problem; not driven by external factors	Low Telemetry requirements technically well-defined; not driven by external factors	Low Degradation driven by cycling behaviour; not by external factors
Secondary Uncertainty	Mod Advance notice allows pre-activation SoC verification; partial observability possible	Low Dispatch-based control verifiable through standard testing protocols	Low Advance notice window allows pre-activation SoC verification	Low Fully captured at T5	Low Degradation is operator's responsibility
Tertiary Uncertainty	Low Advance notice reduces scope for opportunism; non-compliance easily detectable	Low Standard testing protocols limit scope for parameter manipulation	Low Advance notice allows pre-activation; opportunism easily detectable	Low Fully captured at T5	Low Degradation is operator's responsibility
Uncertainty Score	Mod	Low	Low	Low	Low
Frequency	Low Contracted once per contract period	Low (occasional) / High (chronic) Rare activations / near-daily activations	Low (occasional) / High (chronic) Rare activations / near-daily constraint	High Continuous real-time data stream	Low
Governance Recommendation	Mod	Low	Mod / Low	Low	Low

Table C.3: Transaction analysis for congestion management services

Voltage control

Level 2 Transaction Analysis — Voltage & Reactive Power Support										
	T3 — Availability obligation		T4 — Dispatch & control rights		T5 — Market participation & SoC conflict		T6 — Telemetry & information rights		T7 — Degradation & cycling rights (voltage-specific)	
Site Specificity	High	Reactive power cannot travel far; asset must be at voltage-stressed node	N/A		N/A		N/A		N/A	
Dedicated Asset Specificity	Mod	Commercial freedom alongside the voltage support commitment	Low	Four-quadrant parameters locked; all other settings free	Low	Reactive power requires no energy; commercial freedom largely intact	Low	Telemetry required but does not restrict commercial use	Low	Minimum cycling impact on commercial freedom
Temporal Specificity	Mod	Short response window; value depending on timing	N/A		Low Requires no specific SoC level		N/A		N/A	
Physical Asset Specificity	N/A		Low	Four-quadrant capability becoming standard	N/A		Low	Standard equipment	N/A	
Human Asset Specificity	N/A		Low	Parameters documented and transferable to new operator	N/A		Low	Parameters documented and transferable to new operator	Low	Parameters documented and transferable to new operator
Asset Specificity Score	High		Low		Low		Low		Mod	
Primary Uncertainty	Mod	Voltage conditions partly foreseeable but depend on unpredictable vRES output and load patterns	Low	Technical parameters well-defined	N/A		Low	Telemetry requirements technically well-defined; not driven by external factors	Low	Degradation driven by cycling behaviour; not by external factors
Secondary Uncertainty	Low	Frequent activation; capability regularly observable	Low	Four-quadrant settings verifiable through standard testing protocols	N/A		Low	Fully captured at T5	Low	Degradation is operator's responsibility
Tertiary Uncertainty	Low	Real-time measurability limits scope for opportunism	Low	Standard testing protocols limit scope for parameter manipulation	N/A		Low	Fully captured at T5	Low	Degradation is operator's responsibility
Uncertainty Score	Mod		Low		Low		Low		Low	
Frequency	Low	Contracted once per contract period	High	Frequent activations	Low	SoC irrelevant	High	Continuous real-time data stream	Low	
Governance Recommendation	High		Low		Low		Low		Low	

Table C.4: Transaction analysis for voltage and reactive power support services

Balancing

Level 2 Transaction Analysis — Balancing (FCR, aFRR, mFRR)					
	T3 — Availability obligation	T4 — Dispatch & control rights	T5 — Market participation & SoC conflict	T6 — Telemetry & information rights	T7 — Degradation & cycling rights (balancing-specific)
Site Specificity	Low location irrelevant	N/A	N/A	N/A	N/A
Dedicated Asset Specificity	Low Barely constrain commercial freedom	Low Standardised dispatch interface; all other settings free	Low Full commercial freedom; value stacking possible	Low Telemetry required but does not restrict commercial use	Low Shallow cycling; no significant commercial restrictions
Temporal Specificity	Low Service value not tied to one moment; defined response windows allow flexibility	N/A	Mod Response window exist but is very short	N/A	N/A
Physical Asset Specificity	N/A	Low Standard inverter sufficient	N/A	Low Standard equipment	N/A
Human Asset Specificity	N/A	Low Parameters documented and transferable to new operator	N/A	Low Parameters documented and transferable to new operator	Low Parameters documented and transferable to new operator
Asset Specificity Score	Low	Low	Mod	Low	Low
Primary Uncertainty	Low Frequency disturbance timing uncertain but ENTSO-E product definitions provide stable framework	Low Technical parameters well-defined	Low SoC conflict is a behavioural problem; not driven by external factors	Low Telemetry requirements technically well-defined; not driven by external factors	Low Degradation driven by cycling behaviour; not by external factors
Secondary Uncertainty	Low Frequent activation; capability regularly observable	Low Standardised parameters verifiable through standard testing protocols	Mod Standard telemetry allows SoC monitoring	Low Fully captured at T5	Low Degradation is operator's responsibility
Tertiary Uncertainty	Low Competitive market and standard penalties limit opportunistic behaviour	Low Standardised penalties and monitoring limit scope for opportunism	Low Frequent activation and standard monitoring limit opportunism	Low Fully captured at T5	Low Degradation is operator's responsibility
Uncertainty Score	Low	Low	Low	Low	Low
Frequency	Low Contracted once per contract period	High Very frequent activations	High Frequent activation depletes SoC	High Continuous real-time data stream	Low
Governance Recommendation	Low	Low	Mod	Low	Low

Table C.5: Transaction analysis for balancing services

System strength

Level 2 Transaction Analysis — System Strength					
	T3 — Availability obligation	T4 — Dispatch & control rights	T5 — Market participation & SoC conflict	T6 — Telemetry & information rights	T7 — Degradation & cycling rights (system strength-specific)
Site Specificity	High Fault current contribution is strictly local; asset must be at specific weak node	N/A	N/A	N/A	N/A
Dedicated Asset Specificity	High Similar to inertia but availability further limits which other services can be delivered simultaneously.	Low GFM parameters locked; all other settings free	Mod Availability constraint but does not eliminate commercial freedom	Low Telemetry required but does not restrict commercial use	Mod SoC window constraints cycling but commercial cycling possible
Temporal Specificity	High Service value entirely dependent on availability at exact moment of fault	N/A	High SoC must be correct at every moment; no warning possible	N/A	N/A
Physical Asset Specificity	N/A	Low GFM becoming standard	N/A	High Measurement methodology under development, not yet available	N/A
Human Asset Specificity	N/A	Low Parameters documented and transferable to new operator	N/A	Low Parameters documented and transferable to new operator	Low Parameters documented and transferable to new operator
Asset Specificity Score	High	Low	High	High	Mod
Primary Uncertainty	High No standardised product definition for system strength; fault occurrence unpredictable	Low Technical parameters well-defined	Low SoC conflict is a behavioural problem; not driven by external factors	Low Telemetry requirements technically well-defined; not driven by external factors	Low Degradation driven by cycling behaviour; not by external factors
Secondary Uncertainty	High Fault current gap and rare faults; capability not observable during normal operation	High GFM parameters cannot be fully verified without real fault event	High TSO cannot continuously observe SoC	Low Fully captured at T5	Low Degradation is operator's responsibility
Tertiary Uncertainty	High Operator has persistent incentive to appear available while actual fault current capability unverifiable	High Operator can alter GFM parameters; actual capability only testable during real faults	High Persistent financial incentive to deplete SoC; fault occurrence used as excuse	Low Fully captured at T5	Low Degradation is operator's responsibility
Uncertainty Score	High	High	High	Low	Low
Frequency	Low Contracted once per contract period	Low Settings configured once; autonomous response thereafter	High Continuous grid-forming constraint	High Continuous real-time data stream	Low
Governance Recommendation	High	Mod	High	High	Mod

Table C.6: Transaction analysis for system strength services

Black Start and Restoration

Level 2 Transaction Analysis — Black Start & System Restoration					
	T3 — Availability obligation	T4 — Dispatch & control rights	T5 — Market participation & SoC conflict	T6 — Telemetry & information rights	T7 — Degradation & cycling rights (black start-specific)
Site Specificity	High Restoration sequence requires asset at specific network location to re-energise defined network segment	N/A	N/A	N/A	N/A
Dedicated Asset Specificity	High Asset committed exclusively to black start readiness; no alternative use compatible with full charge requirement	Low Restoration parameters locked; all other settings free	High Asset must remain fully charged at all times; commercial use structurally excluded	Low Telemetry monitors compliance but adds no commercial restrictions beyond T5	Low Black start activations extremely rare; minimal actual cycling
Temporal Specificity	High Asset must be fully charged and ready at exact moment of blackout	N/A	High SoC must be at maximum at every moment; blackout can occur without any warning	N/A	N/A
Physical Asset Specificity	N/A	Low GFM and is-landing becoming standard	N/A	High Measurement methodology under development, not yet available	N/A
Human Asset Specificity	N/A	Low Parameters documented and transferable to new operator	N/A	Low Parameters documented and transferable to new operator	Low Parameters documented and transferable to new operator
Asset Specificity Score	High	Low	High	High	Low
Primary Uncertainty	High Blackout timing completely unpredictable; may never occur during asset lifetime	Low Technical parameters well-defined	Low SoC conflict is a behavioural problem; not driven by external factors	Low Telemetry requirements technically well-defined; not driven by external factors	Low Degradation driven by cycling behaviour; not by external factors
Secondary Uncertainty	High Rare activation; actual restoration capability rarely observable	High Restoration sequence parameters only fully verifiable during real blackout or drill	Mod SoC observable via energy flows but cannot be guaranteed at exact moment of blackout	Low Fully captured at T5	Low Degradation is operator's responsibility
Tertiary Uncertainty	Mod Commercial activity observable but strategic SoC management within limits possible	High Operator could alter restoration sequence parameters without TSO detecting it between drills	Mod Commercial activity observable but strategic SoC management within limits possible	Low Fully captured at T5	Low Degradation is operator's responsibility
Uncertainty Score	High	High	Mod	Low	Low
Frequency	Low Contracted once per contract period	Low Rare activation	High Permanent full-charge requirement	High Continuous real-time data stream	Low
Governance Recommendation	High	Mod	High	High	Low

Table C.7: Transaction analysis for black start and system restoration services

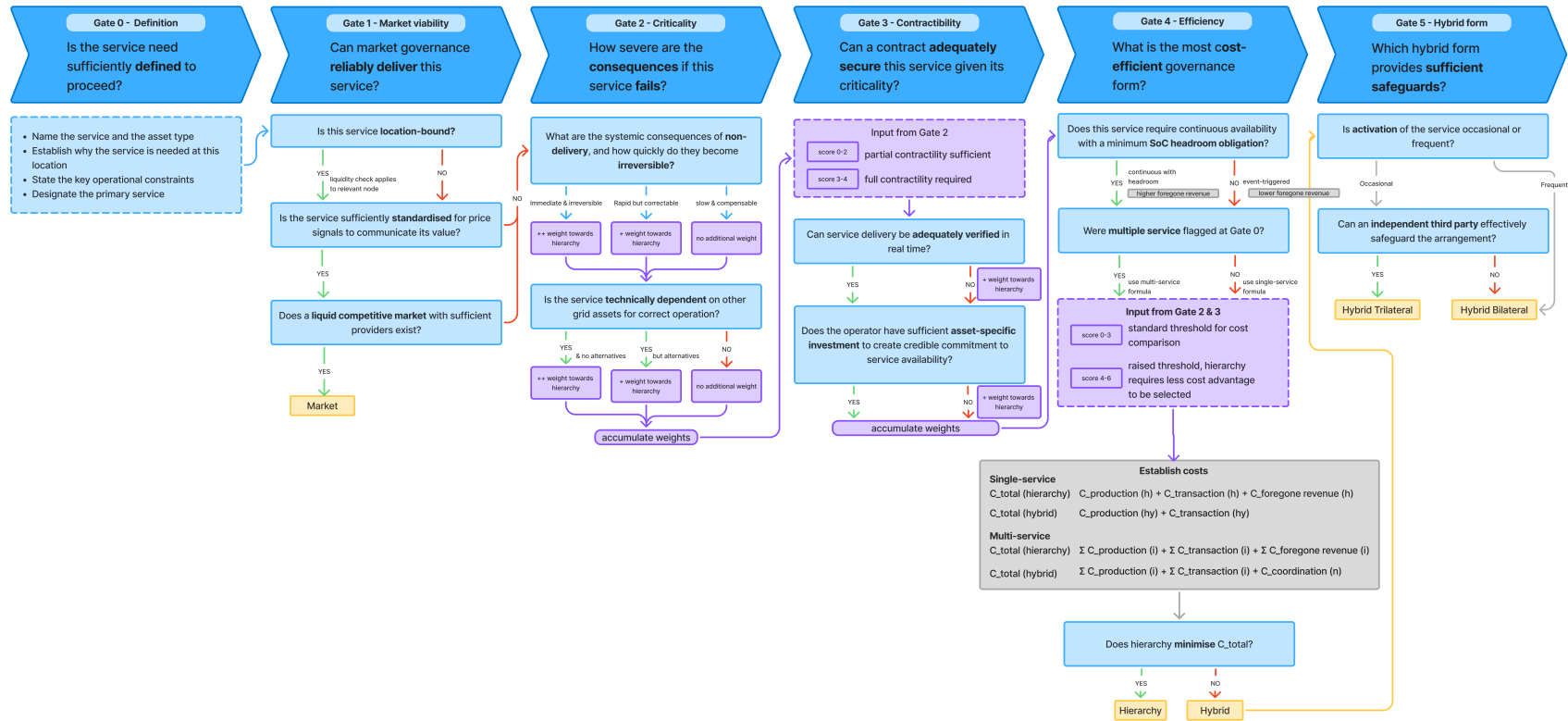
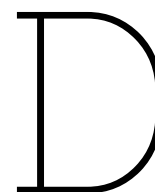


Figure C.1: Overview of all the gates



Interview protocol and questions

This appendix documents the interview protocol used to validate the System Service Governance Framework developed in Chapter 7. Four semi-structured interviews were conducted with experienced professionals from TenneT and the broader Dutch electricity sector. The interviews served to assess the face validity of the framework: whether its analytical logic is recognisable in practice, whether its governance recommendations align with sector experience, and whether relevant considerations are missing or incorrectly formulated.

The protocol consists of three parts. The informed consent form sets out the purpose of the study, the nature of participation, and the data handling arrangements. The interview guide structures the conversation in three phases: an introductory phase establishing the participant's context and experience, a framework walkthrough in which the participant applies the framework gate by gate to a service they are familiar with, and a reflection phase in which broader questions about usability and outcome validity are discussed. Questions were shared with participants in advance to facilitate informed and reflective responses.

Participants are referred to using neutral labels in the thesis to preserve anonymity. No confidential or commercially sensitive information was requested or retained.

Informed consent form

You are being invited to participate in a research study titled *Governing Battery Energy Storage in the Dutch Transmission System: A Transaction Cost Analysis*. This study is conducted by Annegien Koopal from TU Delft as part of a Master's thesis project, in collaboration with TenneT B.V.

What is this study about?

This research develops a decision framework to analyse the appropriate governance form for Battery Energy Storage System (BESS)-based system flexibility services in the Dutch electricity system.

Like all analytical frameworks, it relies on assumptions. The purpose of this study is to validate those assumptions with experienced professionals.

Your expertise helps assess:

- whether the framework's analytical steps are practically recognisable,
- whether important governance considerations may be missing,
- whether the framework's outputs align with how BESS procurement challenges are understood in practice.

The goal is to strengthen both the academic quality and practical relevance of the framework.

The results will be used for a Master's thesis at TU Delft and may later be used in academic publications or presentations.

What would your participation involve?

If you agree to participate, you will take part in a single interview lasting approximately 45–60 minutes. The interview will follow a structured format in which the framework's gate logic and underlying assumptions are presented and discussed.

You will be asked to reflect on:

- whether the analytical steps and governance criteria are realistic,
- whether important governance considerations may be missing,
- whether certain simplifications could affect the framework's outputs.

The discussion focuses solely on analytical logic and governance reasoning. You are not expected to share confidential or strategically sensitive company information.

How will your data be handled?

For practical purposes, your name and email address will be used for scheduling and consent. With your permission, the interview may be audio-recorded to ensure accurate transcription.

Your responses will be treated confidentially:

- Your name, job title, and department will not appear in the thesis or publications.
- You will be referred to using neutral labels such as "Expert 1".
- Any details that could indirectly identify you will be removed.

Data will be stored securely on TU Delft-approved systems. Only the researcher and academic supervisor will have access. Audio recordings will be deleted after transcription. Anonymised research data will be retained in line with TU Delft research data management policies.

Are there any risks?

Participation involves minimal risk. The main potential risk would be reputational if statements were traceable to you personally. This is mitigated through strict anonymisation and aggregated reporting.

If commercially sensitive information is mentioned unintentionally, it will not be included in transcripts or publications.

There are no physical or psychological risks beyond normal professional discussion.

Your rights

Participation is entirely voluntary. You may:

- decline to answer any question,
- stop the interview at any time,
- withdraw your data up to 08-05-26.

Withdrawing will have no consequences for your professional role or relationship with TU Delft or TenneT.

No financial compensation is provided for participation.

Interview guide

Semi-structured interviews provide a flexible yet systematic approach to the collection of qualitative data. To facilitate informed and reflective responses, the interview questions were shared with participants in advance. In total, four experts were interviewed to validate the SSGF and provide their opinions.

Purpose of the Interviews

The purpose of this interview is to assess the *face validity* of the ACM-framework developed in this research. Specifically, the interview evaluates whether:

- the gate structure and associated questions are recognisable and logically consistent with TenneT's operational practice,
- the governance recommendation produced by the framework aligns with the expert's expectations based on their experience,
- relevant factors are missing or incorrectly formulated, thereby limiting the framework's practical applicability.

Part 1: Introduction and Context

[10 minutes]

Welcome and thank you for taking the time to participate. I will briefly explain the purpose of this study and the structure of this interview.

In my Master's thesis, I investigate how BESS-based system flexibility services in the Dutch electricity system can be governed most efficiently. The central question is which governance form is economically efficient for each type of service, and whether the Dutch Energy Act allows that governance form.

The research is based on Williamson's Transaction Cost Economics (TCE). This theory suggests that the organisation of a service depends on the characteristics of the underlying transaction. For example, synthetic inertia is location-specific, requires continuous availability, and is difficult to monitor. In such cases, standard market procurement may be inefficient. TCE predicts that long-term contracts or direct ownership may be more efficient. The framework developed in this research formalises this logic step by step.

Within the framework, three governance forms are distinguished:

- **Market:** TenneT procures the service competitively from multiple providers,
- **Hybrid:** TenneT contracts a single provider through a long-term bilateral agreement with specific obligations and safeguards,
- **Hierarchy:** TenneT owns and operates the asset itself (e.g., synchronous condensers).

A key distinction in the framework is between production costs and transaction costs:

- **Production costs** are the direct costs of delivering the service (e.g., investment, operation, and availability costs). These are typically lower under market governance due to competition.
- **Transaction costs** are the costs of organising the relationship (e.g., contracting, monitoring, enforcement). These increase when services are difficult to specify or verify.

The central premise is that the efficient governance form minimises the sum of production and transaction costs.

As part of this research, a decision framework has been developed that could support ACM in assessing whether an exemption from standard market procurement is justified. The framework consists of six gates evaluating service characteristics, criticality, market viability, contractability, efficiency, and legal feasibility.

The purpose of this interview is not to assess whether your answers are correct, but whether the framework asks the right questions and produces meaningful outputs. Critical feedback is therefore highly

valuable.

We will go through the framework gate by gate for a service you are familiar with. Afterwards, I will ask a few broader reflection questions.

Before we begin, three short questions:

- Could you briefly describe your role at TenneT and the flexibility services you are most involved with?
- Are there services where standard procurement contracts do not work well? For example, due to monitoring difficulties or location dependency?
- Has TenneT experienced situations where the procurement framework was insufficient for a specific service? Could you provide an example?

Part 2: Framework Walkthrough

I will share my screen and we will go through the framework together. For each gate, I will ask you to answer the questions for a service you are familiar with.

While doing so, I will observe where clarification is needed or where questions could be improved.

After each gate, I will ask a short validation question:

“Does the logic of this gate make sense to you, or is something missing?”

Part 3: Reflection

[15 minutes]

After completing the framework, I will ask a number of broader reflection questions.

Usability of the Framework

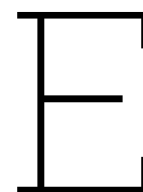
- Would this framework be useful in practice for TenneT when preparing a FINC request or an Article 3.33 exemption request to ACM?
- Are there gates you would remove or combine? Why?
- Are there factors missing from the framework that you consider important for governance decisions?

Outcome of the Framework

- Does the governance recommendation produced by the framework align with your expectations based on experience?
- If the outcome differs from current or planned TenneT practice, what would that imply for how TenneT could justify its position to ACM?

Closing Questions

- Did anything in the framework surprise you, positively or negatively?
- Is there anything you would like to add that we have not discussed?



Interview Summary

Samenvatting interview Expert 1

Achtergrond Expert 1 Expert 1 is werkzaam bij TenneT, met ervaring in de operationele en marktgerichte kant van systeemflexibiliteitsdiensten. Hij is betrokken bij opzetten van Europese regelgeving voor flexibiliteit productdefinities en mede aan het onderzoeken hoe in NL meer flexibiliteit en nieuwe vormen van flexibiliteit (als technieken) uit de markt kan worden gehaald. Op het moment van het interview houdt hij zich onder meer bezig met de ontwikkeling van een productcatalogus voor gestandaardiseerde flexibiliteitsdiensten en de inzet van nieuwe technologieën zoals batterijen binnen bestaande marktstructuren.

Gate 0: batterij-specifieke beperkingen verdienen aparte vermelding Expert 1 wijst er aan het begin van het gesprek op dat de State of Charge (SoC) slechts één van de operationele beperkingen van een batterij is. Minstens zo relevant zijn de compensatie-effecten (bekend als rebound effect): om een dienst te kunnen leveren moet de batterij soms eerst worden opgeladen of ontladen, en die handeling heeft zelf ook neveneffecten op het net en op de beschikbaarheid van andere diensten. Hij adviseert deze batterij-specifieke constraints explicieter te benoemen in Gate 0, naast de SoC-eis. Dit rebound effect kan ook bij andere technologieën voorkomen (zoals warmte, koude, perslucht etc.)

Gate 1: non-delivery heeft ook indirecte cascade-effecten Expert 1 onderschrijft het belang van de criticaliteitscheck, maar voegt een nuance toe: niet alleen het uitblijven van een dienst is relevant, ook de levering zelf kan in bepaalde netwerksituaties neveneffecten hebben op andere diensten of de activatie van andere assets. Hij wijst erop dat in een gespannen netsituatie een onjuiste of onvolledige levering van bijvoorbeeld congestiemanagement kan leiden tot dynamische onbalans problemen. Dit maakt de beoordeling van criticaliteit complexer dan een eenvoudige ja/nee-vraag over directe gevolgen.

Locatiegebondenheid: gradueel, niet binair Expert 1 nuanceert de locatiegebondenheid-check in Gate 2. Hij maakt onderscheid tussen actief en blindvermogen: actief vermogen kan relatief makkelijk over het net worden verschoven, terwijl blindvermogen strikt locatiegebonden is en praktisch niet getransporteerd kan worden. Congestiemanagement zit daar tussenin: het is locatieafhankelijk, maar biedt nog enige geografische flexibiliteit in de keuze van aanbieders. Dit maakt de marktviabiliteitsbeoordeling gradueel in plaats van binair: de mate van locatiegebondenheid bepaalt de marge voor marktforming, niet de onmogelijkheid ervan.

Efficiëntie gate: goedkoopste is niet altijd de beste oplossing Expert 1 plaatst vraagtekens bij een puur kostengedreven efficiëntiecheck. Hij geeft aan dat in de TenneT-praktijk de goedkoopste optie in congestiemanagement niet altijd de meest effectieve is, omdat de locatie van de aanbieder en de fysieke werking van het net bepalen hoeveel effect een activatie daadwerkelijk heeft op het

congestieprobleem. Efficiëntie en effectiviteit moeten samen worden meegewogen: een goedkopere aanbieder op de verkeerde locatie is per saldo duurder. Hij adviseert dit onderscheid expliciet in de efficiëntiecheck te verankeren.

Trilateraal toezicht: in de praktijk beperkt tot transparantie Expert 1 reageert genuanceerd op de trilaterale governance-optie. Hij erkent dat een derde partij, in dit geval de ACM, toezicht zou kunnen houden op de prijsvorming in bilaterale contracten, maar stelt dat dit in de praktijk neerkomt op een transparantieverplichting richting de toezichthouder, niet op actieve prijsregulering. Ook zal er dan gekeken moeten worden naar wat nodig is om deze transparantie te behalen. Verder zal er ook gekeken moeten worden naar Europese regelgeving. Het zou kunnen dat deze regelgeving hier eventueel al zaken voorschijft. Een andere marktpartij als derde partij is in zijn ogen onwenselijk vanwege belangenconflicten. Hij adviseert in het framework explicieter te maken wie die derde partij concreet kan zijn en wat haar bevoegdheden precies omvatten.

Marktverantwoordelijkheid ligt mede bij TenneT Expert 1 benadrukt dat TenneT als systeembeheerder ook een eigen verantwoordelijkheid heeft voor het aantrekken van voldoende marktaanbieders, met name in regio's waar de markt schaars is. Hij wijst erop dat industriële partijen zoals staalfabrieken en papierfabrieken flexibiliteitsdiensten beschouwen als bijkomende inkomsten, niet als kernactiviteit, en dus extra perspectief (om een goede businesscase te maken) en informatie nodig hebben om actief te worden. Dit marktfacilitaire aspect ontbreekt volgens hem als expliciete stap in het framework. Dit is ook van belang als partijen onder voorwaarden flexibiliteit aan willen bieden om meer aansluitcapaciteit te verkrijgen of beter gebruik willen maken van aansluitcapaciteit.

Contractvorm en -duur als onderschatte factor Expert 1 attendeert op het belang van de contractvorm en -duur als element in de governance-keuze. Langjarige contracten bieden zekerheid voor TenneT, maar beperken tegelijk de toetreding van nieuwe marktpartijen en kunnen de marktdynamiek verstoren. Kortere contracten bieden meer marktflexibiliteit, maar minder zekerheid. Hij suggereert dit als een expliciet criterium op te nemen in de contractability-check van Gate 3.

Juridisch kader: Europese regels bieden meer ruimte dan energiewet suggereert Expert 1 wijst erop dat de Europese regelgeving, die boven de Energiewet staat, meer handelingsruimte biedt dan soms binnen TenneT wordt verondersteld. Hij adviseert het framework niet te begrenzen door de huidige nationale interpretatie van de Energiewet, maar ook te kijken naar wat op Europees niveau mogelijk is. Als er een governance gap bestaat, is er altijd ruimte om in gesprek te gaan met de ACM, het Ministerie van EZK of zelfs op Europees niveau. Hij moedigt aan om vanuit behoefte te redeneren in plaats van vanuit bestaande regelgeving.

Normative positie: TSO-eigendom van batterijen vraagt goede onderbouwing Expert 1 neemt geen uitgesproken stellingname in, maar geeft aan dat TSO-eigendom van batterijen in principe mogelijk moet zijn als dat aantoonbaar nodig is. Hij verwijst naar synchrone condensatoren als bestand voorbeeld waarbij TSO-eigendom gerechtvaardigd werd op basis van leveringszekerheid en het ontbreken van marktaanbod. Voor batterijen ontbreekt momenteel een vergelijkbare onderbouwing. Hij waarschuwt dat eigen opslagassets van de TSO concurrerend werken op de markt en dat de unbundlingregels beperkingen opleggen aan het laden en ontladen op basis van marktprijzen.

Overige opmerkingen Expert 1 beoordeelt het framework als een goed startpunt. Hij adviseert de batterijspecifieke constraints (SoC, compensatie-effecten, beschikbaarheidsrisico's) meer prominent mee te nemen in Gate 0 en Gate 1. Verder zou de rol van de derde partij in de trilaterale governance-optie duidelijker moeten worden gespecificeerd. Hij biedt aan het framework later nogmaals te reviewen of aanvullingen te geven als er nog vragen zijn.

Interview Summary - expert 2

Achtergrond Expert 2 Expert 2 is werkzaam binnen de regulatoire en beleidsmatige afdeling van TenneT. Haar expertise richt zich op de vertaling van wet- en regelgeving naar de praktijk van con-

tractering en inkoop van systeem diensten, waaronder spanningsregeling en blindvermogen. Ze is direct betrokken bij de raakvlakken tussen regulatorische kaders.

Gate 1 — Criticaliteit: te binair Expert 2 plaatst vraagtekens bij de logica van Gate 1, waarbij een hoge kritikaliteit leidt tot het overslaan van de markttoets. Haar redenering: als een dienst juist heel kritisch is, en er al marktpartijen bestaan die die dienst kunnen leveren, en in dat geval is het efficiënter om die direct te contracteren in plaats van TSO-eigendom na te streven. Bovendien duurt het installeren van eigen assets bij TenneT ook lang vanwege interne procedures en vergunningstrajecten, dus de tijdswinst van TSO-eigendom is niet vanzelfsprekend. Ze concludeert dat de stap "hoge kritikaliteit → sla markt over" te zwart-wit is geformuleerd.

Alert/Emergency State-terminologie De interviewer introduceerde de stelling dat TenneT met een eigen batterij alleen in alert of emergency state mag handelen. Expert 2 reageerde met onbekendheid: ze herkende deze beperking niet uit de Energiewet en betwijfelde of die er daadwerkelijk in staat. Ze gaf aan dit te willen verifiëren, en merkte op dat het praktisch ook weinig zinvol is: een batterij die alleen in extreme omstandigheden mag worden ingezet staat het overgrote deel van de tijd stil, wat economisch inefficiënt is. Synchrone condensatoren — het bestaande voorbeeld van TSO-eigendom — staan altijd aan als baseline. Ze adviseerde de interviewer om de interpretatie van deze bepaling te heroverwegen.

Terminologie: markt vs. hybride Een substantieel deel van het gesprek betrof het verschil in terminologie tussen de academische TCE-literatuur en het jargon van TenneT. TenneT spreekt van "markt-gebaseerde inkoop" voor alle contracten die tot stand komen via een open tender of aanbidding, ook als het gaat om jaarlijkse één-op-ééncontracten met één gascentrale. Vanuit TCE is dat een hybride governancevorm, geen markt. Expert 2 bevestigde dat dit een terminologisch verschil is, niet een inhoudelijk conflict: beide beschrijvingen zijn juist vanuit hun eigen perspectief. Ze adviseerde in de thesis een heldere definitieparagraaf op te nemen zodat lezers uit de praktijk niet struikelen over de benamingen.

Foregone revenue: ander referentiepunt Expert 2 nuanceert het begrip *C_foregone_revenue*. Vanuit haar perspectief is het referentiepunt niet de gemiste marktopbrengst van een vrijhandelende batterij, maar de inkoopbesparing voor TenneT: als TenneT een eigen batterij heeft en de dienst daarmee goedkoper kan leveren dan via marktinkoop, dan is dat de relevante besparing. Ze erkende wel dat een markt-batterij optimaler benut kan worden (handel, balancering, energiemarkt) dan een TenneT-batterij, en dat dit een sociaal welvaartsverlies kan inhouden, maar vanuit TenneT's inkooplogica is de relevante maatstaf de vergelijking met wat de markt zou vragen.

Normative positie: TSO-eigendom Expert 2 nam geen uitgesproken normatief standpunt in over het eigenaarschap van batterijen door TSO's. Ze gaf aan dat als TenneT zelf een batterij zou plaatsen, die logischerwijs zo geoptimaliseerd zou worden dat hij zo veel mogelijk gebruikt wordt, vergelijkbaar met synchrone condensatoren. Ze wees erop dat een TenneT-batterij altijd kleiner zal zijn dan een commerciële batterij, omdat het handelsgedeelte ervan ontbreekt. Ze erkende dat dit sociaal welvaartsverlies oplevert, maar beschouwde dit als een te accepteren afruil, aangezien de dienst anders niet beschikbaar is. Ze adviseerde bij tegenstrijdige inzichten de opvatting van Expert 1 te volgen.

Overige opmerkingen Expert 2 vroeg zich af of het sequentiële karakter van het framework (stap 1 → 2 → 3 → 4) niet deels vervangen zou moeten worden door parallelle evaluaties. Ze suggereerde dat de legal feasibility check eerder in het proces zou kunnen verschijnen, omdat juridische onmogelijkheid de verdere analyse kan kortsluiten. Ze beoordeelde het framework als "een goede guide" en gaf aan het nuttig te vinden als de terminologie helder wordt gedefinieerd.

Interview Summary - expert 3

Achtergrond Expert 3 Expert 3 is werkzaam binnen de beleids- en marktgerichte afdeling van TenneT. Zijn expertise richt zich op systeemmarkten, flexibiliteit, de kwantificering van flexibiliteitscapaciteit

en leveringszekerheid. Hij wordt intern en extern frequent geraadpleegd over vraagstukken rondom batterijpositionering en nieuwe flexibiliteitstechnologieën. Op het moment van het interview houdt hij zich onder meer bezig met langetermijnbeleidsmatige afwegingen rond leveringszekerheid en marktontwerp.

Congestiemanagement: verschuiving naar pre-DA contracten Expert 3 signaleert een trend bij TenneT waarbij steeds meer congestiemanagement preventief wordt georganiseerd via capaciteitsbeperkende contracten vóór de day-aheadmarkt, in plaats van operationeel in te grijpen op basis van netveiligheidsanalyses dichterbij real-time. Hij beschouwt dit als een uiting van risicoaversie: men wil ervoor zorgen dat congestie wordt voorkomen, ook als die congestie mogelijk helemaal niet had opgetreden. Hij wijst erop dat de effectiviteit van deze aanpak moeilijk te evalueren is, omdat de counterfactual ontbreekt: je weet niet wat de markt had gedaan als je niet preventief had ingegrepen. Dit maakt kostenvergelijkingen tussen interventiestrategieën structureel onvolledig.

Terminologie: markt omvat ook bilaterale contracten Een substantieel deel van het gesprek betrof de definitie van "de markt." Vanuit de ACM-optiek is alles wat via aangeslotenen wordt gecontracteerd, inclusief één-op-één-langetermijncontracten, marktgebaseerd. Expert 3 stelt dat het begrip "hybride", zoals gebruikt in de TCE-literatuur, in de TenneT-praktijk niet als onderscheidende categorie wordt gehanteerd: een bilateraal contract met een gascentrale of fabriek is gewoon een afspraak met een aangeslotene, en dat is de markt. Hij adviseert in de thesis een heldere definitieparagraaf op te nemen om terminologische verwarring bij praktijklezers te voorkomen.

Criticaliteitscheck: 100% zekerheid is een illusie Expert 3 stelt kritische vragen bij de binaire aard van de criticaliteitscheck in Gate 1. Hij betoogt dat 100% leveringszekerheid voor geen enkele dienst, ook niet buiten de energiesector, gegarandeerd kan worden, en dat een ja/nee-vraag over "nationaal falen bij niet-levering" daarmee altijd te bevestigend uitvalt. Als je de criticaliteitsvraag heel strikt neemt, zou je voor vrijwel alle systeemdiensten de markttoets kunnen overslaan. Hij pleit voor een genuanceerder criterium dat rekening houdt met de mate van substitueerbaarheid en de geografische spreiding van het risico.

Efficiëntiecheck: impliciete waarden structureel onderschat Expert 3 onderschrijft het principe van de kostenafweging in Gate 4 van het framework, maar plaatst een fundamentele kanttekening bij de uitvoerbaarheid ervan in de praktijk. Hij stelt dat de expliciete kosten van TSO-eigendom (capex, energie-inkoop) goed kwantificeerbaar zijn, maar dat de impliciete waarde van een batterij voor een marktpartij, de optionaliteitswaarde door gecombineerde inzet op meerdere markten zoals balanceren, energie en systeemdiensten, structureel moeilijk te kwantificeren is. Deze impliciete waarden worden door netbeheerders consistent onderschat, omdat ze niet in een offerte of een eenduidige kostenindicator tot uitdrukking komen. Het gevolg is een structurele bias in de vergelijking ten nadele van de marktoptie.

Normative positie: TSO-eigendom absoluut af te raden Expert 3 neemt een uitgesproken normatief standpunt in: een TSO of DSO zou nooit zelf een batterij moeten bezitten. Zijn redenering is dat een batterij voor x procent van de tijd wordt ingezet voor een systeemdienst, maar dat de resterende tijd optionaliteitswaarde heeft die een marktpartij wél kan vermarkten en een netbeheerder niet. Dit maakt eigenbezit per definitie duurder dan contracteren. Hij verwierpt ook het leveringszekerheidsargument: het feit dat je de asset zelf bezit geeft geen 100% garantie, uitval is altijd mogelijk. De garanties liggen in contractafspraken, niet in eigendomsstructuren. Zijn conclusie is dat TSO-eigendom van batterijen altijd een schijngevoel van veiligheid geeft en maatschappelijk welvaartsverlies oplevert.

Overige opmerkingen Expert 3 beoordeelt het framework als conceptueel solide en de criteria als valide, maar waarschuwt dat de praktijk weerbarstiger is dan de theorie suggereert. De kosten-batenafweging die het framework veronderstelt, is in zijn ogen nooit een exacte wetenschap: ze is altijd afhankelijk van aannames over impliciete waarden, en daarmee vatbaar voor lobby en perspectiefverschillen. Hij vergelijkt dit met de bredere uitdaging van netinvesteringen, waar kosten expliciet zijn maar

baten (economische activiteit, elektrificatie) per definitie impliciet en omstreden zijn. Hij raadt aan dit in de thesis expliciet te erkennen als beperking van het framework.

Interview Summary - expert 4

Achtergrond Expert 4 Expert 4 is werkzaam binnen de strategie en innovatiegerelateerde afdeling van TenneT. Zijn expertise richt zich op flexibiliteitsinkoop, congestiemanagement en de strategische afweging tussen marktgebaseerde en inhouse oplossingen voor systeemflexibiliteitsdiensten. Hij is nauw betrokken bij de praktische uitvoering van contractering met marktpartijen en heeft directe ervaring met de operationele en juridische beperkingen waar TenneT mee te maken heeft.

Gate 1 — Liquiditeit is te smal als criterium Expert 4 plaatst vraagtekens bij de focus van Gate 1 op liquiditeit als enige reden om de markt te verlaten. Zijn redenering: een markt kan voldoende liquide zijn, maar desondanks maatschappelijk duurder zijn dan TSO-eigendom. Het relevante criterium is niet alleen of er genoeg aanbieders zijn, maar ook of de dienst goedkoper zelf geleverd kan worden. Hij stelt voor om naast een liquiditeitstekort expliciet ook een kostenoverwicht als uitstapcriterium te benoemen: "ofwel de markt levert het niet, ofwel wij kunnen het zelf goedkoper." Dit zou eerder in het framework terug moeten komen dan nu het geval is, ook al bij Gate 1.

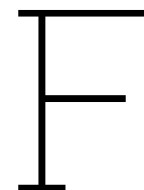
Congestie als praktische beperking buiten het framework Expert 4 wijst op een fundamenteel praktisch probleem dat het framework niet expliciet meeneemt: netcongestie. Op veel locaties kunnen batterijen helemaal niet worden aangesloten, simpelweg omdat er geen transportcapaciteit is. Dit betekent dat de liquiditeit op die locaties structureel achterblijft, niet omdat de markt het product niet wil leveren, maar omdat TenneT de assets niet kan aansluiten. Hij adviseert dit als contextuele beperking te benoemen in het framework of de thesis, zodat duidelijk wordt waarom de markt in bepaalde gevallen nooit van de grond kan komen. Het is in zijn ogen een van de grootste verklaringen voor de liquiditeitsachterstand.

Continu reserveren versus event-triggered diensten Expert 4 nuanceert de relatie tussen het type dienst (continu versus event-getriggerd) en de omzet van de asset. Hij is het niet volledig eens met de redenering dat continu-diensten meer handelsvrijheid bieden: juist bij continu-reservering verliest een marktbeheerder zijn volledige handelscapaciteit en wordt de dienst extreem duur. Congestiecontracten waarbij een batterij de dag van tevoren wordt afgeroepen, geven de batterij juist vrijwel volledige handelsvrijheid op andere momenten. Hij beschouwt de kostprijs van reservering als sterk afhankelijk van de contractvorm en adviseert dit onderscheid scherper te maken in de efficiëntiebeoordeling.

ACM-positie: marktgedreven preferent Expert 4 brengt de positie van de ACM expliciet in het gesprek. Waar wordt aangegeven dat ACM doorgaans marktgedreven oplossingen prefereert en als meest economisch ziet. Expert 4 begrijpt die redenering, maar betwijfelt of die voor alle diensten en alle situaties geldt, met name gezien de praktische congestieproblematiek. Hij beschouwt de TCE-benadering van het framework als een waardevolle aanvulling op dit debat: het biedt een gestructureerde rechtvaardiging voor TSO-eigendom die verder gaat dan de intuïtie van de ACM.

Normative positie: TSO-eigendom Expert 4 neemt geen uitgesproken normatief standpunt in, maar geeft aan dat als kan worden bewezen dat TSO-eigendom maatschappelijk goedkoper is, er geen reden is om dat niet te doen. Hij erkent tegelijkertijd dat de marktmechanismen voor congestiemanagement nog onvoldoende zijn uitontwikkeld om definitief te kunnen beoordelen of ze falen. Hij deelt de zorg van de ACM dat het overhaast omarmen van TSO-eigendom prematuur kan zijn als marktgebaseerde alternatieven nog niet volledig zijn beproefd.

Overige opmerkingen Expert 4 beoordeelt het framework als theoretisch solide en logisch opgebouwd, maar mist een expliciete koppeling met de praktische realiteit van netcongestie. Hij adviseert in de thesis de context van het framework duidelijk te maken waarom liquiditeit achterblijft, zodat lezers uit de praktijk het framework niet als te abstract ervaren. En adviseert ook met ACM in gesprek te gaan.



Case Study Analysis

This appendix presents the full gate-by-gate analysis for the three case studies examined in Chapter 8: Case A (synthetic inertia at Utrecht Lage Weide), Case B (N-1 curative congestion management at Utrecht Lage Weide), and Case C (multi-service combining both). Each case is assessed through the six gates of the System Service Governance Framework, from service definition at Gate 0 through to the legal feasibility check.

Readers who want the overall findings without the full analytical detail should go directly to the cross-case comparison table at the end of this appendix, which summarises the gate outcomes, accumulated weights, and final governance recommendations for all three cases side by side. The detailed gate analyses are reference material for readers who wish to examine the reasoning behind a specific gate outcome or verify a specific scoring decision.

Chapter 6 predicted a hierarchy for synthetic inertia, driven by irreducible information asymmetry at T4 and T6, and by the absence of standardisation. The SSGF produces a different recommendation: hybrid bilateral. The difference arises at Gate 4. Because the synthetic inertia headroom constraint is mild and compatible with simultaneous market participation, the non-trading condition under hierarchy forfeits identifiable and substantial stacking revenues that a private operator at the same location currently captures. This cost difference is sufficiently large to overcome the raised threshold from Gates 2 and 3.

The SSGF does not contradict Chapter 6; it refines the prediction by introducing a full cost comparison that the TCE transaction analysis alone cannot provide.

Case A: Synthetic Inertia at Utrecht Lage Weide 150 kV

Gate 0: Service Definition

- **Service**
 - Synthetic inertia provision at the Utrecht Lage Weide 150 kV node (ULW150), delivered by a BESS with grid-forming capability.
- **Why this service is needed**
 - Dutch system inertia has declined from a mean of 87 GWs in 2020 to 61 GWs in 2024 and is projected to fall below the ENTSO-E recommended minimum of $H_{\text{syn}} > 2$ seconds, the threshold above which RoCoF remains below 1 Hz/s in the majority of plausible system split events [97], for 70% of the time by 2030 [7].
 - The Eneco CHP fleet at Utrecht — Lage Weide 6 (248 MW), Merwedekanaal 11 (103 MW), and Merwedekanaal 12 (225 MW) — has a combined electrical capacity of approximately 576 MW [98]. Based on a typical inertia constant of $H = 5.5$ seconds for combined cycle gas

turbine units [59], and applying $KE = H \cdot S$ as established in Section 4.3, the fleet currently contributes an estimated 3,168 MWs of synchronous inertia to the Utrecht sub-grid. This is the author's own estimate based on publicly available capacity figures and typical H values; the actual inertia constants of these specific units are not publicly available.

- A TenneT–Eneco contract signed in July 2025 defers planned closure from 2028 to the end of 2029; from 2030, all three units close and their inertia contribution is permanently lost [9].
 - No synchronous condenser or equivalent replacement is planned for the Utrecht sub-grid in the 2030–2033 window — unlike Nieuwdorp (Zeeland), where TenneT has already planned one for 2031–2034 [89].
 - TenneT identifies grid-forming technology as a necessary dynamic measure to supplement fixed inertia provision beyond 2030 [7]; the Moerdijk pilot (RWE, June 2025) is the first step toward developing standards for this in the Netherlands [92].
- **Spatial scope**
 - Lage Weide 6 connects directly at ULW150, the most critically loaded node in the FGU network [99].
 - Merwedekanaal 11 and 12 connect at the adjacent Utrecht Merwedekanaal station, electrically linked to ULW150 within the same meshed sub-grid [89].
 - The FGU region hosts substantial inverter-based wind capacity in Flevoland, which contributes zero synchronous inertia — meaning the local inertia deficit is most acute during periods of high renewable generation [100].
 - No planned inertia replacement exists for this sub-grid in the 2030–2033 window [89].
 - **Time profile**
 - Service need opens from 2030 when the Eneco fleet closes [9].
 - Frequency fluctuations are stochastic — not forecastable or schedulable.
 - **Operational constraints**
 - The asset must operate continuously in grid-forming mode — synthetic inertia is always-on and cannot be activated on demand [7].
 - The asset must maintain sufficient bidirectional headroom at its operating point to ensure consistent inertia provision [46].
 - The binding constraint is continuous availability, not SoC direction; SoC path dependency does not create a structural conflict with service stacking in this configuration.
 - **Number of services and technical compatibility**
 - Single service — synthetic inertia only. Multi-service flag is not raised.
 - The mild headroom constraint is compatible with simultaneous participation in FCR and wholesale energy markets.
 - **Regulatory status**
 - While ENTSO-E Project Inertia establishes the system-level adequacy metric, no asset-level product specification for procurement purposes exists in the Dutch Grid Code or any applicable EU network code: there is no definition of what a single provider must deliver in terms of virtual inertia constant, droop settings, response characteristics, or asset-level compliance testing protocol [7, 92]. This absence of standardisation is the central regulatory fact of Case A and recurs at every subsequent gate.

Gate 0 outcome All nine criteria are satisfied. Proceed to Gate 1.

Gate 1: Market Viability

- **Q1 — Location boundedness**

- Synthetic inertia has a system-wide effect in principle — a grid-forming BESS anywhere in the CE synchronous area contributes to the same inertia pool [7].
- However, local RoCoF following a frequency disturbance depends on electrical proximity to inertia sources [97].
- The Utrecht sub-grid loses 576 MW of synchronous generation from two specific nodes simultaneously; a localised deficit, not a diffuse system-wide reduction [98].
- **Answer:** partially location-bound → liquidity check applies to the Utrecht 150 kV sub-grid specifically. The degree of location-boundedness carries forward to Gate 4.
- **Q2 — Standardisation and price signals**
 - While ENTSO-E Project Inertia establishes the system-level adequacy metric ($H_{\text{syn}} > 2$ seconds) [97], no asset-level product specification for procurement purposes exists in the Dutch Grid Code, the ENTSO-E Requirements for Generators, or any applicable EU network code [7].
 - The Moerdijk pilot confirms that such asset-level standards are under development, not yet established [92].
 - Without a product definition, price signals cannot communicate the value of the service and market parties cannot submit bids for a service that has not been specified.
- **Answer:** NO → market ruled out. Proceed to Gate 2.

Gate 1 outcome Market governance is not viable. Proceed to Gate 2.

Gate 2: Criticality

Gate 2 produces accumulated weights only — no governance output, no bypass.

- **Q1 — Severity and irreversibility**
 - Synchronous generators contribute rotational inertia as an inherent physical property of being online, as established in Section 4.1. The Eneco CHP fleet currently provides approximately 3,168 MW of inertia to the Utrecht sub-grid simply by operating; when these units close from 2030, that contribution is permanently lost.
 - The governance concern is prospective: as the Dutch system approaches the ENTSO-E minimum of $H_{\text{syn}} > 2$ seconds for 70% of the time by 2030 [7], losing 3,168 MWs from a single sub-grid without replacement directly worsens a documented national shortfall [59].
 - If RoCoF approaches or exceeds 1 Hz/s, blackout risk from system splitting increases significantly; at 2 Hz/s generation units risk inadvertent disconnection and cascade events [97, 57]. RoCoF events unfold in milliseconds; not correctable in real time as established in section 4.1.
 - While the 2030 timeframe allows for alternatives to emerge, such as other GFM-BESS projects in the region, the absence of a governance framework means there is no mechanism to ensure this happens.
- **Answer:** rapid but correctable → + weight towards hierarchy.
- **Q2 — Technical interdependency**
 - The grid-forming BESS provides synthetic inertia through its own internal control dynamics and does not depend on other grid assets for correct operation.
 - VSM parameterisation requires coordination with TenneT's system model, but this is an operational configuration requirement rather than a functional dependency on other assets [46].
- **Answer:** no interdependency → no additional weight.

Gate 2 summary

Table F.1: Gate 2 assessment — Case A, synthetic inertia

Question	Finding	Weight
Q1 — Severity and irreversibility	Rapid but correctable — 2030 time-frame allows alternatives to emerge, but no mechanism ensures this without a governance framework	++ hierarchy
Q2 — Technical interdependency	No functional dependency on other grid assets	no additional weight

Accumulated weight from Gate 2: 1. Proceed to Gate 3.

Gate 3: Contractability

Input from Gate 2: accumulated weight 1 → low range; standard contractability requirements apply.

- **Q1 — Verification**

- TenneT can verify VSM software parameters ex ante by directly inspecting inverter settings before operation begins.
- After a frequency fluctuation, TenneT can observe that an inertial response occurred somewhere in the sub-grid, but cannot attribute that response to a specific asset in real time.
- No standardised measurement protocols or compliance testing procedures currently exist in the Dutch Grid Code for this service [46].
- Partial ex ante verification does not constitute adequate contractual assurance for a continuous availability obligation where activation is instantaneous and system-wide attribution is unavailable.

- **Answer:** NO → + weight towards hierarchy.

- **Q2 — Credible commitment**

- VSM parameterisation is a software setting with low switching cost: the operator can modify parameters without material cost, effort, or detection by TenneT.
- The grid connection serves multiple commercial purposes — energy arbitrage, FCR, and congestion management — and is not dedicated to inertia provision.
- The operator retains strong outside options and faces limited lock-in; the asset-specific investment required to constitute a credible commitment to continuous availability does not exist in this configuration.

- **Answer:** NO → + weight towards hierarchy.

Gate 3 summary

Table F.2: Gate 3 assessment — Case A, synthetic inertia

Question	Finding	Weight
Q1 — Verification	Ex ante parameter inspection possible; ex post attribution not possible in real time	+ hierarchy
Q2 — Credible commitment	GFM hardware mandatory across new installations; VSM is a software setting; grid connection multipurpose	+ hierarchy

Combined accumulated weight from Gates 2 and 3: 3 → raised threshold applies at Gate 4. Proceed to Gate 4.

Gate 4: Efficiency

Input from Gates 2 and 3: accumulated weight 3 → raised threshold applies. Hierarchy requires less of a cost advantage to be selected.

• Step 1 — Availability type

- Synthetic inertia requires the asset to be permanently online in grid-forming mode — it is not event-triggered.
- The asset must maintain sufficient bidirectional headroom at its operating point, but this constraint is mild relative to directional services.
- The availability type is continuous with headroom, implying a higher $C_{\text{foregone revenue}}$ under hierarchy, moderated by stacking compatibility with FCR and wholesale markets.

• Step 2 — Number of services

- Case A is a single-service case. The single-service cost formula applies.

• Step 3 — Cost assessment

- $C_{\text{production}}$
 - * The physical BESS asset, grid-forming inverter, and grid connection must exist regardless of governance form.
 - * No decisive advantage for either form.
 - * $C_{\text{production}}^{(h)} \approx C_{\text{production}}^{(hy)}$
- $C_{\text{foregone revenue}}$
 - * The Eneco CHP fleet currently operating at this location provides congestion management services for TenneT and Stedin, and feeds electricity directly into the regional grid at peak times [9]. A BESS connected at the same location would, based on its technical eligibility and grid connection, be able to participate in the same congestion management services, and additionally in FCR, AFRR, and wholesale markets that the CHP fleet's technical characteristics preclude.
 - * A BESS connected at the same location is eligible for the same revenue streams.
 - * Under hierarchy, Article 3.33(2) prohibits TenneT from using an owned asset to buy or sell electricity — all stacking revenue is foregone.
 - * Under hybrid, a private operator retains full access to these revenues, subject only to the mild headroom obligation.
 - * $C_{\text{foregone revenue}}^{(h)} \gg C_{\text{foregone revenue}}^{(hy)}$ — significant advantage to hybrid.
- $C_{\text{transaction}}$ — *hierarchy*
 - * TenneT would need to develop internal operational competence in grid-forming BESS technology — a capability outside its current remit.
 - * ACM approval is required before ownership is permitted under any available legal route.
 - * $C_{\text{transaction}}^{(h)}$ is elevated.
- $C_{\text{transaction}}$ — *hybrid*
 - * No contract template, regulatory basis, or enforcement precedent for this service currently exists.
 - * The Moerdijk pilot is developing the technical standards on which contractual monitoring would depend [92].
 - * The Moerdijk pilot launched in June 2025 [92]. If standards reach sufficient maturity approximately two years after pilot completion — by mid-2027 — this leaves approximately 2.5 years before the service gap opens in 2030 when the Eneco fleet closes [9]. This timeline is the author's own estimate based on these two cited dates.

* $C_{\text{transaction}}^{(hy)}$ is currently elevated but on a credible path to reduction before 2030.

Step 4 — Cost comparison

Table F.3: Gate 4 cost comparison — Case A, synthetic inertia

Cost component	Hierarchy	Hybrid	Advantage
$C_{\text{production}}$	Equivalent	Equivalent	Neutral
$C_{\text{foregone revenue}}$	High — non-trading condition forfeits FCR, aFRR, wholesale, and congestion management revenues	Moderate — mild headroom obligation compatible with stacking	Hybrid
$C_{\text{transaction}}$	Elevated — technology novelty, ACM approval, regulatory complexity	Currently elevated; reducible by 2030 via Moerdijk	Hybrid (conditional)
C_{total}	High	Lower — conditional on standard readiness by 2027	Hybrid

- Hierarchy does not minimise C_{total} .
- Even under the raised threshold, the non-trading condition under hierarchy forfeits identifiable and substantial market revenues that a private operator at the same location currently captures.
- This cost difference is sufficiently large to overcome the raised threshold.
- **Answer:** NO — hybrid minimises C_{total} . Proceed to Gate 5.

Gate 5: Hybrid Form

- **Q1 — Activation frequency**
 - Synthetic inertia is an always-on capability — the asset operates permanently in grid-forming mode.
 - The actual inertial response is triggered by frequency disturbance events, which occur at most tens of times per year.
 - The service is best characterised as occasional activation of a continuously available asset — activation is not frequent in the sense that generates the mutual dependence and lock-in that bilateral governance manages through the relationship itself [19].
- **Answer:** occasional → proceed to Q2.
- **Q2 — Third-party safeguarding**
 - No independent body currently holds the technical competence to verify grid-forming BESS synthetic inertia compliance — the measurement standards that would enable such verification do not yet exist.
 - Under the Energy Law 2026, ACM has no formal legal authority to act as an independent third-party safeguard in bilateral contracts for this service, as established in Section 8.8.
- **Answer:** NO → hybrid bilateral.

Gate 5 summary

Table F.4: Gate 5 assessment — Case A, synthetic inertia

Question	Finding	Outcome
Q1 — Activation frequency	Occasional activation of a continuously available asset	Proceed to Q2
Q2 — Third-party safeguarding	No independent safeguarding capacity or legal mandate under Energy Law 2026	Hybrid bilateral

Hybrid bilateral is the TCE output. Proceed to legal feasibility check.

Legal Feasibility Check

- Synthetic inertia qualifies as a non-frequency ancillary service under Article 1.1 of the Energy Law 2026, which defines that category to include inertia for local system stability. Article 3.28 governs procurement [18].
- Under Article 3.28(1), TenneT must procure non-frequency ancillary services through transparent, non-discriminatory, and market-based procedures. This route is not available: no product definition exists in the Dutch Grid Code or any applicable EU network code, and a transparent competitive tender cannot be conducted for a service that has not been specified. The standard tender route is ruled out by the same standardisation gap that ruled out market governance at Gate 1 [18].
- Under Article 3.28(3), ACM may exempt TenneT from the market procurement obligation if it judges that market-based procurement is not economically efficient. The absence of a standardised product definition is a structural barrier, not merely a practical one: market-based procurement is economically inefficient where no basis for competitive comparison exists, and TenneT can demonstrate this to ACM using the same evidence base that supports the Gate 1 finding [18].
- If the exemption is granted, TenneT may enter a long-term bilateral contract with a private BESS operator without prior competitive tendering, consistent with the hybrid bilateral recommendation from Gate 5. Observation O4, established in chapter 7, confirms that this procurement-level route is legally available and does not require TenneT to own the asset [18].
- No governance gap exists. The hybrid bilateral governance form recommended by the TCE gate sequence is legally available through Article 3.28(3) exemption route, subject to ACM approval [76].
- Two practical conditions must be noted. First, the Article 3.28(3) demonstration requires a defined service specification: TenneT must be able to characterise what it is procuring, even if a full Grid Code product definition does not yet exist. The Moerdijk pilot output is therefore a prerequisite for the ACM submission, not merely a parallel workstream. Second, the 2030 service gap leaves approximately 2.5 years between anticipated standard maturity and the operational deadline — a timeline that is achievable but requires proactive ACM engagement beginning no later than 2027.

Governance recommendation: hybrid bilateral via Article 3.28(3) exemption.

Case Study: N-1 Curative

Gate 0: Service Need and Operational Logic

Case B — BESS for N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 0 checks whether the TSO need is clear enough to even evaluate governance.

- **Service:**
 - N-1 curative congestion management at the Utrecht Lage Weide 150 kV node, delivered by a BESS that provides immediate ramp-up or ramp-down response after a contingency

occurs on the Utrecht Lage Weide–Soest 150 kV connection.

- **Why this service is needed:**

- The Utrecht Lage Weide–Soest 150 kV connection is the single most critically loaded asset in the FGU network [87]
- The network is currently operating at full capacity — no new connections are possible at this node [87]
- N-0 operation is not permitted on this asset as it is part of a meshed network [87]
- TenneT currently manages congestion through preventive measures, but these are insufficient to resolve the bottleneck [87]
- The structural solution, Utrecht Noord, is not expected until 2033–2035; Utrecht Zuid may provide limited relief from 2033 [9]
- The curative product bridges the period until structural network expansion is complete [author’s analytical conclusion based on TenneT congestion report].

- **Spatial scope:**

- The service is strictly location-bound; the BESS must be connected at or electrically adjacent to ULW150 to directly influence power flows on the Utrecht Lage Weide–Soest connection
- An asset at the wrong node provides little or no relief for this specific bottleneck — as established in Section 4.1
- Unlike inertia, congestion management relief is driven by grid physics and cannot be provided from a distant node; as established in Section 4.1

- **Time profile:**

- Service need is immediate; the congestion exists now and persists until 2033–2035 [87]
- Activation is event-triggered; the BESS responds after a contingency occurs on the Utrecht Lage Weide–Soest connection
- TenneT performs grid security analysis in day-ahead and intraday timeframes; activation instructions are issued in real time following a contingency [internal TenneT document, Systeemcode Art. 9.11]
- Activation pattern is predictable and seasonal; overloading occurs primarily March–September between 09:00–16:00 [87]
- In accordance with Article 9.11 of the Systeemcode Elektriciteit, TenneT performs grid security analysis in the day-ahead and intraday timeframes and can instruct the operator to reserve the BESS for curative response the day before the congestion window opens, providing advance notice that allows the operator to plan market participation around the reservation obligation.

- **Operational state:**

- The BESS does not require continuous 24/7 availability.
- Availability is required during the hours when the Utrecht Lage Weide–Soest connection is at risk of overloading, primarily March–September between 09:00–16:00 [87]
- Based on TenneT’s power flow analysis for 2033, the N-1 load exceeds the 100% limit approximately 65% of operating hours in the congestion window [87]
- For this analysis, it is assumed that during all hours in which the limit is exceeded, the BESS must be fully reserved for curative response; no market participation is possible during these hours
- During the remaining approximately 35% of hours, the operator retains full market freedom
- Activation is event-triggered; the BESS only responds if an actual N-1 contingency occurs while the line is near or above its limit

- During constrained hours, activation is absorption-led — driven by excess renewable injection during solar peak hours [87]. The BESS must therefore maintain sufficient SoC headroom to absorb excess power when called upon, as established in Section 4.2.
- This creates a directional SoC requirement: the asset must enter the congestion window with low-to-mid SoC during constrained periods, as established in Section 4.2
- This SoC constraint may conflict with overnight energy market participation, as established in Section 4.2
- Key implication for Gate 4: $C_{\text{foregone_revenue}}$ under hybrid is significant but partial, approximately 65% of congestion window hours are fully reserved, with market freedom retained for the remaining 35%
- **Minimum technical requirements:**
 - Response time: immediate ramp-up or ramp-down following contingency.
 - Power rating: based on TenneT's 2033 N-1 power flow analysis for the Utrecht Lage Weide–Soest connection, the N-1 load exceeds the 100% limit (approximately 210 MW) by up to approximately 270 MW in peak hours, with a maximum technical limit of approximately 315 MW [87]. The required curative response capacity is therefore in the range of 100–270 MW, depending on the specific contingency scenario; the exact sizing requires detailed grid studies beyond the scope of this analysis.
 - Grid connection: direct connection at or adjacent to ULW150 for maximum effectiveness on the binding constraint
 - Standard grid-following inverter is sufficient; grid-forming capability is not required for this service, as established in Section 4.2
- **Number of services:**
 - Single; N-1 curative congestion management only
- **Regulatory status:**
 - Standard redispatch and CSC products exist under Netcode Bijlage 11 and 12
 - The N-1 curative product is a new product currently being developed by TenneT, no formal product definition exists yet [internal TenneT document]

Gate 0 outcome: Service need is sufficiently defined. Proceed to Gate 1.

Gate 1: Market Viability

Case B — BESS for N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 1 checks whether market governance can reliably deliver this service.

- **Q1 — Location boundedness:**
 - Is this service location-bound?
 - Congestion management is strictly location-bound, as established in Section 4.1, relief from a binding constraint depends on grid physics and can only be provided from assets connected at or near the constrained node
 - The Utrecht Lage Weide–Soest connection is the single most binding constraint in the FGU network; an asset at any other node provides little or no relief [87]
 - This is a stronger location-boundedness than Case A; inertia has a partial system-wide dimension, congestion management has none
 - Answer: YES, strictly location-bound → liquidity check applies to ULW150 specifically. Strong location-boundedness carried forward to Gate 4.
- **Q2 — Standardisation and price signals:**
 - Is the service sufficiently standardised for price signals to communicate its value?

- Standard redispatch and CSC products exist under Netcode Bijlage 11 and 12; these are established product definitions [75]
- However, the N-1 curative product is a new product currently being developed by TenneT; no formal product definition exists yet [**internal tennet document**]
- The value of curative response cannot be communicated through existing price signals because the product specification, response time, activation conditions, and performance metrics have not yet been defined
- Answer: NO, market ruled out. Proceed to Gate 2.

Gate 1 outcome: Market governance is not viable. Proceed to Gate 2.

Gate 2: Criticality (revised)

Case B — BESS for N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 2 assesses the severity of the consequences if this service fails. Produces weights only; no bypass.

• Q1 — Severity and irreversibility:

- What are the systemic consequences of non-delivery, and how quickly do they become irreversible?
- The N-1 curative approach deliberately allows the Utrecht Lage Weide–Soest connection to operate beyond the N-1 secure state, relying on the curative BESS to resolve any contingency that occurs
- If the BESS fails to respond after a contingency, the line is already operating above its secure limit without a safety net; this is fundamentally different from the current preventive approach, where TenneT maintains N-1 security at all times
- Non-delivery therefore does not mean falling back to the current situation, it means the line is exposed to overloading without any remedial action available
- Overloading of the Utrecht Lage Weide–Soest connection, the most critically loaded asset in the FGU network, risks cascade tripping of connected equipment [87]
- The response must occur within seconds of the contingency; there is no time for TenneT to arrange alternative measures in real time
- Answer: immediate and irreversible → ++ weight towards hierarchy

• Q2 — Technical interdependency:

- Is the service technically dependent on other grid assets for correct operation?
- The BESS provides congestion relief through its own charge and discharge capability; it does not depend on other grid assets for correct operation
- Answer: NO, no additional weight towards hierarchy

Gate 2 summary:

Question	Finding	Weight
Q1 — Severity and irreversibility	Immediate and irreversible — line already beyond N-1 secure state when curative response is needed	++ hierarchy
Q2 — Technical interdependency	No dependency on other grid assets	no additional weight

Accumulated weight from Gate 2: 2

Gate 2 outcome: LOW-MODERATE criticality weight. Standard contractability requirements apply in Gate 3. Proceed to Gate 3.

Gate 3: Contractability

Case B — BESS for N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 3 checks whether a contract can adequately secure this service given its criticality. Input from Gate 2: accumulated weight 2 → standard contractability requirements apply.

- **Q1 — Verification:**

- Can service delivery be adequately verified in real time?
- Congestion management performance is directly observable in real time, TenneT can measure power flows on the Utrecht Lage Weide–Soest connection continuously [87]
- If the BESS responds curatively after a contingency, the resulting change in power flow is immediately visible in TenneT's grid monitoring systems
- SoC availability can be verified through telemetry before the congestion window opens
- Answer: YES → no additional weight

- **Q2 — Credible commitments:**

- The credible commitment question asks whether the operator has made sufficient asset-specific investments to make walking away from the contract costly — and therefore whether TenneT can trust the operator to remain committed to service availability
- The battery cells, racks, and grid-following inverter are all redeployable for other services — FCR, aFRR, day-ahead, intraday, and standard redispatch — without high cost or effort
- The grid connection at ULW150 provides access to multiple revenue streams independent of the N-1 curative contract — FCR, aFRR, wholesale markets, and standard congestion management are all accessible from this location
- If TenneT does not offer attractive contract terms, or if the contract is terminated, the operator can simply redirect the BESS to other markets without material loss
- No component of the investment is dedicated exclusively to the N-1 curative service — the operator faces minimal lock-in and retains strong outside options throughout the contract lifetime
- The absence of asset-specific investment means there is no natural mechanism that commits the operator to prioritising the N-1 curative obligation over more attractive market opportunities
- Answer: NO → → → ++ + weight towards hierarchy

Gate 3 summary:

Question	Finding	Weight
Q1 — Verification	Power flows directly measurable in real time — full ex post verification possible	no additional weight
Q2 — Credible commitments	Grid connection is asset-specific, but battery and inverter are redeployable	+ hierarchy

Accumulated weight from Gates 2 and 3: 3 → HIGH threshold applies in Gate 4

Gate 3 outcome: Contractability is partially constrained. Proceed to Gate 4.

Gate 4: Efficiency

Case B — BESS for N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 4 assesses which governance form is the most cost-efficient. Input from Gates 2 and 3: accumulated weight 3 → HIGH threshold applies. Hierarchy requires less cost advantage to be selected.

- **Step 1 — Availability type:**

- Does this service require continuous availability with a minimum SoC headroom obligation?
- The service is event-triggered; the BESS only responds when a contingency occurs during a constrained hour
- However, during constrained hours, the BESS must be fully reserved, as established in Gate 0, approximately 65% of congestion window hours require full reservation
- Outside constrained hours, the operator retains full market freedom
- Answer: event-triggered with partial reservation → lower $C_{\text{foregone_revenue}}$ than Case A, but not negligible
- **Step 2 — Select cost inputs:**
 - Were multiple services flagged at Gate 0?
 - Case B is a single-service case; N-1 curative congestion management only
 - Answer: single-service formula applies
- **Step 3 — Establish costs:**
 - $C_{\text{production}}$:
 - * Physical BESS asset and grid connection must exist regardless of governance form
 - * No decisive advantage for either form
 - * $C_{\text{production}}(\text{h}) \approx C_{\text{production}}(\text{hy})$
 - $C_{\text{foregone_revenue}}$:
 - * The Eneco CHP fleet at this location currently participates in FCR, aFRR, day-ahead and intraday wholesale markets, and congestion management services
 - * A BESS at the same location is eligible for the same markets
 - * Under hierarchy: TenneT is subject to the non-trading condition under Art. 3.33(2) — all potential market revenue is foregone regardless of whether the line is constrained or not
 - * Under hybrid: the operator forfeits market participation only during constrained hours (~65% of congestion window hours). During the remaining ~35% of congestion window hours, and all hours outside the congestion window, full market participation is retained
 - * The congestion window is seasonal — March to September, 09:00–16:00 — meaning the majority of annual hours remain available for market participation under hybrid
 - * $C_{\text{foregone_revenue}}(\text{h}) \gg C_{\text{foregone_revenue}}(\text{hy})$ — significant advantage to hybrid
 - $C_{\text{transaction}}$ (**hierarchy**):
 - * TenneT would need to develop internal operational competence in BESS dispatch and SoC management
 - * Ownership of battery assets raises regulatory complications under Energiewet unbundling rules; ACM approval required
 - * $C_{\text{transaction}}(\text{h})$ is elevated
 - $C_{\text{transaction}}$ (**hybrid**):
 - * Verification costs are low; power flows are directly measurable in real time, as established in Gate 3
 - * Standard redispatch and CSC contract templates already exist under Netcode Bijlage 11 and 12 — the N-1 curative product requires adaptation but builds on existing frameworks
 - * The main transaction cost is the development of the curative product specification, currently underway at TenneT [internal TenneT document]
 - * Once the product is defined, contracting is straightforward compared to Case A

- * $C_{\text{transaction}}(\text{hy})$ is moderate and on a clear path to reduction once the product specification is complete

Step 4 — Cost comparison:

Cost component	Hierarchy	Hybrid	Advantage
$C_{\text{production}}$	High	High	Neutral
$C_{\text{foregone_revenue}}$	High — non-trading condition forfeits all market revenue	Moderate — only 65% of congestion window hours reserved	Hybrid
$C_{\text{transaction}}$	Elevated — BESS ownership, ACM approval	Moderate — builds on existing redispatch framework	Hybrid
C_{total}	High	Lower	Hybrid

Does hierarchy minimise C_{total} ?

NO; hybrid minimises C_{total} . Under the non-trading condition in the hierarchy, the operator forfeits all market revenues, whereas under the hybrid condition, the operator retains substantial market freedom. Unlike Case A, where $C_{\text{transaction}}$ under hybrid was severely elevated due to absent standards, here the existing redispatch framework provides a foundation, making hybrid transaction costs more manageable.

Even under the HIGH threshold from Gates 2 and 3, the hybrid advantage is clear.

Answer: NO → proceed to Gate 5

Gate 4 outcome: Hybrid governance minimises C_{total} . Proceed to Gate 5.

Gate 5: Hybrid Form

Case B — BESS for N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 5 checks which hybrid form provides sufficient safeguards.

• Q1 — Activation frequency:

- Is activation of the service occasional or frequent?
- The N-1 curative product is activated after a contingency occurs on the Utrecht Lage Weide–Soest connection
- Based on TenneT's heatmap analysis, the line exceeds its limit hundreds of hours per year — primarily March–September between 09:00–16:00 [87]
- Within those constrained hours, actual contingencies are less frequent — but the asset must be reserved and ready during all constrained hours
- The activation pattern is predictable, seasonal, and recurrent, not a rare, exceptional event
- Answer: frequent → Hybrid Bilateral. Proceed to legal feasibility check.

Gate 5 outcome: Hybrid Bilateral is the recommended governance form. Proceed to legal feasibility check.

Legal Feasibility Check

Case B — BESS for N-1 Curative Congestion Management at Utrecht Lage Weide

Checks whether the recommended governance form is legally permitted under the Energiewet and EU unbundling rules.

Input from Gate 5: Hybrid Bilateral

• Hybrid Bilateral Route

- Can TenneT demonstrate that market-based procurement is economically inefficient?
- Gate 1 confirmed that no standardised market exists for the N-1 curative product, the product definition does not yet exist
- Gate 4 confirmed that hybrid minimises C_{total} — market governance is not viable
- However, the question here is specifically whether TenneT can demonstrate economic inefficiency of market procurement to ACM's satisfaction
- The existing redispatch and CSC framework under Netcode Bijlage 11 and 12 provides a legal basis for bilateral contracting of congestion management services
- TenneT already contracts congestion management services bilaterally — the Eneco CHP contract is a direct precedent [9]
- The N-1 curative product is a more specific version of this — bilateral contracting is already the established practice for congestion management in the Netherlands
- Answer: YES → governance recommendation → Art. 3.28 lid 3 or Art. 3.29 lid 2, subject to ACM approval

Case study C: Multi-service

Gate 0: Service Need and Operational Logic

Case C — Multi-Service BESS: Synthetic Inertia and N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 0 checks whether the TSO need is clear enough to even evaluate governance.

- **Service:**

- A single BESS asset at the Utrecht Lage Weide 150 kV node providing two services simultaneously:
 - * Primary service 1: Synthetic inertia via grid-forming capability — as defined in Case A
 - * Primary service 2: N-1 curative congestion management — as defined in Case B

- **Why this multi-service configuration is relevant:**

- Cases A and B establish independent governance recommendations for the same asset at the same location
- In practice, a single BESS at ULW150 is technically capable of providing both services simultaneously — deploying two separate assets for the same location would be economically inefficient
- The multi-service case asks whether combining both services changes the governance recommendation — and whether the SoC constraints of the two services are compatible

- **Spatial scope:**

- Identical to Cases A and B — ULW150 Utrecht Lage Weide and adjacent Utrecht 150 kV sub-grid
- Both services require connection at or near ULW150 — the location requirement is reinforcing, not conflicting

- **Time profile:**

- Synthetic inertia: always-on, continuous availability required
- N-1 curative congestion management: event-triggered, seasonal activation March–September 09:00–16:00
- The two time profiles partially overlap — during the congestion window the asset must simultaneously maintain grid-forming mode and SoC headroom for curative response

- **Operational state and SoC compatibility — the critical Gate 0 question:**

- This is where Case C differs fundamentally from Cases A and B individually.
- Case A requires: Continuous grid-forming mode, mild mid-SoC band for bidirectional headroom
- Case B requires: Low-to-mid SoC entering the congestion window for absorption-led curative response, full reservation during constrained hours
- Are these compatible?
 - * Outside the congestion window: YES — the mild SoC constraint of inertia is compatible with free market participation
 - * During the congestion window: PARTIAL CONFLICT
 - Inertia requires mid-SoC for bidirectional response
 - Congestion management requires low-to-mid SoC for absorption headroom
 - Both require the asset to be available — no fundamental conflict on availability
 - The directional SoC bias of congestion management is more restrictive than the mild constraint of inertia — but both point in the same direction during solar peak hours when absorption is needed
 - * During a curative activation event: POTENTIAL CONFLICT
 - Curative response requires immediate absorption — BESS must discharge or absorb rapidly
 - Inertia response must remain active during and after the contingency
 - A sufficiently large BESS can handle both simultaneously if sized correctly
- Assessment: The SoC constraints are partially compatible — both services point toward low-to-mid SoC during the congestion window, which is consistent. The main risk is sizing — the asset must be large enough to provide both services simultaneously without one undermining the other.

- **Minimum technical requirements:**

- Grid-forming inverter — required for synthetic inertia, compatible with congestion management
- Standard grid-following inverter is insufficient — grid-forming is the binding requirement
- Power rating must accommodate both services simultaneously — sizing is a key design parameter
- Direct connection at or adjacent to ULW150

- **Number of services:**

- Two — synthetic inertia and N-1 curative congestion management
- Multi-service formula applies in Gate 4
- Technical compatibility: partially compatible with careful sizing — as established above

- **Primary service designation:**

- Both services are co-primary — neither subordinates the other
- The SoC path dependency analysis confirms partial compatibility — proceed with multi-service analysis

Gate 0 outcome: Service need is sufficiently defined. SoC constraints are partially compatible. Proceed to Gate 1.

Gate 1: Market Viability

Case C — Multi-Service BESS: Synthetic Inertia and N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 1 checks whether market governance can reliably deliver this service.

- **Q1 — Location boundedness:**

- Is this service location-bound?
- Both services are location-bound at ULW150 — as established in Cases A and B
- Synthetic inertia is partially location-bound — local RoCoF dimension makes ULW150 the preferred connection point
- N-1 curative congestion management is strictly location-bound — grid physics require connection at or near ULW150
- The combination is therefore at least as location-bound as the more restrictive of the two services — strictly location-bound
- Answer: YES — strictly location-bound → liquidity check applies to ULW150 specifically. Strong location-boundedness carried forward to Gate 4.

- **Q2 — Standardisation and price signals:**

- Is the service sufficiently standardised for price signals to communicate its value?
- Neither service has a complete product definition:
 - * Synthetic inertia from GFM-BESS has no product definition in the Dutch Grid Code or any applicable EU network code — as established in Case A
 - * The N-1 curative product is currently being developed by TenneT — no formal product definition exists yet — as established in Case B
- A multi-service product combining both is even further from standardisation than either individually
- No price signal can communicate the value of a product that does not yet exist
- Answer: NO — market ruled out. Proceed to Gate 2.

Gate 1 outcome: Market governance is not viable. Proceed to Gate 2.

Gate 2: Criticality

Case C — Multi-Service BESS: Synthetic Inertia and N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 2 assesses the severity of the consequences if this service fails. Produces weights only — no bypass.

- **Q1 — Severity and irreversibility:**

- What are the systemic consequences of non-delivery, and how quickly do they become irreversible?
- Non-delivery of the multi-service asset means both services fail simultaneously — the inertia gap and the curative congestion management gap open at the same time
- For synthetic inertia: rapid but correctable if alternatives emerge — as established in Case A (+ weight)
- For N-1 curative congestion management: immediate and irreversible in the moment of a contingency — the line is already beyond N-1 secure state when the curative response is needed — as established in Case B (++ weight)
- The combination does not reduce severity — it compounds it. The most severe consequence determines the classification

- Answer: immediate and irreversible → ++ weight towards hierarchy
- **Q2 — Technical interdependency:**
 - Is the service technically dependent on other grid assets for correct operation?
 - As established in both Cases A and B, neither service individually depends on other grid assets for correct operation
 - The multi-service combination does not introduce new dependencies on other grid assets
 - The internal SoC compatibility between the two services is an operational constraint — not a dependency on external grid assets
 - Answer: NO → no additional weight towards hierarchy

Gate 2 summary:

Question	Finding	Weight
Q1 — Severity and irreversibility	Immediate and irreversible — N-1 curative consequence dominates	++ hierarchy
Q2 — Technical interdependency	No dependency on other grid assets	no additional weight

Accumulated weight from Gate 2: 2

Gate 2 outcome: MODERATE criticality weight. Standard contractability requirements apply in Gate 3. Proceed to Gate 3.

Gate 3: Contractability

Gate 3 checks whether a contract can adequately secure this service given its criticality.

Input from Gate 2: accumulated weight 2 → standard contractability requirements apply.

- **Q1 — Verification:**
 - For N-1 curative congestion management: power flows are directly measurable in real time — TenneT can observe the curative response immediately after a contingency, as established in Case B
 - For synthetic inertia: TenneT can verify VSM software parameters ex ante through direct inspection of inverter settings, but cannot attribute inertial response to a specific asset in real time, as established in Case A
 - In a multi-service contract, both services must be adequately verifiable — the weakest link determines the classification
 - Synthetic inertia remains non-verifiable in real time regardless of the congestion management component
 - **Answer:** NO — synthetic inertia not verifiable in real time → ++ + weight towards hierarchy
- **Q2 — Credible commitments:**
 - Grid-forming inverter hardware is becoming a regulatory requirement across new BESS installations — it is not an investment specific to this service combination [tennet_internal]
 - VSM parameterisation is a software setting with low switching cost — the operator can modify parameters without material cost, effort, or detection by TenneT
 - The grid connection at ULW150 provides access to multiple revenue streams independent of this contract — FCR, aFRR, wholesale markets, and standard congestion management are all accessible from this location
 - Battery cells and racks are largely redeployable for other services

- The multi-service configuration does not materially increase asset specificity compared to Cases A and B individually — the operator retains strong outside options throughout the contract lifetime
- **Answer:** NO — insufficient asset-specific investment → + weight towards hierarchy

Gate 3 summary

Table F.5: Gate 3 assessment — Case C, multi-service

Question	Finding	Weight
Q1 — Verification	Congestion management verifiable in real time; synthetic inertia not — weakest link applies	++ + hierarchy
Q2 — Credible commitments	Low asset specificity — GFM hardware becoming mandatory, VSM is software, grid connection multipurpose	++ + hierarchy

Accumulated weight from Gates 2 and 3: 4 → raised threshold applies at Gate 4. Proceed to Gate 4.

Gate 4: Efficiency

Case C — Multi-Service BESS: Synthetic Inertia and N-1 Curative Congestion Management at Utrecht Lage Weide

Gate 4 assesses which governance form is the most cost-efficient. Input from Gates 2 and 3: accumulated weight 4 → HIGH threshold applies. Hierarchy requires less cost advantage to be selected.

- **Step 1 — Availability type:**

- Does this service require continuous availability with a minimum SoC headroom obligation?
- Synthetic inertia requires continuous availability in grid-forming mode — always-on
- N-1 curative congestion management requires full reservation during constrained hours — event-triggered with partial reservation
- The combination requires both: continuous grid-forming mode plus directional SoC management during the congestion window
- Answer: continuous with headroom — higher $C_{\text{foregone_revenue}}$ than Case B, but partially offset by market freedom outside the congestion window

- **Step 2 — Select cost inputs:**

- Were multiple services flagged at Gate 0?
- Case C is a multi-service case — synthetic inertia and N-1 curative congestion management
- Answer: multi-service formula applies including $C_{\text{coordination}}$

- **Step 3 — Establish costs:**

- $C_{\text{production}}$:
 - * A single BESS asset serving both services is more efficient than two separate assets
 - * $C_{\text{production}}$ is shared across both services — this is the key efficiency argument for the multi-service configuration
 - * $C_{\text{production}}(h) \approx C_{\text{production}}(hy)$ — but both are lower per service than Cases A and B individually
- $C_{\text{foregone_revenue}}$:

- * Under hierarchy: TenneT subject to non-trading condition under Art. 3.33(2) — all potential market revenue foregone for both services
- * Under hybrid: operator forfeits market participation during constrained hours (~65% of congestion window) and must maintain continuous grid-forming mode
- * The SoC compatibility analysis in Gate 0 established that both services point toward low-to-mid SoC during the congestion window — the constraints are directionally consistent, meaning the foregone revenue from combining services is not substantially greater than Case B alone
- * Outside the congestion window, the operator retains market freedom subject only to the mild SoC headroom constraint of inertia
- * $C_{\text{foregone_revenue}}(\text{h}) \gg C_{\text{foregone_revenue}}(\text{hy})$ — significant advantage to hybrid
- $C_{\text{transaction}}$ (**hierarchy**):
 - * TenneT would need to develop internal operational competence in both GFM-BESS technology and curative dispatch — two novel capabilities
 - * Ownership complications under Energiewet unbundling rules — ACM approval required
 - * Managing two services internally adds coordination complexity
 - * $C_{\text{transaction}}(\text{h})$ is elevated — higher than either case individually
- $C_{\text{transaction}}$ (**hybrid**):
 - * Verification costs: congestion management is straightforward, inertia requires ex ante parameter inspection — combined monitoring infrastructure needed
 - * No contract template exists for the combined service, but the congestion management framework provides a partial foundation
 - * The Moerdijk pilot is developing inertia standards — reducible by 2027
 - * $C_{\text{transaction}}(\text{hy})$ is currently elevated but on a path to reduction
- $C_{\text{coordination}}$:
 - * The multi-service formula includes $C_{\text{coordination}}$ — the cost of coordinating two services under a single contract
 - * SoC compatibility is partial — the operator must actively manage SoC to satisfy both services simultaneously
 - * TenneT must coordinate activation signals for both services — dispatch logic becomes more complex
 - * However SoC constraints are directionally consistent during the congestion window — coordination is manageable
 - * $C_{\text{coordination}}$ is moderate — non-trivial but not prohibitive

Step 4 — Cost comparison:

Does hierarchy minimise C_{total} ?

NO — hybrid minimises C_{total} . The non-trading condition makes hierarchy structurally expensive across both services. The multi-service configuration actually strengthens the case for hybrid — $C_{\text{production}}$ is shared, $C_{\text{foregone_revenue}}$ is not substantially greater than Case B alone, and $C_{\text{coordination}}$ is manageable given the directional SoC compatibility established in Gate 0.

Answer: NO → proceed to Gate 5

Gate 4 outcome: Hybrid governance minimises C_{total} . Proceed to Gate 5.

Cost component	Hierarchy	Hybrid	Advantage
$C_{\text{production}}$	High — shared across services	High — shared across services	Neutral — both benefit from single asset
$C_{\text{foregone_revenue}}$	Very high — non-trading condition forfeits all revenue for both services	Moderate — directionally consistent SoC constraints limit additional foregone revenue	Hybrid
$C_{\text{transaction}}$	Very elevated — two novel services, ACM approval, internal competence for both	Currently elevated, reducible via Moerdijk and existing redispatch framework	Hybrid — conditional
$C_{\text{coordination}}$	N/A — internal coordination under hierarchy	Moderate — SoC management and dispatch coordination required	Hybrid — manageable
C_{total}	Very high	Lower — conditional on standard readiness	Hybrid

Gate 5: Hybrid Form

Case C — Multi-Service BESS: Synthetic Inertia and N-1 Curative Congestion Management at Utrecht Lage Weide

• Q1 — Activation frequency:

- Is activation of the service occasional or frequent?
- Synthetic inertia is an always-on capability — the asset operates permanently in grid-forming mode; the actual inertial response is occasional, occurring at most tens of times per year
- N-1 curative congestion management activates frequently — the line exceeds its limit hundreds of hours per year, primarily March–September between 09:00–16:00 [87]
- The combination is governed by the most frequently activated service — N-1 curative activation is frequent and determines the classification
- **Answer:** frequent → Hybrid Bilateral. Proceed to legal feasibility check.

Gate 5 outcome: Hybrid Bilateral is the recommended governance form. Proceed to legal feasibility check.

Legal Feasibility Check

Case C — Multi-Service BESS

Input from Gate 5: Hybrid Bilateral.

• Hybrid Bilateral Route:

- Can TenneT demonstrate that market-based procurement is economically inefficient?
- Gate 1 confirmed that no standardised market exists for either service — neither product definition exists
- Gate 4 confirmed that hybrid minimises C_{total} across both services
- The congestion management component provides the primary legal foundation — TenneT already contracts congestion management services bilaterally, and the Eneco CHP contract is a direct precedent [9]
- The existing redispatch and CSC framework under Netcode Bijlage 11 and 12 provides a legal basis for bilateral contracting of congestion management services

-
- The synthetic inertia component has no direct precedent — but it is a co-service within a single bilateral contract, not a standalone arrangement
 - The combined contract can be structured primarily under the congestion management legal framework — Art. 3.28 lid 3 or Art. 3.29 lid 2 — with the inertia component as an additional contractual obligation
 - **Answer:** YES → governance recommendation → Art. 3.28 lid 3 or Art. 3.29 lid 2, subject to ACM approval [18]
 - **Key observations relative to Cases A and B:**
 - Case A: Hybrid Bilateral recommended but legally uncertain — no product definition, no precedent, requires Art. 3.28(3) exemption
 - Case B: Hybrid Bilateral recommended and legally straightforward — existing congestion management framework applies directly
 - Case C: Hybrid Bilateral recommended — the congestion management component provides the legal foundation, with inertia as an additional contractual obligation. Legally more feasible than Case A alone but requires careful contract design to address the inertia verification problem identified in Gate 3

Governance recommendation: Hybrid Bilateral via Art. 3.28 lid 3 or Art. 3.29 lid 2, subject to ACM approval.

Cross-case comparison

Table F.6: Cross-case comparison of governance framework outcomes

	Case A Synthetic inertia	Case B N-1 curative congestion management	Case C Multi-service
Gate 1	Missing market — no product definition	Missing market — product under development	Missing market — neither service standardised
Gate 2 Q1	+ (rapid but correctable — 2030 timeframe)	++ (immediate and irreversible — line already beyond N-1 secure state)	++ (N-1 curative consequence dominates)
Gate 2 Q2	No interdependency	No interdependency	No interdependency
Gate 2 weight	1	2	2
Gate 3 Q1	+ (ex ante only — no real-time attribution)	No weight (power flows directly measurable)	+ (inertia weakest link)
Gate 3 Q2	+ (low asset specificity — GFM mandatory, VSM software, connection multipurpose)	+ (grid connection specific, battery redeployable)	+ (low asset specificity)
Gates 2+3 weight	3	3	4
Gate 4 availability	Continuous with mild headroom	Event-triggered with partial reservation	Continuous with headroom + partial reservation
Gate 4 formula	Single-service	Single-service	Multi-service
Gate 4 outcome	Hybrid minimises C_{total}	Hybrid minimises C_{total}	Hybrid minimises C_{total}
Gate 5	Occasional → Q2 → no third party → Hybrid Bilateral	Frequent → Hybrid Bilateral	Frequent → Hybrid Bilateral
Legal basis	Art. 3.28(3) — ACM exemption required	Art. 3.28(3) or Art. 3.29(2) — congestion management precedent	Art. 3.28(3) or Art. 3.29(2) — congestion management provides foundation
TRC	Not applicable — hybrid recommended	Not applicable	Not applicable
Final recommendation	Hybrid Bilateral	Hybrid Bilateral	Hybrid Bilateral



Sensitivity Analysis

When Would Hierarchy Be Selected?

The sensitivity analysis asks: under what conditions would the framework produce a hierarchy recommendation instead of hybrid bilateral? Two parameters are varied independently and then jointly.

The two binding constraints identified across all three cases:

- The non-trading condition — Art. 3.33(2) makes hierarchy structurally expensive by prohibiting TenneT from participating in energy markets when owning the asset
- Low asset specificity — the operator retains strong outside options, weakening credible commitments in Gate 3 Q2

Scenario 1 — Congestion hours increase beyond viability threshold What if the percentage of constrained hours increases to the point where the business case for a private operator collapses?

TenneT's 2033 power flow analysis projects that the N-1 load exceeds the 100% limit approximately 65% of congestion window hours [tennet_congestie_fgu_2026]. This leaves approximately 35% of hours during which the operator retains market freedom. The sensitivity question is: what happens as congestion worsens and constrained hours increase?

Effect on Gate 4 as constrained hours increase:

- At 65% constrained hours (baseline): operator retains 35% market freedom — viable business case under hybrid
- At 80% constrained hours: operator retains 20% market freedom — marginal business case
- At 90%+ constrained hours: operator retains less than 10% market freedom — business case collapses

Result:

- As constrained hours approach 90%, $C_{\text{foregone_revenue}}$ under hybrid approaches the same level as under hierarchy — the revenue stacking advantage of hybrid disappears
- No market party would bid at a price TenneT can afford to pay — hybrid governance becomes theoretically preferred but practically unavailable
- TenneT faces a governance gap: the market party alternative does not exist and hierarchy becomes the only viable option — not because it is efficient in TCE terms but because the alternative has ceased to exist

Policy implication:

Worsening congestion does not make hierarchy more efficient — it makes hybrid unviable. This distinction matters: TenneT would not choose hierarchy because it is better governed, but because no

private operator will take on the contract. This points to a structural market failure that cannot be resolved through governance design alone — it requires either network investment to reduce congestion or regulatory reform to make the business case viable for private operators.

Scenario 2 — Asset specificity increased What if GFM inverter hardware became truly dedicated to inertia provision — not a regulatory requirement across new installations, not redeployable for other services?

Effect on Gate 3 Q2:

- The operator faces genuine lock-in — the GFM asset has no commercial value outside the inertia contract
- Credible commitment is now strong — the operator cannot credibly threaten to redeploy
- Gate 3 Q2 flips from + weight to no additional weight

Effect on accumulated weight:

- Case A: Gates 2+3 weight drops from 3 to 2 → standard threshold at Gate 4
- Case B: Gates 2+3 weight drops from 3 to 2 → standard threshold at Gate 4
- Case C: Gates 2+3 weight drops from 4 to 3 → raised threshold remains at Gate 4

Effect on Gate 4:

- Lower accumulated weight means hierarchy needs a larger cost advantage to be selected
- But $C_{\text{foregone_revenue}}$ under hierarchy is still very high due to non-trading condition
- Hierarchy is not selected in this scenario alone — the non-trading condition still dominates

Policy implication:

Higher asset specificity strengthens the contractability case for hierarchy but cannot overcome the structural cost disadvantage created by the non-trading condition alone.

Scenario 3 — Both conditions combined What if congestion hours increase beyond the viability threshold AND asset specificity is high?

Effect on Gate 3 Q2:

- Credible commitment is strong — + weight removed
- Accumulated weight from Gates 2+3 drops across all cases

Effect on Gate 4:

- $C_{\text{foregone_revenue}}^{(h)} \approx C_{\text{foregone_revenue}}^{(hy)}$ — hybrid business case has collapsed due to high constrained hours
- $C_{\text{transaction}}$ under hierarchy is still elevated but now comparable to hybrid
- The raised threshold from Gates 2+3 is lower — hierarchy needs less cost advantage

Result by case:

- Case A: Gates 2+3 weight 2 → standard threshold → Hierarchy selected
- Case B: Gates 2+3 weight 3 → raised threshold → Hierarchy selected — hybrid no longer viable as private operators will not bid
- Case C: Gates 2+3 weight 3 → raised threshold → Hierarchy selected — same logic as Case B

Why all cases tip to hierarchy under this combined scenario:

- The collapse of the hybrid business case removes the primary cost advantage of hybrid governance
- High asset specificity removes the credible commitment problem — the operator is genuinely locked in

- With $C_{\text{foregone_revenue}}$ neutralised and transaction costs comparable, even the raised threshold in Cases B and C can be overcome
- Hierarchy is selected not as the preferred governance form but as the only remaining viable option

Summary

Table G.1: Sensitivity analysis — conditions under which hierarchy is selected

Scenario	Case A	Case B	Case C	
Baseline	Hybrid	Hybrid	Hybrid	
Scenario 1 — Congestion > 90%	Hybrid	Hierarchy*	Hierarchy*	*Hierarchy by
Scenario 2 — High asset specificity	Hybrid	Hybrid	Hybrid	
Scenario 3 — Both combined	Hierarchy	Hierarchy	Hierarchy	

necessity — hybrid governance is theoretically preferred but practically unavailable as no private operator will bid.

Overall finding:

The sensitivity analysis reveals two distinct pathways to hierarchy. The first is efficiency-driven, when asset specificity is sufficiently high that credible commitment is strong and the non-trading condition is neutralised by the collapse of the hybrid business case, hierarchy becomes the most cost-efficient governance form. The second is necessity-driven, when congestion is so severe that no private operator will take on a hybrid contract at an acceptable price, hierarchy becomes the only remaining option regardless of its efficiency properties.

This distinction has an important policy implication. The current baseline sits well within the hybrid zone; 65% constrained hours leaves a viable business case for private operators. But the trajectory is toward worsening congestion. If structural network investments, Utrecht Zuid and Utrecht Noord, do not materialise on schedule, the system may cross the viability threshold before network relief arrives. In that scenario, TenneT faces not a governance choice but a governance necessity: hierarchy by default, not by design.