

Bridging the Capacity Gap

A Mixed-Methods Assessment of Project-Level Flexibility and Station-Level Grid Congestion in Laakhavens Hollands Spoor

Author: Batuhan Tazegül
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TU Delft FAKTON ENERGY

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A Mixed-Methods Assessment of Project-Level Flexibility and Station-Level Grid Congestion in Laakhavens Hollands Spoor

By

Batuhan Tazegül

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Thesis committee:	Dr. P.W.G. Bots,	TU Delft,	chair and first supervisor
	Prof. Dr. T.A.P. Metze	TU Delft,	second supervisor
	Dr. T.S.G.H. Rodhouse,	TU Delft,	advisor
	J. Mieras	Fakton Energy,	external advisor

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Preface

This thesis marks the completion of my Master's programme in Engineering and Policy Analysis at Delft University of Technology. The research was conducted at the intersection of urban redevelopment, electricity-grid congestion and energy flexibility, with Laakhavens Hollands Spoor in The Hague as the central case.

Working on this thesis showed me how closely technical energy-system questions are connected to planning, governance and actor responsibilities. What initially appeared to be a capacity problem at one electricity station gradually developed into a broader socio-technical question concerning project phasing, grid access, ownership, coordination and the practical organisation of flexibility. Combining stakeholder interviews with quantitative modelling was challenging, but also made the research particularly valuable and engaging.

I would like to sincerely thank my supervisors, Dr. Pieter Bots, Dr. Toyah Rodhouse and Prof. T.A.P. Metze, for their guidance, critical feedback and support throughout the research process. Their input helped me sharpen the research design, strengthen the analytical framework and improve the interpretation and presentation of the results.

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Executive summary

Laakhavens Hollands Spoor is planned as a major high-density redevelopment in The Hague, but the electricity system serving it has almost no room to absorb that growth. Approximately 9,000–11,000 new dwellings are planned alongside employment, commercial and public functions, while station Jan Wapstraat has 38 MW of available transport capacity and reinforcement is not planned until the end of 2036. Development decisions are made largely project by project, yet their electricity demand accumulates at the same station. This thesis examines whether flexibility can bridge part of that capacity gap before reinforcement and how its organisation must evolve as grid pressure increases.

An exploratory sequential mixed-methods case study combines documentary analysis, four stakeholder interviews and quantitative energy-system modelling. The qualitative analysis identifies technically relevant flexibility options and the institutional conditions affecting their implementation. These findings inform a Linny-R optimisation model representing eight cumulative development phases and testing flexible WKO/ATES operation, battery storage, smart EV charging and controllable HyER generation at project and area-wide scales.

The results show that the available station margin disappears early. Without congestion-oriented flexibility, corrected functional loading rises from 37.1 MW in Phase 1 to 45.2 MW in Phase 8. The 38 MW limit is already marginally exceeded in Phase 2, while Phase 3 reaches 39.1 MW and confirms the emerging constraint. By Phase 8, the station limit is exceeded during 438 annual hours, with a maximum exceedance of 7.15 MW and approximately 614 MWh above the threshold. The central concern is therefore not only the final deficit: the remaining station margin is consumed while much of the redevelopment is still to follow.

Flexibility can substantially extend the amount of development that can be accommodated, but its effectiveness changes as demand accumulates. Flexible WKO/ATES operation accommodates the modelled programme through Phase 4, while favourable flexibility inherited from earlier projects can extend this through Phase 5. From Phase 6 onward, however, none of the evaluated configurations in which additional flexibility is concentrated in the newly added project fully eliminates congestion. Earlier projects therefore influence not only demand but also the flexibility and headroom available to later developments. Phase 6 marks an important shift: the technical problem has become too cumulative to be addressed solely within the boundary of the next individual project.

The strongest technical result emerges when flexibility is coordinated across the full development portfolio. Under the evaluated assumptions, the integrated Phase 8 scenario eliminates residual congestion during the 336-hour critical period by coordinating WKO/ATES, batteries, smart charging and HyER across all eight projects. However, the station remains exactly at its 38 MW limit for 90 hours. This should therefore be interpreted as an upper technical potential with little robustness margin, not as a guaranteed solution or evidence that reinforcement is unnecessary. Reduced modelled loading also does not automatically create formal transport rights for individual projects.

The institutional analysis shows why this technical potential cannot simply be assumed to materialise. Investment, ownership and operational control remain predominantly project-specific. Area-wide congestion management would require shared information, dispatch authority, performance

verification, compensation arrangements and responsibilities that remain workable after projects are completed or transferred. The technically strongest configuration is therefore not currently the most institutionally feasible one.

The strategic implication is to prepare coordination before it becomes technically unavoidable. Phase 2 is an early signpost that unused station headroom can no longer be relied upon; Phase 6 is a stronger trigger showing that additional flexibility concentrated in the newest project is no longer sufficient. The recommended pathway is therefore adaptive: preserve future flexibility options in early projects, develop coordinated project-level arrangements as interdependence increases, and retain deeper area-wide integration as a conditional option rather than an immediate end-state.

The broader lesson extends beyond LHHS. Grid congestion in phased urban redevelopment is not only a shortage of network capacity or flexible technology; it is also a mismatch between the scale and timing of decisions. Projects can be optimised individually while their combined consequences emerge later at a shared network constraint. Flexibility can help bridge the period before reinforcement, but only if early technical and institutional choices preserve the ability to coordinate when that interdependence becomes material.

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1 Introduction

1.1 Background and problem definition

Dutch cities must accommodate urban growth and electrification while electricity-grid capacity is increasingly constraining development. Housing, electric mobility, electrified heating and cooling and commercial functions add demand to existing networks, while reinforcement often develops more slowly than urban projects. Grid congestion has therefore become an immediate constraint on economic activity and spatial development rather than only a long-term infrastructure issue (Netbeheer Nederland, 2026).

Government, regulators and network operators respond through network investment, revised capacity-allocation procedures and measures to improve the use of existing capacity. Since January 2026, network operators must apply the ACM's revised prioritisation framework in congestion areas, while the government has announced earlier capacity applications for municipalities preparing housing developments. These measures illustrate that congestion is both a physical and an institutional problem: scarce network capacity must not only be expanded, but also allocated and used effectively (ACM, 2025; Rijksoverheid, 2026).

Flexibility can contribute by shifting demand, storing energy or providing local generation when the network is constrained. Options include smart EV charging, batteries, controllable heating and cooling, thermal storage and local generation. Their value depends on when, where and for which objective they are operated (IEA, 2025; Eid et al., 2016). Implementation additionally depends on investment, ownership, operational control, incentives and coordination. Technical controllability alone does not ensure that an asset will be available for congestion management (Eid et al., 2016; Mlecnik et al., 2020). Flexibility must therefore be considered as a socio-technical arrangement rather than as a technical resource alone.

1.2 Case context: Laakhavens Hollands Spoor

This thesis examines the redevelopment of Laakhavens Hollands Spoor (LHHS) in The Hague. The area forms part of the Central Innovation District and is planned as a high-density mixed-use district with approximately 9,000–11,000 new dwellings alongside employment, commercial and public functions. Development is phased over multiple projects and actors rather than delivered as one integrated project (Gemeente Den Haag, 2025b).

The relevant upstream electricity constraint is station Jan Wapstraat, which supplies an area larger than LHHS. Stedin reports 38 MW of available transport capacity. For 2026, contracted demand and autonomous growth require 36.2 MW, while a further 3.5 MW has been requested by customers on the waiting list. This exceeds the available capacity, while reinforcement is planned for the end of 2036 (Stedin, 2025).

This creates both a timing and a scale mismatch. Development demand emerges incrementally before reinforcement, while decisions on energy systems and flexibility are primarily taken within

individual projects even though congestion occurs at the shared station level. Project-level flexibility may therefore affect, but does not automatically resolve, the constraint at Jan Wapstraat.

1.3 Research gap

Technical flexibility research often quantifies the potential of resources such as smart charging, battery storage and controllable building systems, but commonly assumes that the required assets and control arrangements are available (Anwar et al., 2022; Efkarpidis et al., 2023; Li et al., 2021). Governance and urban-infrastructure research, meanwhile, shows that implementation depends on ownership, authority, incentives and coordination, but less often quantifies the consequences of these arrangements at a specific constrained network boundary (Monstadt, 2009; Mlecnik et al., 2020).

The gap addressed by this thesis lies between these perspectives. In phased urban redevelopment, flexibility must be assessed both as a technical response to a shared network constraint and as an arrangement that must remain implementable across actors and over time. This is particularly relevant where project-specific decisions accumulate before the wider network constraint is reinforced.

The thesis therefore combines case-specific institutional analysis with quantitative scenario modelling to assess how flexibility performs across successive development phases and what forms of coordination are required at different scales. This combination is directly relevant to **Engineering and Policy Analysis**, because addressing grid congestion requires analysis of both the technical system and the actors, institutions and decision processes through which interventions can be implemented.

1.4 Research objective and research questions

The objective of this research is to assess how flexibility can reduce electricity-grid congestion during the phased redevelopment of Laakhavens Hollands Spoor, while accounting for both technical performance and the institutional conditions required for implementation.
The main research question is:

To what extent can technically relevant and institutionally feasible flexibility arrangements reduce station-level electricity-grid congestion during the phased redevelopment of Laakhavens Hollands Spoor prior to planned grid reinforcement?

The main question is addressed through three sub-research questions:

RQ1. Which urban-development, electricity-system and phasing conditions define the pre-reinforcement context of Laakhavens Hollands Spoor?

RQ2. Which flexibility arrangements are technically relevant and institutionally feasible in Laakhavens Hollands Spoor, and which governance conditions shape their implementation?

RQ3. How do modelled electricity demand and station loading develop across the redevelopment phases, and what is the effect of selected flexibility arrangements on peak loading, congestion duration and congestion volume?

1.5 Research approach

This research applies an exploratory sequential mixed-methods single-case study. Documents and stakeholder interviews are used to reconstruct the case, identify relevant flexibility measures and analyse the institutional conditions affecting their implementation. These findings inform quantitative scenarios of phased electricity demand, station loading and flexibility operation. The qualitative and quantitative findings provide the basis for a theory-informed strategic synthesis of how the timing and scale of flexibility coordination could develop as the redevelopment progresses. This synthesis is subsequently considered together with the underlying findings in the final integrated interpretation of the main research question.

2 State of the art

This chapter develops the theoretical basis for examining electricity-grid congestion and flexibility in phased urban redevelopment. The subject sits at the intersection of power-system engineering, building and district energy research, urban development and public governance. Treating any one of these fields in isolation would narrow the problem too early. The chapter therefore follows a funnel structure. It first positions electricity infrastructure within the wider urban energy transition, then defines congestion and flexibility, and subsequently examines the coordination and institutional conditions through which technical resources can become a dependable network service. It concludes with the research gap and the analytical framework used in this thesis.

2.1 Urban energy transition and electricity infrastructure

Energy transitions are not simply processes in which one technology replaces another. Sustainability-transition research describes them as long-term and contested changes in which technologies, infrastructures, markets, regulations, business structures, user practices and cultural meanings develop together. Their direction is shaped by multiple actors and by choices made while the future remains uncertain. This means that technical improvement can contribute to a transition without, by itself, changing the wider system in which the technology is embedded (Köhler et al., 2019).

This socio-technical perspective is particularly relevant to urban infrastructure. Electricity, heat, mobility and the built environment are organised through durable physical networks as well as through organisations, rules and investment practices. Monstadt (2009) conceptualises these configurations as urban infrastructure regimes and emphasises that their material and institutional components shape place-specific development paths. Coenen et al. (2021) similarly show that energy transitions are recursively embedded in regions: place-specific infrastructures, institutions, markets, policies and resources shape transition processes, while those processes also reshape places. Relevant actors and dependencies may operate both within and beyond the area and at multiple governance levels. Urban energy change is consequently conditioned by existing networks, ownership structures and public-private relationships rather than implemented on an empty site. Infrastructure is not merely a technical backdrop to urban development. It both enables development and restricts which development pathways remain feasible (Monstadt, 2009; Köhler et al., 2019; Coenen et al., 2021).

Electrification makes this relationship increasingly visible. Electricity demand from buildings, heating and cooling, mobility and other urban functions may grow faster than network capacity can be expanded. Grid reinforcement remains necessary, but planning, permitting and constructing network infrastructure generally takes longer than deploying many demand-side technologies and new electricity-consuming functions. The International Energy Agency therefore treats grid expansion, modernisation and more effective use of existing infrastructure as complementary responses. Flexibility may improve utilisation or defer part of an investment need, but it is not a general substitute for reinforcement (IEA, 2023).

Urban redevelopment connects these different timelines. Spatial plans and development decisions determine where demand will emerge, the functions that create it and the sequence in which projects become operational. Network planning determines when additional capacity can be provided and at which network level. Because these decisions are taken by different organisations under different procedures, their timing and system boundaries need not coincide. This temporal and organisational separation can create a capacity gap in which development progresses while the infrastructure required to serve its cumulative electricity demand is still being prepared (IEA, 2023; Monstadt, 2009).

The existence of a local public authority does not remove this coordination problem. Cheung et al. (2023) argue that urban transition capacity must be specified as capacity for what, capacity of whom and capacity built through which process. A municipality may possess spatial-planning instruments and convening power while lacking ownership of network infrastructure or operational control over private energy assets. Conversely, infrastructure operators and developers can have strong technical or investment capacities within their own domains without having authority over the urban programme as a whole. The relevant question is therefore not whether a city can generically lead the transition, but how actor-specific capacities combine around a defined problem (Cheung et al., 2023).

Taken together, this literature positions electricity-grid congestion in redevelopment as a planning problem created by the interaction of material capacity, development sequencing, institutional authority and durable choices. Urban programmes and electricity infrastructure co-evolve, but not necessarily through integrated decisions or aligned time horizons (Monstadt, 2009; Coenen et al., 2021; Cheung et al., 2023).

2.2 Congestion, hosting capacity and scale

Electricity-grid congestion occurs when requested power flows at a particular location and time cannot be accommodated within the operational limits of the relevant network infrastructure. Annual electricity consumption alone is therefore an insufficient indicator. A development with moderate annual use can still contribute substantially to a critical peak when its demand coincides with other loads. The relevant constraint is defined by a network boundary and by the periods in which that boundary is most heavily loaded (Bollen & Rönnberg, 2017; IEA, 2023).

The related concept of hosting capacity clarifies why this limit should not be treated as a context-free constant. Hosting capacity expresses how much additional production or consumption equipment can be connected before specified network-performance limits are exceeded. Its value depends on the technology being assessed, the location and pattern of connections, existing demand and generation, network configuration, the selected performance criteria, input uncertainty and the planner's accepted level of risk. Results from one network or one set of assumptions cannot therefore be transferred directly to another setting (Bollen & Rönnberg, 2017).

Hosting capacity and congestion are connected but analytically distinct. Hosting-capacity assessment estimates the additional equipment or demand that a network can accommodate under defined assumptions. Congestion refers to the periods and locations at which requested flows exceed the capacity available at a specific boundary. A threshold used in a planning model is therefore meaningful only together with its system boundary, profiles, simultaneity assumptions and uncertainty. This thesis does not estimate the complete hosting capacity of a distribution network. It

examines how phased development demand affects loading at an identified constrained station (Bollen & Rönnberg, 2017).

The choice of scale is not only technical. Environmental-governance research shows that the physical scale of a problem, the jurisdiction with formal authority and the scale at which implementation resources are organised may differ. Rescaling planning responsibility does not automatically rescale finance, infrastructure ownership or operational control. Localisation can consequently transfer expectations to a lower level without transferring the powers and resources required to meet them (Newig & Moss, 2017).

For electricity flexibility, this creates several relevant boundaries. A resource can be owned and controlled at building or project level, shared at district level, connected within a station's feeding area, and affected by constraints elsewhere in the wider network. Optimising one boundary does not guarantee an improvement at another. A lower project peak may coincide with a higher station peak, while an area-wide reduction may be irrelevant to a constraint outside the electrical area in which the resources are located. A physical reduction in loading and the institutional allocation of network access are therefore analytically separate questions. Locational and institutional fit must be examined alongside technical effect (Newig & Moss, 2017; Potenciano Menci & Valarezo, 2024).

In this thesis, congestion is accordingly understood as a socio-technical planning constraint. It is technical because it concerns operational network limits, spatial because the effect of a resource depends on its electrical location, temporal because peaks and development occur at particular moments, and institutional because access, control and responsibility are organised through rules and actor relationships. This definition avoids treating either the station or the redevelopment area as a self-contained system (Monstadt, 2009; Newig & Moss, 2017).

2.3 From technical flexibility to congestion mitigation

Flexibility broadly refers to the capability of demand, generation, storage or conversion processes to alter their operation in response to changing conditions. It is not one technology or one fixed quantity. Ulbig and Andersson (2015) characterise operational flexibility through interdependent power, energy, ramp-rate and duration capabilities. In the built environment, the available response additionally depends on the reference profile, the service that must be retained, the control strategy, the assessment horizon and the metric used. A flexibility estimate is therefore conditional on both the physical resource and the question for which it is calculated (Junker et al., 2018; Li et al., 2022).

Flexibility should also be distinguished from permanent demand reduction. A flexible load is often shifted rather than removed. A thermal system may later need to restore a temperature or storage level, a battery must be recharged, and postponed consumption must still satisfy the underlying service. The resulting recovery can create a new peak or reduce the benefit achieved during the original event. Evaluating only one hour can consequently overstate the usable response. Timing, duration, energy balance and post-activation effects must be considered together (Ulbig & Andersson, 2015; Li et al., 2022; Dawes et al., 2025).

Different urban energy resources illustrate these constraints without defining the preferred solution in advance. Controllable demand can move consumption within an operational window. Electrical storage can separate the timing of grid import from the timing of local use, but its response depends

on power, energy, state of charge, efficiency, degradation and its assigned duty profile (Zhao et al., 2023). Electrified heating and cooling can use thermal storage or building inertia, although comfort limits, conversion capacity, thermal state and recovery requirements constrain the response. Finck et al. (2020), for example, demonstrate controllable heating flexibility in a real building, but their controller follows price signals rather than a local station constraint. Local generation can reduce net import only when production coincides with the relevant peak or can be dispatched when required. Multi-energy coordination can widen the available options by connecting electricity, heat, cooling, fuels and mobility, but the effect still depends on the network and operational boundary represented in the control problem (Mancarella, 2014).

These examples expose the difference between a flexible asset and the provision of a particular system service. The same battery, charging system or thermal installation can be operated for self-consumption, electricity prices, comfort, balancing, a connection limit or local congestion. These objectives can produce different and sometimes conflicting schedules. Stawska et al. (2021) show in a bounded modelling study that demand response used for system balancing is not automatically available or directionally helpful for distribution-level congestion management. Their results are scenario-specific, but they support the more general proposition that a resource must be controlled for, or explicitly coordinated with, the relevant network objective.

Flexibility can contribute to congestion mitigation only when several conditions align. First, the response must occur during the constrained period and account for recovery afterwards. Second, it must be electrically located where a change affects the relevant network boundary. Third, it must provide sufficient power and duration, subject to the energy and service constraints of the resource. Fourth, its control objective must correspond to the congestion problem rather than to an unrelated market or project objective. Fifth, the response must be dependable enough for the purpose for which it is counted. Each condition follows from a different feature of flexibility, and none can be inferred from the mere presence of a controllable technology (Ulbig & Andersson, 2015; Junker et al., 2018; Stawska et al., 2021; Li et al., 2022).

Dependability does not require every resource to behave with complete certainty, but it does require uncertainty to be represented. At multi-building scale, diversity can smooth individual variations and create portfolio benefits, yet aggregation also introduces uncertainty about occupancy, user behaviour, weather, equipment availability, baselines, communication and control. Dawes et al. (2025) find that the realisation of building flexibility at scale depends on physical assets, occupant behaviour, control and coordination, and the infrastructures connecting buildings. Aggregated potential should therefore not be calculated as an unqualified sum of nominal asset capacities.
The distinction developed here is between technical flexibility and flexibility as congestion mitigation. Technical flexibility is the capability of a resource to alter its electricity profile within its physical and service constraints. Technical relevance is narrower: it concerns whether the response can plausibly change loading at the network boundary under study, given its timing, location, magnitude, duration, recovery and control objective. Actual congestion mitigation additionally requires that the response can be accessed and delivered when needed. That step moves the analysis from resources to collective delivery arrangements (Junker et al., 2018; Stawska et al., 2021; Li et al., 2022; Dawes et al., 2025).

2.4 From flexible assets to collective delivery

When the relevant constraint lies above an individual connection, flexibility becomes a coordination problem. Buildings and projects can differ in demand profiles, technologies, ownership, contractual position and willingness to participate. Their individual responses may complement each other, cancel each other or shift demand into the same recovery period. Multi-building flexibility therefore depends not only on the available assets but also on forecasting, data exchange, interoperability and the way control decisions are combined (Dawes et al., 2025; Li et al., 2022).

Aggregation does not have one meaning. Mancarella (2014) distinguishes commercial aggregation from technically constrained aggregation. A commercial portfolio can combine resources for trading without representing their common electrical location or internal network constraints. A technically coordinated portfolio, such as a technically constrained virtual power plant or microgrid, includes the network conditions relevant to operation. This distinction is important in urban redevelopment because shared ownership, a collective energy system or one commercial service provider does not automatically imply control for a station-level objective. Asset scope and control objective are separate analytical dimensions (Mancarella, 2014).

Coordination structures also allocate agency and information differently. Charbonnier et al. (2022) show that strategies described under broad labels such as decentralised coordination can differ in who makes decisions, which information is exchanged and whether participating units cooperate or compete. Central control may enable direct system-level optimisation but creates information, communication and acceptance requirements. More distributed arrangements can preserve local autonomy and privacy, but alignment with a common network objective must then be produced through signals, contracts or iterative coordination. No single structure is inherently appropriate across all contexts (Charbonnier et al., 2022).

An aggregator is one possible intermediary, not a solution in itself. Aggregation can reduce transaction costs, combine small resources, manage forecasts and represent participants towards system actors. Burger et al. (2017) caution, however, that the value of an aggregator depends on the concrete function it performs. Some value is fundamental, while other value arises temporarily from current regulation, market design or technology. For local congestion mitigation, an intermediary would therefore need a defined role in securing locational eligibility, access to resources and accountable delivery rather than merely combining commercial volumes (Burger et al., 2017; Potenciano Menci & Valarezo, 2024).

The delivery of local flexibility can be viewed as an end-to-end architecture. Potenciano Menci and Valarezo (2024) identify mutually dependent business, functional, information, communication and physical layers in local flexibility-market designs. Even where no market is used, the underlying questions remain relevant: which resources are eligible, who can activate them, what product or obligation is defined, how availability and baselines are established, how performance is measured and verified, how non-delivery is handled, and how the arrangement interacts with network operation. The IEA (2025) similarly identifies metering, interoperable control, locational signals, standardised processes and clear responsibilities as enabling conditions for scaling demand flexibility.
A market, platform, bilateral agreement, collective contract or common operator can each organise parts of this delivery chain. The literature does not establish that one of these forms is universally superior, and many local flexibility initiatives remain pilots or evolving designs. A market taxonomy

describes design choices rather than proving which arrangement is effective in a particular redevelopment area. Institutional analysis must therefore begin with the service and coordination problem, then evaluate which arrangement could meet it, rather than assuming a preferred organisational form in advance (Potenciano Menci & Valarezo, 2024; Torriti, 2024).

Collective delivery therefore requires an arrangement that connects relevant resources to a common objective and sustains access, control, information, verification and accountability across organisational boundaries (Charbonnier et al., 2022; Potenciano Menci & Valarezo, 2024).

2.5 Institutional feasibility in urban redevelopment

Technical capability does not determine whether flexibility can be implemented in practice. Flexible resources must be financed, installed, commissioned, accessed, controlled and maintained by actors operating under specific rules and organisational arrangements. Many resources are located behind private connections or embedded in building, mobility and thermal systems whose primary purpose is to provide another service. Mlecnik et al. (2020) show that technically flexible buildings do not automatically become service providers because service development also depends on policy pathways, market access, viable roles, aggregation and the involvement of building owners and users. Institutional feasibility is therefore treated here as the extent to which a technically relevant arrangement can plausibly be implemented, operated and maintained within the applicable rules, actor relationships and development process.

The first institutional issue is authority and operational control. Ownership, investment responsibility, data access and the authority to change operation can be assigned to different actors. The actor experiencing a network constraint may not control the resources capable of responding to it, while the asset controller may have no obligation or incentive to pursue the wider network objective. Torriti (2024) accordingly frames demand flexibility governance through coordination, performance, funding, market transformation and engagement rather than through technology deployment alone. For a specific arrangement, institutional analysis must identify who can commit the resource, who issues or receives the signal, which service remains protected and who is accountable for delivery (Torriti, 2024; Mlecnik et al., 2020).

The second issue is the allocation of investment, operating costs, benefits and risks. Flexible operation may require additional equipment, metering, software, communication, design work and contracting. It can also create degradation, comfort or service risks and future obligations (Zhao et al., 2023). These burdens and benefits may fall on different actors and at different times. A developer can face an early investment decision while a future building owner operates the asset, a network operator or later project benefits from reduced loading, and users experience operational constraints. Treating flexibility as a collective resource therefore requires a rationale for participation and a method for allocating costs and risks, not only evidence of aggregate technical benefit (Mlecnik et al., 2020; Knox et al., 2022).

The third issue is information and contractual durability. Congestion-oriented operation may require forecasts, measurements, equipment status, operational constraints and confirmation of performance. Data access is tied to ownership, privacy, commercial interests, interoperability and responsibility for errors. Contracts must specify not only participation but also the relevant control objective, availability, activation conditions, measurement, non-delivery and the treatment of changed circumstances

(Potenciano Menci & Valarezo, 2024; IEA, 2025). Because ownership, operators and users can change after completion, continuity from design and development into occupation and routine asset management is an analytical requirement for any arrangement intended to remain operational over time (Mlecnik et al., 2020; Petersen & Heurkens, 2018; Bonfert et al., 2024).

Urban-development governance shapes whether these conditions can be created. Public planning authorities rarely depend on one instrument. Petersen and Heurkens (2018) show, in three deliberately selected urban-development cases, that public actors influenced private energy decisions through phased combinations of shaping, regulatory, stimulus and capacity-building instruments. Early targets and minimum standards created direction, while finance, tendering, risk reduction and knowledge exchange supported implementation. Their successful cases cannot be copied directly, but they demonstrate that public influence depends on instrument combinations, timing and the surrounding institutional and market context rather than on a generic call for municipal leadership (Petersen & Heurkens, 2018).

Municipal capacity is itself an institutional variable. Cheung et al. (2023) show that the ability to mobilise urban energy change depends on infrastructure, ownership, regulation, actor coalitions, learning and framing. Strumińska-Kutra et al. (2023) add that collaboration with external actors does not remove the need for internal institutional adaptation. Established administrative routines, departmental boundaries and accountability structures can conflict with cross-sector and experimental ways of working. A municipality may therefore support a pilot or convene actors while still lacking the internal mandate, continuity or procedures required to embed the arrangement in regular development practice (Cheung et al., 2023; Strumińska-Kutra et al., 2023).

Recent Dutch evidence reinforces this distinction between ambition and organisational capacity. Braams et al. (2024), studying civil servants within a Dutch ministry, identify institutional conditions concerning formal and informal structures, organisational culture, capabilities and external orientation. Although their findings concern national government and should not be transferred mechanically to municipalities, they show that transition-oriented work can be constrained by existing mandates, routines and accountability arrangements even where policy ambition is present. Institutional feasibility therefore concerns whether the responsible organisation can act consistently, not merely whether it supports the objective in principle (Braams et al., 2024).

Bonfert et al. (2024) similarly distinguish several functions through which local authorities can support energy transitions, including enabling, coordinating, brokering and creating favourable conditions. Their comparative case evidence also shows the limitations of relying on temporary innovation projects and external partners. Pilots can generate learning and demonstrate possibilities, but the capacity to initiate an experiment is different from the capacity to institutionalise, scale and maintain its results. For phased redevelopment, this temporal distinction matters because the arrangement may need to remain credible across planning, construction, occupation and changes in asset ownership (Bonfert et al., 2024).

Institutional feasibility also has a distributional and procedural dimension. A technically efficient arrangement can still allocate access, decision power, costs, inconvenience or risk unevenly. In their systematic review of smart local energy systems, Knox et al. (2022) distinguish distributional, recognition and procedural justice. This perspective does not imply that every flexibility arrangement will produce injustice, nor does it determine the outcome in the present case. It does require the

analysis to ask who can participate, whose constraints and interests are recognised, how decisions are made and who bears the consequences of non-delivery or restricted operation (Knox et al., 2022).

The institutional literature therefore shifts the unit of analysis from individual actors or technologies to the arrangement through which differentiated capacities, responsibilities and interests are connected to an operational objective. Institutional feasibility depends on a workable combination of authority, finance, control, information, verification, risk allocation, organisational capacity, continuity and legitimacy. Collaboration can contribute to that combination, but does not itself specify who decides, who pays or who remains responsible (Torriti, 2024; Potenciano Menci & Valarezo, 2024; Bonfert et al., 2024).

2.6 Theoretical synthesis and analytical framework

The literature reviewed above shows that technically oriented flexibility research and institutional research describe complementary parts of the same delivery problem. Building and multi-building studies specify flexible resources, operating constraints, recovery effects, aggregation and uncertainty. Governance-oriented studies instead identify the authority, coordination, organisational capacity and continuity required to mobilise these resources. Considered together, these bodies of literature show that the technical capability of an asset does not establish whether it can provide a dependable service at a specific network boundary (Li et al., 2022; Mlecnik et al., 2020; Dawes et al., 2025; Torriti, 2024).

This thesis combines these perspectives through two analytical lenses. **Technical relevance** concerns whether a flexibility mechanism can meaningfully influence the network constraint under investigation. It considers the timing and electrical location of the response, its magnitude and duration, recovery effects, operating limits, uncertainty and the objective guiding its control. **Institutional feasibility** concerns whether the arrangement required to mobilise that mechanism can plausibly be established and maintained. It considers authority, ownership, finance, incentives, data access, contracting, coordination, accountability, organisational capacity, continuity and legitimacy. Neither lens can substitute for the other. A technically effective response may lack an implementable delivery arrangement, while an institutionally attractive arrangement may have little effect on the relevant network constraint (Li et al., 2022; Dawes et al., 2025; Torriti, 2024).

The analytical object is therefore a **flexibility arrangement** rather than a technology or actor considered in isolation. Such an arrangement combines a flexible resource with its electrical location and operating objective, as well as the actors and institutional provisions needed to access, control and maintain it. The same asset can consequently produce different network effects when operated for self-consumption, energy prices, connection limits or local congestion. Similarly, shared ownership or infrastructure does not by itself establish coordination around a shared network objective (Mancarella, 2014; Charbonnier et al., 2022; Potenciano Menci & Valarezo, 2024).

The empirical and quantitative analyses are organised around four questions:
Which resource or process is flexible, and within which physical and service constraints?
Can its response affect the relevant network boundary at the required time, location, magnitude and duration?

Which actors must provide authority, access, control, information, finance and accountability? Can the resulting arrangement be implemented and maintained throughout the development and operational phases?

These questions are sensitising rather than prescriptive. They do not determine in advance which case-specific resources or actor relationships will prove relevant. Document analysis and interviews are used to identify the available resources, interests, responsibilities and institutional conditions. The quantitative assessment subsequently examines the technical effects of selected flexibility arrangements. Institutional conditions are not converted into a numerical score. Instead, they inform the selection and interpretation of the modelled arrangements and clarify which assumptions would have to hold for a technically effective outcome to be realised in practice.

The central theoretical proposition is that technical flexibility becomes congestion mitigation only when the response is spatially and temporally relevant, controlled for the applicable network objective, and embedded in an arrangement that secures access, coordination, verification, responsibility and continuity. This proposition connects the technical and institutional analyses without assuming in advance that a particular actor, technology or governance form constitutes the solution (Li et al., 2022; Charbonnier et al., 2022; Potenciano Menci & Valarezo, 2024; Torriti, 2024).

3 Methodology

This chapter explains the overall research design and the methodological choices that connect the theoretical framework to the empirical, quantitative and strategic analyses. The study combines documentary case reconstruction, semi-structured stakeholder interviews, qualitative thematic analysis and quantitative scenario modelling. Chapter 3 establishes the common research architecture, case boundaries, operationalisation and integration logic. The detailed interview procedure is presented with the institutional analysis in Chapter 5, while the model structure, experiment design and verification are presented with the technical assessment in Chapter 6. The theory-informed strategic synthesis through which these findings are translated into development pathways and actor-specific implications is described in Section 3.6 and applied in Chapter 7.

3.1 Research design

This thesis applies an exploratory sequential mixed-methods single-case study design. The design reflects the socio-technical character of the research problem. Assessing whether flexibility can mitigate congestion requires quantitative evidence about electricity demand, development phasing and station loading. Assessing whether that flexibility can be implemented requires qualitative evidence about grid access, authority, ownership, operational control, incentives, coordination and continuity. Combining these forms of evidence makes it possible to examine both the conditional technical effect of flexibility and the arrangements through which that effect would have to be delivered (Creswell & Plano Clark, 2017; Schoonenboom & Johnson, 2017).

A case-study design is appropriate when a contemporary phenomenon is investigated within its real-life context and the phenomenon cannot be separated cleanly from that context (Yin, 2018). In Laakhavens Hollands Spoor, the constraint at Jan Wapstraat is connected to the timing and composition of urban development, the wider supply area, grid-access procedures, collective infrastructure and the responsibilities of public and private actors. These conditions are therefore part of the object of study rather than external background variables. The study does not test a predefined causal hypothesis or evaluate an operating flexibility programme. It explores which arrangements are relevant in this case, how their implementation conditions differ and what technical effects they could produce under stated assumptions.

The mixed-methods design consists of four connected analytical stages followed by a theory-informed strategic synthesis. First, document analysis reconstructs the redevelopment programme, development phases, electricity-system boundary, formal procedures and technical assumptions. Second, stakeholder interviews and thematic analysis examine how the actors involved understand grid access, flexibility and the allocation of responsibilities. Third, case-specific evidence is used to select flexibility mechanisms and operating configurations that can be represented meaningfully in the quantitative assessment. Fourth, the model estimates how cumulative development and selected technical configurations affect station loading before planned reinforcement. Finally, the institutional and technical findings are synthesised to identify strategic development pathways, decision points and actor-specific implications.

The sequence is exploratory because the documentary and qualitative components precede and inform the quantitative assessment. The technical and institutional findings provide the empirical basis for the theory-informed strategic synthesis in Chapter 7. The strategic synthesis is subsequently considered together with the underlying findings in the final integrated interpretation of the main research question. This dependence does not mean that every qualitative finding becomes a model input. Questions concerning ownership, contractual continuity, capacity allocation, organisational responsibility and willingness to participate cannot be represented credibly as hourly technical variables. They remain qualitative findings that delimit and qualify the interpretation of the model outcomes. The connection between the components is therefore selective: qualitative evidence informs what is assessed and under which assumptions, while the model tests the conditional technical effects of selected arrangements (Creswell & Plano Clark, 2017; Fetters et al., 2013; Schoonenboom & Johnson, 2017).

Triangulation supports this design but is not treated as synonymous with mixed-methods integration. Statements concerning formal rules, project information, capacity figures and network characteristics were checked against official documents where possible. Actor perspectives were also compared across organisational roles. Integration goes further by relating the institutional conditions identified qualitatively to the effects estimated quantitatively. The qualitative component is therefore neither a preliminary validation exercise nor a substitute for the model. Each component addresses a different part of the same delivery problem. Figure 3.1 summarises the overall research design and the sequence through which the empirical and quantitative components are connected.

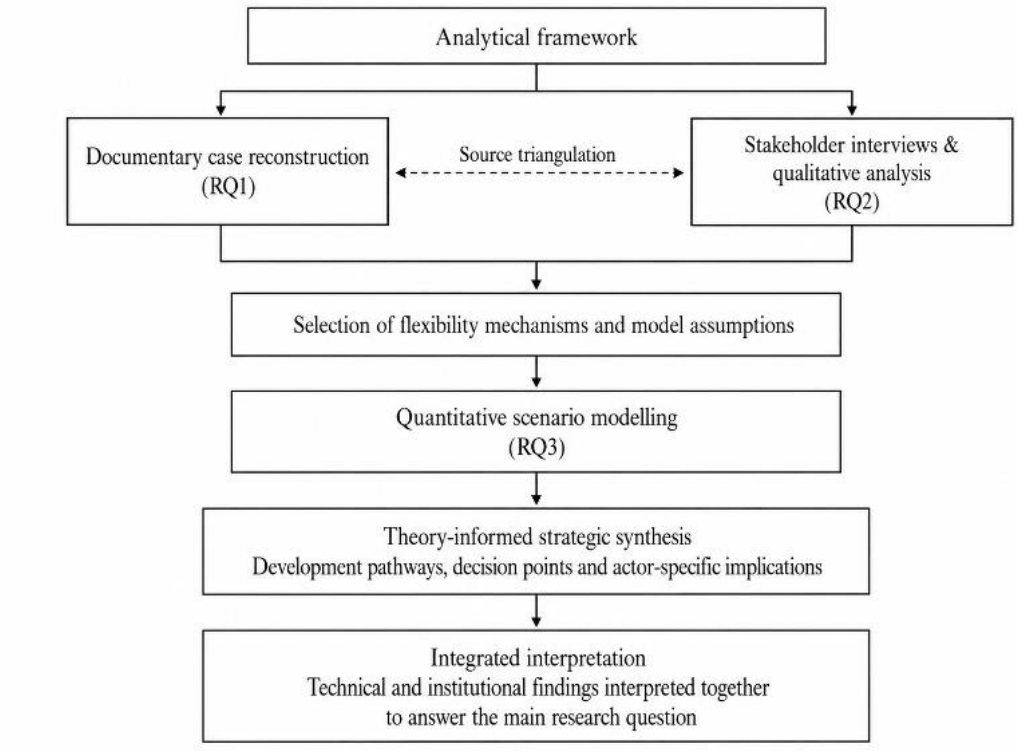


Figure 3.1. Exploratory sequential mixed-methods research design and points of integration.

3.2 Case selection and research boundaries

Laakhavens Hollands Spoor was selected through strategic, information-oriented case selection. The purpose was not to obtain a statistically representative urban-development sample, but to examine an information-rich case in which phased redevelopment, a documented station-level capacity constraint, multiple development actors and several potential flexibility resources coincide. The case is used for analytical generalisation: it provides evidence about mechanisms and actor dependencies that may also be relevant in other phased urban developments, without claiming that the numerical results or institutional conditions are directly transferable (Flyvbjerg, 2006; Yin, 2018).

The research uses two connected spatial boundaries. The redevelopment area is the boundary within which the functional programme, project sequence and potential flexibility resources are reconstructed. The Jan Wapstraat supply area is the relevant electricity-system boundary because the cumulative demand of the redevelopment contributes to the loading of this station together with demand outside Laakhavens Hollands Spoor. Separating these boundaries prevents total station loading from being attributed to the redevelopment alone and prevents project-level peak reduction from being treated automatically as station-level congestion mitigation.

The temporal boundary is the period before planned upstream reinforcement. Projects expected to become operational within this period are included where sufficient programme and phasing information is available. Later or insufficiently specified developments remain part of the wider case context but are not assigned to the pre-reinforcement model sequence. The technical scope covers hourly electricity demand, peak loading, congestion magnitude, volume and duration. Detailed voltage behaviour, reactive power, protection coordination and complete medium- and low-voltage load-flow analysis are outside the scope. The institutional scope covers grid access, authority, ownership, operational control, finance and incentives, information exchange, coordination, accountability and continuity. Costs and incentives are assessed qualitatively; the study does not conduct an investment optimisation, cost-benefit analysis or business-case assessment.

3.3 Operationalisation of the analytical framework

Chapter 2 defines technical relevance and institutional feasibility as complementary analytical lenses and identifies the flexibility arrangement as the unit of analysis. A flexibility arrangement combines a resource with its electrical location and operating objective, as well as the actors and institutional provisions needed to mobilise it. The interview protocol (appendix A) already covered the underlying technical and institutional topics. The final analytical framework was therefore not applied as a deductive coding scheme. It was used during the later abductive interpretation to compare evidence across actors and connect the qualitative findings with the quantitative assessment. Technical relevance concerns whether a response can plausibly influence loading at Jan Wapstraat. The qualitative analysis identifies whether the necessary location, controllability and operating freedom are plausibly present and whether sufficient information is available for modelling. The quantitative analysis then evaluates the conditional effect through maximum residual congestion, congestion volume and congestion duration. Institutional feasibility concerns whether the arrangement required to deliver that response can plausibly be implemented, operated and maintained. It is assessed from

interview and documentary evidence and is not converted into a numerical score. Table 3.1 summarises how these concepts are operationalised in the study.

Table 3.1. Operationalisation of the analytical framework.

Analytical concept	Assessment **dimensions**	**Use in the study**
Technical relevance	Timing and coincidence with the constrained period; electrical location; magnitude and duration; recovery effects; operating limits; uncertainty; control objective.	Documents and interviews establish plausible relevance and available operating freedom. The model assesses conditional effects on maximum residual congestion, congestion volume and congestion duration.
Institutional feasibility	Authority and access; ownership and finance; operational control; incentives and risk allocation; data and coordination; contracting and accountability; organisational capacity; continuity, transferability and legitimacy.	Documents and interviews identify actors, formal conditions, unresolved dependencies and barriers. Arrangements are interpreted qualitatively rather than ranked through a numerical score.

The dimensions functioned as sensitising concepts rather than as a deductive checklist. Their empirical relevance depended on the themes supported by the interview and documentary evidence. They were therefore used to structure the later interpretation, not to require that every dimension appeared as a separate empirical finding.

The two concepts are applied in sequence but interpreted together. A mechanism is not selected for quantitative assessment merely because a technology is present in the area. Its electrical location, available response, service constraints and operating objective must make it relevant to the station boundary. Conversely, a modelled reduction in station loading does not demonstrate that the responsible actors possess the authority, incentives or durable agreements needed to deliver it. Formal access to transport capacity is therefore analysed as institutionally related to, but analytically separate from, the physical reduction of loading.

The qualitative classifications used in Chapter 5 distinguish between arrangements that are established, conditionally feasible, not currently demonstrated or institutionally constrained. Absence of evidence is not interpreted as proof that an arrangement is impossible. It indicates that the case evidence does not currently demonstrate the actors or provisions required for implementation. This distinction allows the analysis to remain critical without turning incomplete information into a definitive negative conclusion.

3.4 Documentary case reconstruction

Document analysis was used to reconstruct the urban-development context, electricity-system boundary, formal procedures and technical assumptions required for the three sub-research questions. The source set included municipal plans and project information, Stedin congestion and network documents, regulatory and governmental decisions, procedural guidance and selected technical material. This was a targeted qualitative document analysis rather than a systematic literature review. Documents were selected for their direct relevance to Laakhavens Hollands Spoor

or Jan Wapstraat, their institutional authority, their recency and their contribution to the research questions.

The final documentary corpus comprised nine documents. Appendix E lists the title, issuing organisation, date or version, document type, selection rationale and analytical use of each document. The corpus was assembled purposively around the information required to reconstruct the case, rather than through a systematic search intended to identify all available documents on urban grid congestion.

The analysis followed a structured process of preparing the source set, extracting relevant information, analysing relationships and inconsistencies, and distilling the findings required for the case reconstruction. This corresponds with the logic of qualitative document analysis described by Bowen (2009) and the READ approach developed by Dalglish et al. (2020). Extraction focused on the functional programme, project phasing, electricity infrastructure, capacity and reinforcement information, grid-access procedures, actor responsibilities and assumptions needed for demand and flexibility modelling.

Documents were not coded through the same fragment-level codebook as the interviews because the two source types served different purposes. Interviews were used primarily to examine actor perspectives, practical interpretations and implementation conditions. Documents were used primarily to establish formal rules, factual case characteristics, planning assumptions and technical inputs. Official and case-specific sources were prioritised when several documents addressed the same issue. Network-operator information was treated as authoritative for reported capacity and network status, while adopted municipal documents were prioritised for the development programme. Public project information supplemented these sources where formal documents lacked project-level detail. Documentary and interview evidence were compared where respondents made statements about formal procedures, project status, grid boundaries or capacity figures. A discrepancy was not resolved automatically by discarding the interview statement. The document was used to describe the formal or officially reported position, while the interview was retained where it revealed how that position was understood or experienced in practice. Because projects, procedures and reinforcement schedules continued to develop during the research period, future dates and programme figures were treated as time-bound planning information rather than fixed predictions (Bowen, 2009; Dalglish et al., 2020).

3.5 Integration of qualitative and quantitative findings

Integration occurs at three points. At the design level, the documentary and qualitative components precede the quantitative assessment and define the case and system boundaries. At the methods level, evidence about relevant resources and operating configurations informs scenario selection, while institutional conditions that cannot be represented credibly as technical variables remain qualitative. At the interpretation level, modelled changes in station loading are evaluated in relation to the authority, control, coordination and continuity required to realise them (Creswell & Plano Clark, 2017; Fetters et al., 2013; Schoonenboom & Johnson, 2017).

This approach prevents the technical and institutional components from becoming parallel reports. The quantitative analysis does not establish institutional feasibility, and the qualitative analysis does not determine the magnitude of congestion mitigation. Their combined interpretation identifies where

a technically effective arrangement is supported by case-specific implementation conditions, where it remains conditional on unresolved governance, and where institutional plausibility is accompanied by only limited technical effect. This combined assessment provides the empirical basis for the strategic synthesis described in the following section. The main research question is ultimately addressed through the final integrated interpretation of the combined assessment and the strategic synthesis.

3.6 Strategic synthesis

The subsequent analytical step translates the combined institutional and technical findings into strategic development pathways for Laakhavens Hollands Spoor. It does not constitute an additional empirical research phase. The synthesis combines the governance configurations, actor dependencies and implementation conditions identified in Chapter 5 with the technical thresholds, interdependencies and flexibility effects identified in Chapter 6. This makes it possible to assess not only which arrangements are technically and institutionally relevant, but also how their organisation may need to evolve as cumulative grid pressure increases.

Selected strategic literature is used as an interpretive rather than deductive framework. Literature on transition management supports the distinction between strategic direction, tactical governance and operational implementation; adaptive-pathway literature supports the sequencing of actions and decision points under uncertainty; and network- and collaborative-governance literature supports the interpretation of coordination forms and actor responsibilities. These perspectives were selected for their relevance to the issues emerging from the combined findings and were not used to code the interviews or determine the quantitative scenarios. Chapter 7 applies them to develop theory-informed strategic recommendations rather than to claim an empirically tested or legally validated governance design.

3.7 Research quality

Research quality was supported through source and method triangulation, explicit case boundaries and an auditable relationship between evidence and interpretation. Official documents were used to check formal rules and reported system characteristics, while interviews provided role-specific interpretations and practical knowledge. Cross-actor comparison reduced dependence on one organisational perspective. The coding workbooks retain the underlying fragments from which the higher-order themes were developed, allowing qualitative claims to be traced to their empirical basis. Quantitative assumptions, inputs, experiment settings and verification checks are documented in Chapter 6 and Appendices C and D. Together, these measures improve the transparency and traceability of the analysis. The remaining methodological limitations and their consequences for interpretation are discussed in Chapter 8.

4 Case study context: Laakhavens Hollands Spoor

This chapter establishes the spatial, programmatic and electricity-infrastructure conditions that define the case. It first describes the phased redevelopment and then identifies the local and upstream network constraints that shape the period assessed in Chapters 5 and 6.

4.1 Urban development and phasing

4.1.1 Spatial and development context

Laakhavens Hollands Spoor is one of eight development areas within The Hague's Central Innovation District, the urban zone around Den Haag Centraal, Hollands Spoor and Laan van NOI. The municipality intends to transform the former harbour and business district into a high-density mixed-use area combining housing, employment, education, amenities and public transport accessibility. Its four subareas, Laakhaven Centraal, Spoorzone HS, Campuskwartier and Schipperskwartier, differ in their existing functions, land ownership and development intensity (Gemeente Den Haag, 2025b; Gemeente Den Haag, n.d.).

The transformation is not delivered as one centrally controlled project. Laakhaven Centraal requires relatively active municipal coordination because ownership is fragmented and several interventions are shared, while individual market parties lead much of the development in Spoorzone HS and Campuskwartier. New electricity demand will therefore emerge through separate projects with different programmes, delivery dates and infrastructure decisions. This phased and multi-actor structure is the relevant unit of analysis, rather than a single future end state (Gemeente Den Haag, 2025b).

4.1.2 Existing and future functional programme

The area already contains a substantial mix of residential and non-residential activity. The approximately 3,100 existing dwellings exclude the temporary dwellings at Stamkartstraat and the Rode Kruis building. These dwellings coexist with large concentrations of offices and education, as well as business premises, retail, care and leisure functions. Redevelopment consequently changes both the scale and temporal composition of electricity demand: existing uses may disappear or be reconfigured, while new functions are added and occupied incrementally (Gemeente Den Haag, 2025a).

Table 4.1. Existing functional programme in Laakhavens Hollands Spoor.

Function	Existing situation
Housing	3,100 dwellings
Housing, estimated floor area	approximately 217,000 m² usable floor area
Business premises	55,000 m²
Retail: home-furnishing	50,000 m²
Retail: other	10,000 m²

Function	Existing situation
Services, leisure and hospitality	10,000 m²
Offices	130,000 m²
Education	127,000 m²
Care and welfare	6,700 m²
Arts and culture	n.b.
Indoor sport	600 m²

The residential floor-area estimate in Table 4.1 applies an assumed average of 70 m² usable floor area per dwelling. It is a modelling approximation rather than a measured building-stock value and is consistent with the apartment-oriented character of the area (CBS, 2026).

The municipal development envelope, as seen in table 4.2, adds approximately 9,350 to 11,400 dwellings together with offices, business premises, retail, hospitality and societal facilities. The range reflects flexibility within a long-term programme rather than alternative fixed forecasts. Housing is the largest growth component, but the future area remains deliberately mixed-use, with different functions contributing to demand at different times (Gemeente Den Haag, 2025b).

Table 4.2. Municipal programme envelope for Laakhavens Hollands Spoor (Gemeente Den Haag, 2025b).

Function	Municipal programme envelope
Housing	9,350–11,400 dwellings
Offices	68,250–122,000 m² gross floor area
Business premises	21,000–30,000 m²
Retail	16,000–33,500 m²
Services, leisure, hospitality and hotel functions	approximately 15,350–49,150 m²
Education, care, culture, sport and other societal functions	approximately 17,900–36,800 m²

Two infrastructure changes add further electricity demand. First, the mobility strategy prioritises public transport, cycling, shared mobility and a central mobility hub intended to serve multiple surrounding developments, while the number and charging power of future electric vehicles remain uncertain. Second, new buildings are in principle required to connect to the collective heat system for which Eteck received a thirty-year concession in 2021, unless an equally sustainable alternative is provided. The system combines aquifer thermal energy storage with thermal energy from surface water and air-source heat pumps, replacing fossil heating but adding electricity use for heat pumps, circulation and auxiliary equipment (Gemeente Den Haag, 2025b).

The future load is therefore determined by more than the number of dwellings. Building functions, mobility and collective heating create distinct hourly profiles whose coincidence determines the station peak. Chapter 6 translates these programme components into phased electricity-demand profiles; the present chapter establishes only the spatial and temporal context for that analysis.

4.1.3 Major projects and indicative phasing

The programme is implemented through projects that differ in scale, composition and planning maturity. Table 4.3 summarises the principal developments included in the case. Publicly stated dates are treated as indicative planning windows, because completion and occupation may shift as permitting, demolition, design and development agreements progress.

Table 4.3. Major development projects in Laakhavens Hollands Spoor (Gemeente Den Haag, 2026).

Project	Developer or lead party	Main programme	Public status and indicative delivery
The Grace	Included City Development	1,304 dwellings and neighbourhood facilities, including healthcare, community, fitness and hospitality functions	Under construction since 2025; expected completion at the end of 2029
Waldorp Four	Sustay, in cooperation with DUWO, Arcade, Greystar and ABP	1,171 dwellings, together with limited office and hospitality functions	Under construction; expected completion in mid-2028
Escher Gardens	Redevco and SENS Real Estate	1,250 dwellings, 10,000–20,000 m² of offices and 1,000–3,000 m² of retail and other amenities	Zoning plan is final; construction expected to start in 2027 and to be completed in 2030
Struijck II	Municipality of The Hague, Staedion and Stebru	Approximately 180 dwellings with small businesses or amenities in the ground-floor plinth	Design and permit preparation; construction expected to start in 2026–2027 and finish in 2028–2029
MRKT / MegaStores redevelopment	COD and Amvest	Approximately 2,000 dwellings and 35,000 m² of retail, hospitality, commercial and societal amenities	Plan-making phase; phased demolition is expected to start at the end of 2027
Verheeskade 105–197 and 287–329	Ten Brinke, Atenor and Myb	Phase 1 contains approximately 1,064 dwellings and 2,000 m² of offices and amenities; the programme of phase 2 remains under development	Permit application for phase 1 submitted at the end of 2025; construction expected to start in 2026–2027

Project	Developer or lead party	Main programme	Public status and indicative delivery
Verheeskade 25	Municipality of The Hague and MS Vastgoed	Approximately 1,400 dwellings with offices, businesses, hospitality and other amenities	Plan-making phase; development will be phased because the existing UWV building remains temporarily in use; earliest construction start expected in 2026–2027
The Embrace	Municipality of The Hague / future development arrangement	Approximately 800 dwellings, retained commercial and hospitality functions, and a parking facility	Plan-making phase; construction expected to start in 2028–2029

Together, the listed projects represent approximately 9,200 dwellings, excluding the unspecified second phase of the Verheeskade development and later plots. Waldorp Four and The Grace are already under construction, Escher Gardens has a final planning basis, and the remaining projects are at earlier stages. The case therefore combines near-term demand additions with projects whose timing and programme remain more uncertain.

Electricity demand arises when buildings are connected and occupied, not when a planning decision is taken. The quantitative assessment therefore represents eight cumulative project phases rather than exact calendar years. It includes projects expected to become operational before upstream reinforcement and excludes later or insufficiently specified programme capacity. The phase sequence and associated model assumptions are detailed in Chapter 6 and Appendix C.

4.2 Electricity infrastructure and grid constraints

4.2.1 Network hierarchy and Jan Wapstraat

Electricity supply to the redevelopment involves two connected spatial levels. Within Laakhavens, medium-voltage routes, local transformer stations and low-voltage networks connect individual buildings. Their aggregate demand contributes to loading at Jan Wapstraat, a 25/10 kV station serving an area larger than Laakhavens Hollands Spoor. Local infrastructure determines whether a project can be connected physically, whereas Jan Wapstraat constrains simultaneous transport demand across the wider supply area.

Stedin declared structural congestion for electricity demand in the Jan Wapstraat area on 5 March 2025. The limiting component is transformer capacity at the station. The station also lies within a congestion area on TenneT's high-voltage network, so additional local capacity depends on both Stedin reinforcement and sufficient upstream transmission capacity (Stedin, 2025).

Jan Wapstraat has 38 MW of transport capacity. Required transport capacity for contracted demand and autonomous growth is projected at 36.2 MW in 2026. Requests already on the waiting list add 3.5 MW, producing a total requirement of 39.7 MW and a shortage of 1.7 MW. By 2036, contracted demand and autonomous growth are projected to require 50.5 MW; including the waiting list, the

requirement reaches 54.0 MW, 16.0 MW above existing capacity. Stedin consequently reports 0 MW as available for additional transport requests (Stedin, 2025).

These values describe coincident electrical power rather than annual electricity consumption. The congestion report does not isolate the contribution of Laakhavens or identify every overloaded hour. Chapter 6 therefore estimates redevelopment demand bottom-up and represents the remainder of the supply area as an exogenous station load, avoiding attribution of the full 54 MW requirement to the case area.

4.2.2 Local connection infrastructure as enabling infrastructure

The redevelopment also requires expansion of the local distribution network. The main area-level intervention is an additional medium-voltage ring because the existing ring cannot serve the planned volume of development. Stedin indicated that construction had started, that feeder positions were available at Jan Wapstraat and that the ring was expected to be available before the associated housing demand emerged (Interview Stedin).

The new ring improves distribution within Laakhavens but does not increase the 38 MW transport capacity of Jan Wapstraat. Station transformers are not expanded through this intervention, and the binding congestion point therefore remains upstream. Additional local transformer stations will likewise be installed with individual projects. Their capacity and spatial requirements are determined through consultation between Stedin and the developer of each project, but the Stedin interview did not identify these assets as the structural capacity bottleneck (Interview Stedin).

Local physical connectability and station-level transport capacity must therefore be distinguished. Medium- and low-voltage assets are necessary to connect buildings, but they do not create additional headroom at Jan Wapstraat. Separate project connections ultimately remain dependent on a capacity limit shared across the wider supply area.

4.2.3 Planned reinforcement and temporary capacity gap

The structural network response consists of the planned joint TenneT-Stedin HVS Escamp station and a new 21 kV medium-voltage network. At the time of the congestion assessment, commissioning was planned for the end of 2036. This date remains conditional because Stedin can release additional capacity only when the required work in TenneT's upstream network has also been completed (Stedin, 2025).

Several projects are expected to become operational before additional transport capacity is available, while the timing of reinforcement remains dependent on upstream network development.
This pre-reinforcement period defines the temporal boundary of the study. Reinforcement is treated as an exogenous development rather than as an alternative modelled intervention. Chapters 5 and 6 assess whether flexibility can reduce loading during the constrained period, while recognising that a technical reduction does not itself create a contractual right to transport capacity.

4.3 Case synthesis

Laakhavens Hollands Spoor combines phased, project-led urban development with a station constraint that is shared across a larger supply area. Although projects are planned, connected and occupied separately, their coincident demand contributes to the same 38 MW limit at Jan Wapstraat. Local network expansion enables physical connection but does not resolve this upstream constraint. A central case condition is therefore the temporal mismatch between project delivery and network reinforcement. Near-term projects add demand while Jan Wapstraat is already congested, and structural reinforcement is planned only for the end of 2036 and remains dependent on TenneT. This creates a constrained development period in which the timing and coordination of project and infrastructure decisions become increasingly important. Chapter 5 examines the institutional conditions under which flexibility could be organised during this period, and Chapter 6 assesses its technical effect on cumulative station loading.

5 Institutional feasibility and governance of flexibility

5.1 Qualitative method

5.1.1 Interview data

The institutional analysis is based on four semi-structured stakeholder interviews, supported by documentary evidence where findings concern formal procedures, project characteristics or electricity-system conditions. Details about the dates and durations of the interviews can be found in table 5.1. The interviews were used to examine how actors involved in Laakhavens Hollands Spoor understand grid access, flexibility and the conditions under which flexibility could be implemented. Documents provide the formal position on matters such as connection procedures and adopted development plans, while interviews reveal practical uncertainties, actor preferences and dependencies that are not fully visible in those documents.

Respondents were selected purposively because their organisations represent distinct positions within the same case. COD and Redevco provided the perspectives of developers responsible for project delivery, investment decisions and the future transfer of completed properties. The Municipality of The Hague provided an area-development perspective, including coordination between public and private actors. Stedin provided the distribution-system perspective on connection procedures, transport capacity and congestion management. The interviews followed a common protocol covering project phasing, electricity connections, flexibility measures, ownership, operational control, costs, coordination and implementation conditions. Follow-up questions were adapted to each respondent's expertise, consistent with the purpose of semi-structured interviewing (DeJonckheere & Vaughn, 2019; Kallio et al., 2016). The full protocol is included in Appendix A.

Table 5.1. Overview of interviews.

Organisation	Actor perspective	Date	Duration	Format
COD	Developer	02-04-2026	36 minutes	Microsoft Teams
Redevco	Developer	15-04-2026	28 minutes	Microsoft Teams
Municipality of The Hague	Municipality	09-04-2026	34 minutes	Microsoft Teams
Stedin	Distribution system operator	04-04-2026	30 minutes	Microsoft Teams

The interviews were conducted through Microsoft Teams and transcribed using its transcription function. Respondents were offered the opportunity to review a transcript or interview summary and indicated that this was not necessary.

5.1.2 Coding and thematic analysis

The transcripts were divided into substantively coherent fragments and coded manually in Excel. Each fragment retained an interview label and unique identifier. This allowed claims to be traced to their original context and made it possible to distinguish respondent evidence from questions or hypotheses introduced by the interviewer. Analytical findings were based primarily on respondent statements. Interviewer prompts were used only to interpret the response that followed and were not treated as independent evidence.

The first coding round was predominantly inductive. Descriptive codes were assigned without imposing a closed codebook in advance. Codes were subsequently compared, combined and organised into higher-order themes. Across the four interviews, 407 substantively relevant fragments were coded: 112 for COD, 100 for Redevco, 115 for the municipality and 80 for Stedin. These counts indicate the extent of the analysed material, not the importance of a theme. Relevance was determined by the relationship between a fragment and the research questions, the clarity of the evidence and its consequences for technical relevance or institutional feasibility.

The analysis then moved from descriptive coding to thematic interpretation. Following Braun and Clarke (2006), patterns were identified within and across interviews. The later interpretive step was abductive: themes emerging from the interviews were compared iteratively with the research questions and the analytical concepts established in Chapter 2 (Timmermans & Tavory, 2012). This made it possible to distinguish what respondents explicitly reported from the institutional interpretation developed in this chapter. The coding workbooks contain the fragments, codes, themes and analytical memos; a representative excerpt is included in Appendix B.

5.1.3 Cross-actor comparison and qualitative assessment

The interviews represent different institutional positions rather than separate cases. Cross-actor comparison was therefore used to examine how the same capacity problem appears from the perspectives of project delivery, area coordination and network operation. Agreement across actors strengthened a case-level finding. Differences were interpreted in relation to the respondent's responsibilities and access to information rather than resolved by majority judgement. Formal statements about procedures, capacity and adopted plans were checked against official documents where possible. Where an interview statement and an official document differed, the document was used to establish the formal rule, while the interview was retained as evidence of how that rule was understood in practice. Themes were retained when they were supported across perspectives or when an actor-specific issue had material consequences for implementation.
Institutional feasibility was assessed at the level of a specific arrangement, not the technology in general. Table 5.2 defines the categories used throughout the chapter.

Table 5.2. Qualitative assessment categories.

Assessment	Interpretation
Established	The principal actors, authority and implementation arrangements can be identified in the case, and no material institutional barrier was found.
Conditionally feasible	A plausible implementation pathway exists, but one or more necessary agreements, responsibilities or incentives remain unresolved.

Assessment	Interpretation
Not currently demonstrated	The evidence does not identify a case-specific actor or arrangement capable of mobilising the measure for the stated objective.
Institutionally constrained	A concrete regulatory, contractual or organisational barrier restricts implementation or operation.

Absence of evidence was not treated as evidence that an arrangement is impossible. It resulted in the classification *not currently demonstrated* unless the interviews or documents identified a specific barrier.

5.2 Analytical orientation

Four connected findings structure the results. First, grid access is path dependent and connection specific: projects in the same congestion area do not enter redevelopment with the same contractual position. Second, the spatial and thermal programme is more developed than the organisation of electrical flexibility, and the identified measures differ substantially in implementation maturity. Third, a shared asset is not automatically a station-oriented flexibility resource because the scope of an asset and its operational objective are separate dimensions. Fourth, the present allocation of responsibilities and risks favours control within project boundaries, while coordinated operation for the wider Jan Wapstraat constraint has not yet been demonstrated.

Together, these findings reveal the institutional urgency of the case. The two interviewed developers are already making decisions about connections, energy systems and project dependencies. Their evidence indicates a preference for arrangements that remain controllable within their own development boundaries. This direction is understandable from the reported concerns about delivery risk, dependence on other projects and future transferability, but it can also consolidate a fragmented development pattern before area-level control has been organised. The following sections establish this interpretation from the interviews and supporting documentation.

5.3 Grid access is path dependent and connection specific

Chapter 4 established that Laakhavens Hollands Spoor is located within the constrained Jan Wapstraat supply area. At project level, however, congestion is mediated by contractual and procedural conditions. A physical connection, contracted transport capacity, a submitted application, a waiting-list position and eligibility for societal priority are related but distinct. Prioritisation may affect allocation order without creating physical capacity, while existing infrastructure does not automatically provide a right to the capacity required by a future programme. Grid scarcity therefore also produces procedural and distributive questions about access (de Winkel et al., 2025).

5.3.1 Unequal starting positions and the limits of reuse

The contrast between MegaStores and Escher Gardens demonstrates that projects within the same station area can have materially different starting positions. COD is mapping the existing connections, transformer stations, contract holders and contracted capacity at MegaStores. As tenants leave, COD intends to retain both the connections and the associated contracts where possible, and to compare the retained position with the expected requirements of MRKT. At the same time, COD does not treat reuse as certain and, for planning purposes, also considers the redevelopment as a new project that

may require new capacity (Interview COD). The municipality likewise advised developers not to terminate existing connections before their possible future use had been assessed (Interview Municipality of The Hague).

Escher Gardens has no comparable legacy position. The project is being developed mainly on an existing parking area and had not yet reached the level of specification normally required for an address-based application at the time of the interview. Redevco was therefore exploring a generic application in cooperation with the municipality (Interview Redevco). The difference is consequential: MegaStores must manage the continuity and compatibility of existing rights, whereas Escher Gardens depends more directly on obtaining new rights through the application process.

Existing connections are valuable but not freely convertible. Stedin explained that a large-user connection may, under connection-specific conditions, be retained during redevelopment by relocating it temporarily within the same parcel. A large-user connection cannot, however, simply be exchanged for the numerous small-user connections required for individual dwellings. Those residential connections require separate applications. If an existing large-user connection is cancelled, the released capacity enters the general allocation process rather than remaining reserved for the site or Laakhavens (Interview Stedin). Reuse is therefore most plausible when the future function remains compatible with the connection, for example a commercial function, collective charging infrastructure or a WKO/ATES installation, rather than when one large connection must be transformed into many residential connections.

These findings support a case-specific form of path dependence. Previous land use and earlier connection decisions influence the options available during redevelopment. They do not determine the outcome, because retained capacity may still prove unsuitable or insufficient, but they shape which strategies can realistically be pursued. Grid access is consequently not a generic resource attached to the spatial programme. It is connection specific and partly inherited from decisions made before the present redevelopment.

5.3.2 New capacity, prioritisation and responsibility

Where retained capacity is insufficient, application timing becomes part of development strategy. A project needs sufficient maturity to specify its demand, but waiting for full design certainty may weaken its position in the allocation process. This tension was visible in both developer interviews. Redevco was considering an earlier generic application because the final address-level information was not yet available, while COD observed that regulatory changes were moving connection questions towards an earlier stage of development (Interview Redevco; Interview COD).

The applicable allocation framework adds a second distinction between connection types and programme components. Until 1 July 2026, new and enlarged small-user connections in Stedin's service area did not enter the congestion waiting list, although larger commercial and collective connections within the same development could already be affected (Stedin, n.d.-c). From 1 July 2026, small-user requests also enter the waiting-list system and housing may qualify as a basic societal need within priority category 3. A complete application date remains relevant within the category, and priority does not guarantee that capacity will be available when a project requires it (ACM, 2025; Stedin, n.d.-c). Mixed-use development further complicates the position. Facilities that are necessary and proportionate to the residential function may under certain conditions be included

with a housing request, but independently operating offices, retail, mobility facilities and collective installations do not automatically receive the same treatment as housing (Stedin, n.d.-b).

Stedin's *Eerder aanvragen in het bouwproces* procedure allows municipalities and authorised developers to submit requests by development phase before every address is finalised. This can align the application process more closely with long development timelines, but it cannot reserve capacity that is physically unavailable (Stedin, n.d.-b). The municipality can coordinate information and support earlier applications, while developers remain responsible for arranging their project connections with Stedin (Interview Municipality of The Hague). Area-level coordination therefore affects the process without replacing connection-level responsibility.

The implication is that flexibility and grid access must not be conflated. A measure behind a project connection may lower the contracted or requested capacity needed by that project. A reduction in the aggregated Jan Wapstraat peak, however, does not automatically reserve equivalent capacity for the project providing it. The congestion assessment indicates that identified flexibility would first support network reliability and autonomous growth and is insufficient to accommodate all new requests (Stedin, 2025; Stedin, n.d.-a). Translating station-level peak reduction into development access would therefore require verification, commitment and an allocation arrangement in addition to the technical effect. The most direct institutional benefit currently arises when a project can use flexibility to manage its own connection requirement.

5.4 Flexibility is unevenly developed across measures

The interviews identify smart EV charging, battery storage and controllable WKO/ATES operation as the principal flexibility options. Grid-aware building operation and local generation may complement them. Their technical relevance is assessed here only to establish whether a credible flexibility mechanism exists. Chapter 6 quantifies the possible magnitude. The central institutional question is whether the asset, responsible actor and operating conditions can already be identified in the case.

5.4.1 Smart EV charging

Smart charging has the clearest implementation basis. Charging demand will form part of the redevelopment, both within individual projects and in the planned mobility hub with up to approximately 2,000 parking spaces. COD reported that load balancing is becoming familiar in development practice. Charging points can be placed behind a shared connection and their power reduced or postponed when other building demand approaches the connection limit. This creates a tangible control point, although flexibility remains limited by parking duration, the required state of charge at departure and the number of connected vehicles (Interview COD; Interview Municipality of The Hague).

Stedin also identified grid-aware charging as a relevant means of reducing peak demand and stressed that the effect depends on the control regime. Charging that is merely price responsive does not necessarily coincide with the network constraint. Future charging infrastructure in Laakhavens was not part of the flexibility identified among existing users, so its potential must be created as part of the redevelopment (Interview Stedin). The municipality expects substantial charging activity around project parking and the planned mobility hub, but the number and power of charging points and future EV uptake were not fixed at the time of the interview (Interview Municipality of The Hague).

Dutch research supports the relevance of managed charging while also showing why availability cannot be assumed. Aggregated charging can provide congestion-management services, but dependable capacity varies with connection duration and user behaviour (Panda & Tindemans, 2024). Controlled charging aimed at network conditions can reduce congestion more effectively than charging driven mainly by electricity prices (Verbist et al., 2023). Smart charging is therefore conditionally feasible at project or parking-facility level. Charging infrastructure is expected and a control mechanism is familiar, but the responsible operator, user-service constraints and precise control objective must still be specified. Operation across several projects for the Jan Wapstraat constraint has not been demonstrated.

5.4.2 Battery storage

Battery storage is technically suitable for short-duration peak shaving and load shifting, but it is less institutionally developed in the case. Neither interviewed developer had incorporated a battery into a committed project design. COD had not formally assessed neighbourhood or household storage, although a transformer combined with a battery was considered a plausible way to keep a project within available connection capacity. The respondent expected a specialised energy or infrastructure company to be a more likely operator than the developer, while financing and responsibility remained open (Interview COD).

Redevco similarly treated batteries as a possible option rather than a decided component. The interview raised constraints concerning scarce technical space, the separation between building ownership and residents' electricity consumption, the allocation of benefits and the consequences of long-term contracts for later property transactions. In residential development, one investor may provide the asset while many occupants retain individual energy contracts. A technically controllable battery therefore does not by itself determine who may dispatch it, who pays for it or how residents benefit (Interview Redevco).

Stedin confirmed that future batteries could damp peak power, but these assets do not yet exist in the case and were not included in the flexibility identified in the congestion assessment (Interview Stedin). Their contribution also depends on location, capacity and dispatch strategy. Battery operation optimised for market prices or self-consumption will not necessarily coincide with the Jan Wapstraat peak, and charging shifts rather than eliminates electricity demand (Stecca et al., 2020). Battery storage is consequently conditionally feasible only in a broad sense. A credible technical mechanism and possible third-party role exist, but no case-specific arrangement yet assigns location, investment, connection, operation or control objective.

5.4.3 WKO/ATES

WKO/ATES occupies a different position because the thermal infrastructure is already part of the development direction. The municipal strategy identifies collective heat and cold infrastructure and an Eteck concession, and both interviewed developers expect their projects to connect to a WKO/ATES system (Gemeente Den Haag, 2025b; Interview COD; Interview Redevco; Interview Municipality of The Hague). The thermal asset is therefore more institutionally embedded than battery storage. Its use as electrical flexibility is not.

Heat pumps, circulation pumps and auxiliary equipment create electricity demand. Aquifer storage, buffers and building thermal mass may allow part of that demand to move in time, which can provide

electricity-demand flexibility (Fleuchaus et al., 2018; Finck et al., 2017). The operating margin is nevertheless constrained by heating, cooling and hot-water requirements, equipment limits and the thermal state of the system. A WKO/ATES system cannot be treated as a fixed quantity of continuously available electrical flexibility.

The interviews show that the required electrical arrangement remains unresolved. COD identified heating and cooling as a significant future load but could not confirm whether the relevant connection capacity would be organised centrally by Eteck or within project connections. The municipality indicated that the scale of the system was still under discussion, including collective and more clustered configurations. Redevco recognised that combining residential, office and other functions with different heating and cooling profiles could create scale and balancing benefits, but emphasised that a larger shared system also creates dependencies between projects, operators and future owners (Interview COD; Interview Redevco; Interview Municipality of The Hague). Stedin considered future WKO/ATES demand potentially controllable, while noting that unconnected future assets were not part of the flexibility already identified at Jan Wapstraat (Interview Stedin).

WKO/ATES is thus established as planned thermal infrastructure, but its operation as electricity flexibility is not currently demonstrated. The presence of shared thermal infrastructure does not establish available electrical operating freedom, access to station data, authority to change operation or an incentive to respond to the Jan Wapstraat constraint. This distinction is central to the framework developed in Section 5.6.

5.4.4 Complementary measures

Grid-aware building operation, photovoltaic generation and Hyer Power occupy supporting or exploratory positions. Stedin identified coordinated control of building installations, including ventilation, pumps, lifts and charging infrastructure, as a means of lowering simultaneous demand. No project-specific package or responsible controller was identified, so this remains a design principle rather than an established arrangement (Interview Stedin).

Photovoltaic generation can reduce grid import when production coincides with demand, but it is not dispatchable. Redevco also identified limited roof area and competition with technical uses in high-density development (Interview Redevco). PV remains relevant to annual electricity demand but cannot be assumed to deliver dependable peak reduction at Jan Wapstraat.

Hyer Power is considered only as an exploratory form of controllable local generation. The PHIAB 9080 is described as a hydrogen-fuelled combined heat and power unit with stated outputs of 90 kWp electricity and 80 kWp heat (Hyer Power, n.d.; YES!Delft, 2025). It did not emerge from the stakeholder interviews and is not part of the current municipal or developer programme. Hydrogen supply, safety, spatial integration, heat use, costs, ownership and operation would all need to be established. It should therefore be treated as an exploratory modelling option, not as an empirically supported implementation pathway.

Table 5.3 compares the measures without equating technical relevance with implementation maturity.

Table 5.3. Case-specific assessment of flexibility and generation measures.

Measure	Case relevance	Current implementation basis	Principal unresolved conditions
Smart EV charging	Material future load that can partly be shifted	Charging infrastructure is expected and project-level load balancing is familiar	Operator authority, user requirements, data access and alignment of the control objective
Battery storage	Directly controllable short-duration peak shaving and load shifting	Considered technically plausible, but not committed by either interviewed developer	Location, sizing, financing, ownership, connection, operation and dispatch objective
WKO/ATES control	Major electrical load with possible thermal operating freedom	Thermal infrastructure and concession are part of the development direction	Final system scale, electrical connection responsibility, thermal margins, control rights and incentives
Grid-aware buildings	Reduction of simultaneous building demand	Identified by Stedin as a relevant design principle	Identification of controllable assets and operational authority
Photovoltaic generation	Variable local generation that may reduce daytime import	Expected in new development but constrained by roof and technical space	Available surface and coincidence with the station peak
Hyer Power	Potentially controllable local electricity and heat generation	No case-specific commitment or implementation pathway	Hydrogen supply, safety, permitting, heat use, space, costs, ownership and operation

The comparison shows a maturity gap rather than a single ranking of technologies. Smart charging is closest to existing project practice. WKO/ATES is embedded as a thermal service but not as an electrical flexibility resource. Battery storage is technically credible but organisationally unassigned. The remaining measures are supporting or exploratory. The redevelopment programme is therefore more advanced in determining what will be built than in determining how electrical demand could be controlled in relation to the station constraint.

5.5 Governance favours project-bounded control

Technical relevance becomes institutionally meaningful only when actors can invest, operate and accept the consequences of control. Across the interviews, the unresolved issues concern not one missing actor but the configuration of ownership, authority, coordination, incentives and long-term responsibility. The evidence also indicates why project-bounded arrangements currently have a stronger implementation basis than collective grid operation.

5.5.1 Ownership, control and responsibility

Ownership does not automatically confer all rights required for flexibility. Investment, connection responsibility, maintenance, operational control, data access and liability may be distributed among a

developer, building owner, specialised operator and users. A developer may host an asset without operating it, while an operator may control an asset without owning the property or holding the electricity connection. The relevant question is therefore not simply who owns a battery, charging system or WKO/ATES installation, but who is authorised and obliged to modify its operation for a specified objective.

COD considered external operation more plausible for a possible transformer and battery configuration because energy supply and long-term technical operation do not fit naturally with the developer's role in delivering and transferring real estate. This avoids assigning the operational task to the developer, but it leaves investment, connection responsibility, dispatch and performance risk to be agreed (Interview COD). Redevco identified a related separation in residential buildings: a building owner might invest in a shared asset while residents purchase and pay for electricity individually. The presence of an owner and technical operator is therefore insufficient unless user rights, financial obligations and access to consumption or charging data are also addressed (Interview Redevco).

WKO/ATES illustrates the same distinction in another form. A concession holder can operate the thermal system for reliable heat and cold delivery, but this does not establish authority or incentive to adjust electricity demand for station congestion. Across the measures, no single ownership model is required. Project ownership, third-party operation and concession-based operation could each be workable. Institutional feasibility depends on whether the complete chain of responsibilities is internally consistent and matched to the intended control objective.

5.5.2 Coordination and project dependencies

The clearest evidence for the current development direction concerns dependencies between projects. COD stated a preference for solving problems within its own project framework and keeping projects separate where possible. Area solutions require agreements with other developers, and COD associated those links with vulnerability: delay or non-participation by another party could impede its own delivery. The preference is therefore specifically connected to control over timing and implementation risk, rather than a general rejection of cooperation (Interview COD).

Redevco described a comparable tension for collective WKO/ATES and multi-building energy concepts. Combining different demand profiles may create technical or financial benefits, but a failure or contractual problem elsewhere in the shared system can affect another development. The arrangement must also remain acceptable to a later buyer. Redevco consequently treated legal and contractual design as at least as important as technical and financial performance (Interview Redevco). The municipal interview confirms the coexistence of these scales: the municipality uses a cooperation agreement for common subjects and shared infrastructure, while developers primarily evaluate decisions through their own development frameworks (Interview Municipality of The Hague). The combined evidence indicates a structural coordination problem. Each interviewed developer seeks to protect project delivery from dependencies that it cannot control, while station-oriented flexibility requires some combination of shared signals, commitments or operational coordination.

Literature on collective energy arrangements similarly shows that organisational roles, decision rules and the distribution of control are essential and cannot be inferred from the presence of a shared technology (Walker & Devine-Wright, 2008; Caramizaru & Uihlein, 2019). In Laakhavens, cooperation

exists at area-development level, but the interviews do not demonstrate an operational arrangement through which electrical assets across projects respond to Jan Wapstraat.

This creates the main institutional urgency identified in Chapter 5. Connections, technical designs and property arrangements are being developed now, mainly within separate project processes. The case evidence shows that collective electrical control has not yet been incorporated into those processes. Viewed through the literature on institutional path dependence, this creates a risk that later coordination will require the renegotiation or modification of already embedded contracts, responsibilities and technical systems. The evidence does not show that a fragmented outcome is inevitable. It shows that fragmented project optimisation is presently better aligned with the reported responsibilities and risk considerations than collective grid control.

5.5.3 Costs, benefits and incentives

Coordination also depends on whether the actor providing flexibility receives sufficient value. The interviews reveal a potential mismatch between the location of investment, operational restrictions and benefits. Flexibility behind a project connection may lower the capacity requested by that project or help it remain within retained contracted capacity. Those benefits can be captured relatively directly. When the same asset is operated to reduce the aggregated Jan Wapstraat peak, part of the benefit accrues to the wider network or development area while costs and service restrictions remain with the asset owner, operator or user.

The issue is especially visible in residential battery arrangements. Redevco questioned how residents would benefit when a building owner finances an asset but occupants retain individual electricity contracts. A service-charge mechanism was discussed as one possibility, not as an established project arrangement (Interview Redevco). COD likewise left open who would finance a battery and how a specialised operator would recover its costs (Interview COD). These findings correspond with a split-incentive problem in which the decision-maker and beneficiary are not necessarily the same party (Gillingham et al., 2012). For flexibility, the division may involve the property investor, connection holder, operator, resident and network beneficiary simultaneously.

Comparable trade-offs apply to smart charging and WKO/ATES. Charging control may support a project or station constraint while users accept slower charging. WKO/ATES operation may shift electrical demand while the operator remains accountable for heat and cold service. Avoided connection costs, reduced contracted capacity, energy savings, service charges, operator payments or flexibility contracts could provide value, but the interviews did not identify one mechanism that is established across measures. Research on collective energy business models likewise indicates that viable arrangements depend on the specific technology, actors and value proposition rather than a universal ownership or revenue model (Kubli & Puranik, 2023). A station-oriented objective therefore requires not only control authority but also an incentive or compensation mechanism matched to the actor accepting the constraint.

5.5.4 Durability and transferability

Institutional feasibility must extend beyond development and initial operation. Redevco repeatedly linked collective energy decisions to the future saleability of buildings. A buyer inherits contracts,

service obligations and dependencies that may have been designed by the developer. If these are unclear or difficult to manage, the energy arrangement can become a transaction risk and may affect whether a buyer accepts the property (Interview Redevco). This concern also explains why an arrangement that is technically and financially plausible during development may still be rejected. Durable arrangements require transparent rules on service levels, tariffs, maintenance, data access, operational authority and liability. They also need procedures for changes in owners, users, technologies and operators. Third-party operation may remove day-to-day technical responsibilities from a building owner, but creates a long-term contractual dependency that must remain acceptable to successors. WKO/ATES can create particularly durable interdependence because buildings rely on the thermal service throughout operation. Batteries and charging systems may be physically replaceable, but their control and payment arrangements can still become embedded in property and service contracts.

Transferability is therefore not a secondary legal detail. It is an implementation condition that shapes current developer choices. Together, the evidence on coordination, incentives and transferability explains the preference for arrangements within project boundaries more precisely than a general claim that actors are unwilling to cooperate. The interviews show which responsibilities and dependencies they seek to control. They do not yet show a collective arrangement that reallocates those risks credibly.

5.6 Asset scope and control objective are separate dimensions

The interview evidence does not support a simple opposition between individual and collective flexibility. The term collective can refer to shared infrastructure, cooperation between organisations or operation for a wider network objective. These features may coincide but are not equivalent. The framework in Table 5.4 therefore distinguishes asset scope from control objective. Asset scope concerns whether an asset serves one development or several developments. The control objective concerns whether operation primarily protects the participating project or responds to the aggregated Jan Wapstraat constraint. Legal ownership is not used as a separate axis because an externally owned asset may still serve only one project.

Table 5.4. Individual and collective flexibility framework.

Asset scope	Project-level control objective	Collective grid control objective
Project-based assets	**Fragmented project optimisation.** Each development controls its own assets to protect its connection, reduce its peak or maintain user service. Examples include smart charging within one parking facility or a project battery used for local peak shaving.	**Coordinated project flexibility.** Assets remain attached to separate developments but respond to a shared signal or coordinating arrangement. Examples include project charging systems or batteries coordinated to reduce coincident loading at Jan Wapstraat.
Area-based assets	**Shared asset with participant-oriented operation.** Several developments use one asset or infrastructure system, while operation primarily serves participant costs, service requirements or internal performance. A shared WKO/ATES system operated for thermal-service delivery fits this configuration.	**Integrated area flexibility.** A shared asset or portfolio is explicitly operated to reduce area-level electricity demand during the Jan Wapstraat peak. Possible examples include coordinated mobility-hub charging, shared storage or WKO/ATES operation responding to the station constraint.

This distinction changes the interpretation of shared infrastructure. A shared WKO/ATES system remains participant oriented when it is controlled only to deliver thermal services, even if it serves multiple developments. It becomes integrated area flexibility only if station loading is incorporated into the operating objective and the operator has the data, authority and incentive to respond. Conversely, separately owned charging systems can constitute coordinated flexibility if their operation follows a shared grid objective. This is consistent with literature showing that aggregation, asset ownership and operational coordination are analytically distinct. A shared or commercially aggregated portfolio does not automatically respond to a common network constraint, while separately owned resources can be coordinated when their information and control arrangements are aligned with that objective (Mancarella, 2014; Charbonnier et al., 2022).

5.6.1 Current trajectory

The current trajectory is fragmented project optimisation. This conclusion follows from converging evidence rather than from the absence of a single area battery or other technology. COD seeks to resolve capacity and flexibility issues within its own boundaries and limit dependencies on other developments. Redevco assesses collective energy arrangements partly through contractual dependency and future saleability. The municipality coordinates common development matters, but also observes that developers primarily work from their own project frameworks. Stedin identified possible future flexibility assets, but no arrangement through which assets across developments would be controlled for Jan Wapstraat (Interview COD; Interview Redevco; Interview Municipality of The Hague; Interview Stedin).

The planned WKO/ATES infrastructure is closest to the lower-left configuration: a shared asset with participant-oriented operation. A collective thermal system is expected, but its primary demonstrated purpose is heat and cold supply. No evidence establishes station-responsive electrical operation. The two configurations with a collective grid objective are therefore not currently demonstrated. This is not a finding of technical impossibility. It means that a coordinating actor, data exchange, control authority, participation commitments, compensation and transferable agreements have not been established in the available evidence.

The framework clarifies the direction of travel without turning this results chapter into a strategy chapter. Project-level control corresponds most closely with current responsibilities and reported risk preferences. Collective grid control could align operation more directly with the shared constraint, but requires an additional governance layer that is presently absent. The strategic implications and possible development pathways are considered in Chapter 7.

5.7 Synthesis

Table 5.5 summarises the maturity of the measures selected for quantitative assessment. The categories concern their case-specific implementation for the stated objective, not the general maturity of the technologies.

Table 5.5. Synthesis of technical relevance and institutional feasibility.

Measure	Technical relevance	Institutional assessment	Role in Chapter 6
Smart EV charging	Future charging demand is material and partly shiftable within vehicle and user-service constraints.	Conditionally feasible at project or parking-facility level. Cross-project operation for Jan Wapstraat is not currently demonstrated.	Core flexibility measure under different control levels.
Battery storage	Provides short-duration peak shaving and shifts electricity exchange between periods.	Conditionally feasible at project level if a connection holder, financier and operator are identified. A station-oriented arrangement is not currently demonstrated.	Core electricity-storage measure under assumed conditions.
Flexible WKO/ATES operation	Creates a major electrical load and may offer operating freedom through thermal storage and scheduling.	Established as planned thermal infrastructure. Electrical operation for Jan Wapstraat is not currently demonstrated.	Sector-coupling flexibility measure under explicit assumptions.

Measure	Technical relevance	Institutional assessment	Role in Chapter 6
Hyer Power	Dispatchable local generation could reduce grid import while producing heat.	Not currently demonstrated. No case-specific owner, operator or implementation pathway was identified.	Exploratory local-generation option.

The answer to RQ2 consists of four connected findings. First, grid access is path dependent and connection specific. MegaStores can investigate retention of legacy large-user capacity, while Escher Gardens is more dependent on new applications. Even where capacity exists, connection categories and allocation rules constrain how it can support a future mixed-use programme.

Second, the identified flexibility measures have different levels of institutional maturity. Smart charging is closest to existing project practice. WKO/ATES is embedded as thermal infrastructure but not yet organised as electrical flexibility. Batteries remain plausible but unassigned, and Hyer Power is explicitly exploratory. Technical relevance therefore cannot be used as evidence that an implementation pathway already exists.

Third, shared infrastructure does not automatically constitute station-oriented flexibility. Asset scope and control objective are separate dimensions. A shared thermal system can remain participant oriented, while separate project assets could in principle respond to a collective grid objective. The combined interview evidence and analytical framework indicate that the relevant distinction concerns control authority, operational commitment and alignment with the Jan Wapstraat constraint.

Fourth, the present distribution of responsibilities, risks and incentives favours project-bounded control. The interviewed developers seek to limit dependencies that could affect delivery and future transferability. Existing area-level cooperation does not yet provide the operational governance required to coordinate electrical flexibility across projects. The principal gap is consequently not a lack of technically relevant options, but the absence of a demonstrated arrangement that connects project assets and decisions to the collective Jan Wapstraat constraint. None of the selected measures is institutionally constrained in every possible configuration. However, technical relevance does not establish that the actors and arrangements required for implementation are already present.

This gap creates the urgency emerging from the qualitative analysis. Project connections, energy concepts and contractual structures are being shaped while collective electrical control remains undefined. Continued project-specific optimisation may therefore become embedded before the information, authority and incentive structure for wider coordination has been established. Chapter 6 assesses the technical performance of selected measures under explicit assumptions. Those scenarios should be read as tests of technical potential with different levels of institutional maturity, not as evidence that the required governance arrangements already exist or that reduced station loading automatically produces a contractual right to additional transport capacity.

6 Technical assessment of flexibility

This chapter answers RQ3 by assessing how cumulative development changes electricity loading at station Jan Wapstraat and how the evaluated flexibility measures alter the resulting congestion. The analysis follows the order in which the experiments were performed. It first establishes annual functional demand without congestion-oriented operation. It then activates flexible WKO/ATES as the reference operational layer and evaluates battery storage, smart charging and HyER as additions to that reference. Finally, it compares configurations in which additional flexibility is concentrated in the newly added project with an integrated area-wide portfolio.

The chapter makes an important distinction between the onset and the severity of congestion. The modelled station limit is already exceeded in Phase 2. That first exceedance is small, but it shows that the available margin has effectively been exhausted near the start of the development sequence. The exceedance in Phase 3 is larger and no longer depends on that marginal result. Later phases therefore do not create the capacity problem; they enlarge a constraint that is already present. This cumulative logic is central to interpreting the value and limits of flexibility.

The results are comparative scenario outcomes under stated assumptions. They are not forecasts of realised operation and do not establish contractual access to transport capacity. Chapter 5 assesses the institutional setting, while Chapter 7 connects that setting to the technical implications identified here.

6.1 Quantitative method and experiment design

6.1.1 Model purpose, inputs and system boundary

A linear optimisation model was developed in Linny-R to assess hourly electricity loading at Jan Wapstraat as projects are added cumulatively. Linny-R translates production, conversion, storage and transport relations into a linear or mixed-integer linear optimisation problem (Bots, 2023), which was solved with Gurobi (Gurobi Optimization, LLC, 2026). The model determines the least-cost feasible hourly operation of the represented energy system. Grid electricity and other operational inputs are valued through the applied cost and price parameters, while electricity, heating, cooling, mobility and storage services remain subject to their technical constraints.

In the constrained experiments, electricity transport through Jan Wapstraat is additionally limited to 38 MW. Congestion is therefore represented as a binding capacity constraint rather than as a separate optimisation objective. When an otherwise cost-optimal operating schedule is incompatible with this limit, the model can redispatch available WKO/ATES flexibility, battery storage, smart charging and HyER within their respective operating constraints. Energy Not Served is available at a high penalty as a last-resort representation of project demand that cannot be supplied within the active station, take-off and operational constraints. The model is used to compare technical configurations rather than to assess investment profitability, predict actor behaviour or allocate contractual transport rights.

Table 6.1 summarises the model purpose, main inputs, optimisation logic, congestion representation and reported outputs. The detailed system representation, technology parameters and scenario settings are reported in Appendix C.

Table 6.1. Summary of quantitative model inputs, optimisation and outputs.

Element	Specification
Purpose	Assess how cumulative redevelopment and selected flexibility configurations affect electricity loading and residual congestion at Jan Wapstraat.
Main inputs	Development programme and phasing; electricity-demand intensities and hourly profiles; station reference profile; electricity prices; and technology and scenario parameters.
Optimisation	Least-cost feasible hourly operation. In the constrained experiments, electricity transport through Jan Wapstraat is limited to 38 MW and flexible resources can adjust operation within their technical and service constraints.
Congestion representation	Demand that cannot be supplied within the active station and operational constraints is represented through highly penalised Energy Not Served.
Reported outputs	Annual corrected functional peak and threshold exceedance for the unconstrained baseline; residual peak, congestion volume and congestion duration for the constrained flexibility experiments.

The case-specific demand reconstruction used five main input components: the existing and future functional programme, function-specific annual electricity-demand intensities, standard temporal demand profiles, project phasing and a station-level reference profile. Technology, operational and scenario parameters for WKO/ATES, battery storage, EV charging, HyER and local take-off limits were specified separately. The complete parameter set and its sources or modelling assumptions are documented in Appendix C. The existing programme was derived from the municipal area inventory (Gemeente Den Haag, 2025b). Future programmes were compiled from municipal planning documents, project documentation and public project information. Where only gross floor area was available, usable floor area was estimated with a uniform factor of 0.85. The factor is a modelling assumption and not a measured project-specific conversion.

Residential demand was based on average household electricity consumption reported by Statistics Netherlands (CBS, 2025). Non-residential demand was calculated from usable floor area and Dutch function-specific electricity-demand intensities (CBS, 2019). Annual demand was distributed over hourly profiles using the MFFBAS 2026 E1A_AZI_A profile for households (MFFBAS, 2026) and representative profiles from the Liander MOOI EIGEN dataset for offices and other non-residential functions (Liander, 2024). Each profile was normalised and scaled to its annual demand. The applied

programme data, intensity values and assumptions are documented in Appendix C; an example of the resulting functional profile is provided in Appendix D.

The reconstructed existing LHHS demand was embedded in a profile for the wider Jan Wapstraat supply area. Because no measured hourly series for demand outside LHHS was available, residual demand was assigned the same normalised temporal pattern as the reconstructed existing LHHS profile. It was scaled so that the combined station-level reference reached an annual maximum of 36.2 MW, equal to Stedin's projected required transport capacity for 2026 (Stedin, 2025). The 38 MW transport limit was taken from the same congestion assessment (Stedin, 2025).

Both background profiles were held constant across the eight development phases. For existing LHHS, this does not imply that every current function remains operational throughout redevelopment. Existing offices may disappear, be temporarily vacant or be replaced by a larger programme, but the timing and net electricity effect of these changes could not be aligned reliably with the project phases. No speculative phase-specific subtraction was therefore applied. Demand in the remainder of the Jan Wapstraat supply area was also held at the 2026 reference level to isolate the incremental effect of the selected LHHS projects. This excludes subsequent growth elsewhere in the supply area and may therefore underestimate future absolute station loading. The fixed profiles are controlled modelling assumptions, not forecasts that background demand remains unchanged.

The station node consequently supplies four load components: residual demand in the wider feeding area, reconstructed existing LHHS demand, an aggregated block containing projects connected in preceding phases, and the project added in the current phase. The two background demands are exogenous and non-flexible. Each project block contains building demand, EV charging, WKO/ATES and, where activated, battery storage and HyER generation. Both project blocks have a local take-off limit. Load-shedding variables are located within the project blocks, so reported residual congestion represents modelled project demand that cannot be supplied under the station and take-off constraints; it does not represent curtailment of the complete Jan Wapstraat feeding area. Runs caused exclusively by an undersized local take-off were not interpreted as station-level congestion results.

Figure 6.1 summarises the project model. Electricity demand is supplied through project grid import, battery discharge and local HyER generation. WKO/ATES links electricity use to heating, cooling and thermal storage, while smart charging changes the timing of EV demand. Individual projects connect through their take-offs to the shared station constraint.

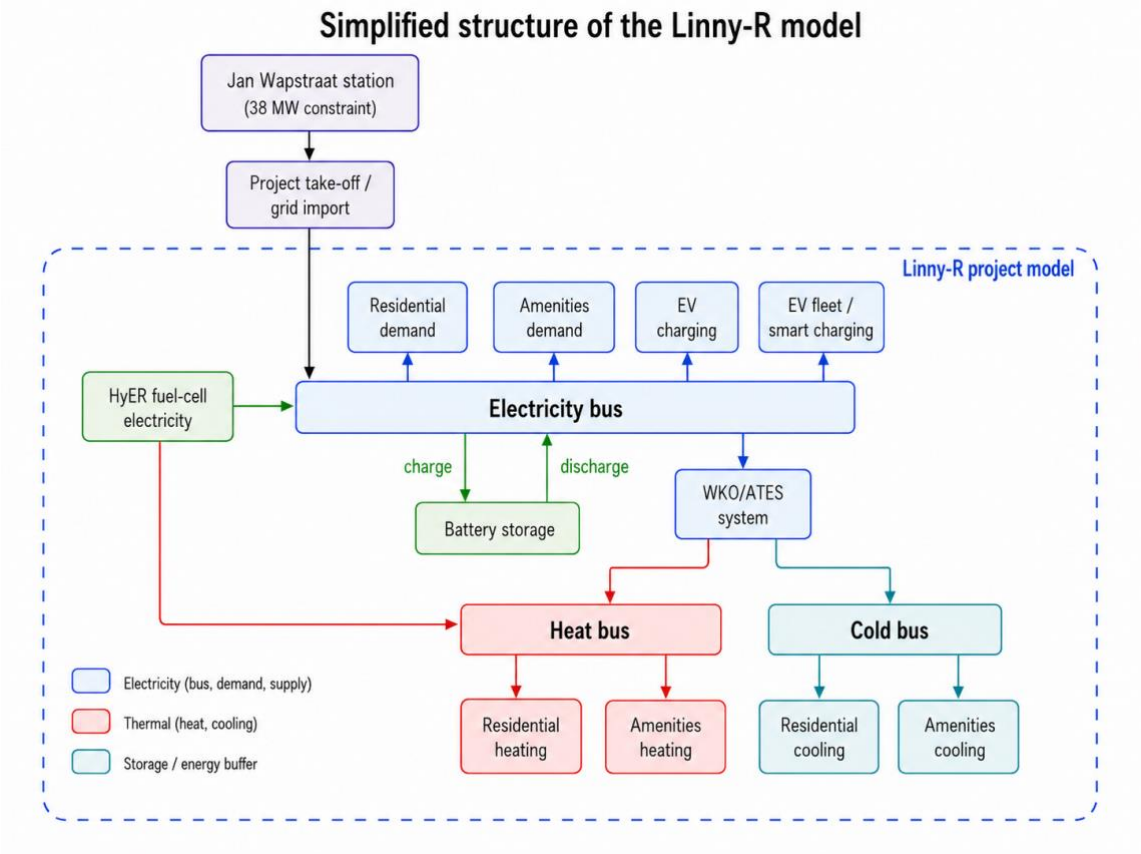


Figure 6.1. Simplified project-level Linny-R block and its connection to Jan Wapstraat.

6.1.2 Baseline construction and performance indicators

Eight cumulative development phases were modelled: Waldorp Four, The Grace, Escher Gardens, Struijck II, Verheeskade 105-197 and 287-329, MRKT, Verheeskade 25 and The Embrace. A phase is therefore a cumulative system state, not an isolated project or an exact calendar year. Each new phase retains all demand and flexibility already introduced in preceding phases.

The annual baseline runs retained the model's cost-minimising operational logic but were performed without the 38 MW station constraint and without congestion-oriented activation of battery storage, smart charging or HyER. Their purpose was to reconstruct annual functional loading and identify when the development programme would exceed the station limit if no flexibility were mobilised for that purpose. Direct electrical heating and cooling could form short price-induced peaks in these unconstrained runs. To prevent those optimisation artefacts from determining the result, the analysis used a corrected functional-load indicator. For each hour, this indicator sums existing-area demand, residential and non-residential building demand, EV charging and WKO/ATES electricity use, while excluding direct electrical heating and cooling processes. The correction was applied to the full hourly series, not as a fixed subtraction from the annual maximum.

$$P_{\text{functional}}(t) = P_{\text{existing}}(t) + P_{\text{residential}}(t) + P_{\text{amenities}}(t) + P_{\text{EV}}(t) + P_{\text{WKO,el}}(t)$$

The corrected functional load is neither measured station loading nor Energy Not Served. It is a consistent indicator of the coincident electricity requirement generated by the included functions. Annual peak, hours above 38 MW and energy above 38 MW are reported for this unconstrained baseline. In the constrained flexibility experiments, station import cannot exceed 38 MW by construction. Remaining congestion is therefore represented by unmet project demand, from which maximum residual congestion, congestion volume and congestion duration are calculated. Congestion volume is its sum over the reporting window and duration is the number of affected hours. The indicators must be read together because flexibility can lower total congestion while shifting the single highest residual peak to another hour.

6.1.3 Simulation horizons

Two simulation horizons serve different analytical purposes. Full-year simulations were used both to establish the unconstrained baseline and to test WKO/ATES flexibility annually. The remaining operational flexibility experiments were conducted over a 672-hour horizon. Timestep 264 is the initial state, timesteps 265 to 432 form a 168-hour preparation period, timesteps 433 to 768 form the 336-hour critical reporting period, and timesteps 769 to 936 form a 168-hour recovery period. The critical reporting period was selected to capture the period surrounding the corrected annual peak identified in the unconstrained baseline simulation. Preparation allows storage and flexible loads to enter the critical period from a plausible state. Recovery reduces the incentive to defer demand or storage replenishment beyond the horizon.

All annual values in Section 6.2 therefore refer to the full-year baseline, whereas congestion volume and duration in Sections 6.3 to 6.7 refer to the 336-hour critical period. The critical period was selected from high loading in the existing-area profile before the flexibility outcomes were inspected. The corrected annual peak subsequently occurred within this period in all phases, providing an ex-post consistency check rather than a basis for selecting a favourable result.

6.1.4 Flexibility layers and experiment design

WKO/ATES flexibility was represented endogenously. Heating and cooling services remained fixed, but thermal storage and conversion could shift part of the associated electricity demand between hours within conversion, storage and temperature constraints. WKO/ATES therefore had no separate on/off selector. Once the Jan Wapstraat constraint was activated, this flexibility was available in every operational experiment. This point defines the experiment sequence.

The Reference pathway is not a no-flexibility case. It is the WKO-only operational reference: the station constraint is active, WKO/ATES can respond, and battery storage, smart charging and HyER are inactive. Battery storage, smart charging and HyER are then evaluated as additional layers on top of that reference. Comparisons between the annual baseline and Reference show the contribution of WKO/ATES; comparisons among operational pathways show the added effect of electrical storage, controllable charging and local generation.

Battery storage followed an hourly energy balance with bounded state of charge and charging and discharging power. New-project capacities of 0, 500 and 1,000 kWh were evaluated. Smart charging allowed 0%, 50% or 100% of EV demand to move within represented vehicle-availability conditions

while preserving the required mobility service and total charging demand. HyER was represented as controllable local electricity and heat generation at 0, 1X or 3X the project-specific base module.

Unlike the demand-shifting measures, HyER reduces grid import through dispatchable generation. Each development phase was represented by a separate model and optimised independently; the phases were not combined within one forward-looking optimisation. Phase 1 contains only Waldorp Four. From Phase 2 onward, all projects connected in preceding phases were aggregated into one inherited portfolio, while the project added in the current phase remained a separate block with its own flexibility selectors. In Phase 3, for example, Waldorp Four and The Grace formed the inherited portfolio and Escher Gardens was represented separately. In Phase 8, the first seven projects formed the inherited portfolio and The Embrace remained separate. The physical amount of inherited demand and flexibility therefore increased as projects were added.

In Phase 1, three battery levels, three smart-charging levels and three HyER levels produced 27 configurations, each tested under three local take-off settings, for 81 runs. From Phase 2 onward, the inherited portfolio followed one of four pathways: Reference, Battery, Smart charging or HyER. The separately represented new project retained the full 27-configuration selector matrix and three take-off settings. This produced 4 x 27 x 3 = 324 runs per phase for Phases 2 to 8, or 2,268 runs. Together with Phase 1, the sequential experiment contained 2,349 runs.

The inherited pathways test whether earlier flexibility investments preserve headroom for later projects. New-project experiments test what can still be achieved when additional measures are concentrated in the project currently being added. A final Phase 8 scenario activates WKO/ATES, batteries, smart charging and HyER across the complete development portfolio and coordinates them around the shared station constraint. This integrated area-wide scenario is an upper technical potential, since it assumes portfolio-wide observability and control. Exact parameters and selector settings are provided in Appendix C.

The distinction between new-project and area-wide configurations concerns the scope across which flexibility resources are made available in the model. It does not represent ownership or governance and should not be equated directly with the four institutional configurations developed in Chapter 5. Institutional implications are considered only when the technical results are integrated with the qualitative findings.

6.1.5 Verification, validation and reproducibility

Verification covered electricity and thermal balances, storage bounds, EV-service requirements, temperature limits, selector activation, solver feasibility and directional behaviour of the flexibility measures. Outputs were exported to CSV and processed through fixed Python mappings. Checks covered time-series length, duplicate runs, missing variables, numerical conversion and the sign convention of Energy Not Served before indicators were calculated. Detailed checks and representative behavioural tests are reported in Appendix D.

Full empirical validation was not possible because the future developments do not yet exist and measured hourly loading at Jan Wapstraat was unavailable. Validation was therefore limited to input consistency, structural plausibility and behavioural verification. The model must consequently be

interpreted as a comparative planning model. It supports conclusions about the relative effects and limits of the evaluated configurations, but not precise forecasts of realised station loading.

6.2 Development of functional electricity demand

6.2.1 Cumulative loading and the loss of station margin

Figure 6.2 and Table 6.2 show the annual corrected functional load before congestion-oriented flexibility is applied. Phase 1 reaches 37.1 MW and remains within the 38 MW station limit. The addition of The Grace raises the unrounded Phase 2 peak to 38.02 MW. The exceedance is only 0.020 MW during one hour, so its exact magnitude should not be treated as a precise forecast. Its analytical significance is nevertheless clear: under the applied assumptions, the remaining station margin is exhausted after the second project phase.

Phase 3 strengthens that conclusion. The corrected peak increases to 39.1 MW, 1.05 MW above the station limit, and exceeds 38 MW during four hours. The identification of an emerging constraint therefore does not rest solely on the marginal Phase 2 result. Phase 4 remains close to this level, after which the challenge accelerates. Peaks rise to 41.2 MW in Phase 5, 43.5 MW in Phase 6 and 45.2 MW in Phase 8. By the final phase, the unconstrained functional profile exceeds the station limit during 438 hours and by 614 MWh annually.

The urgent result is therefore not simply that the final programme requires 7.15 MW more than the station limit at its annual peak. It is that the development sequence consumes the available margin almost immediately, while most of the programme is still to follow. The capacity problem becomes severe later, but the point at which relying on unused station headroom ceases to be a viable development logic occurs much earlier.

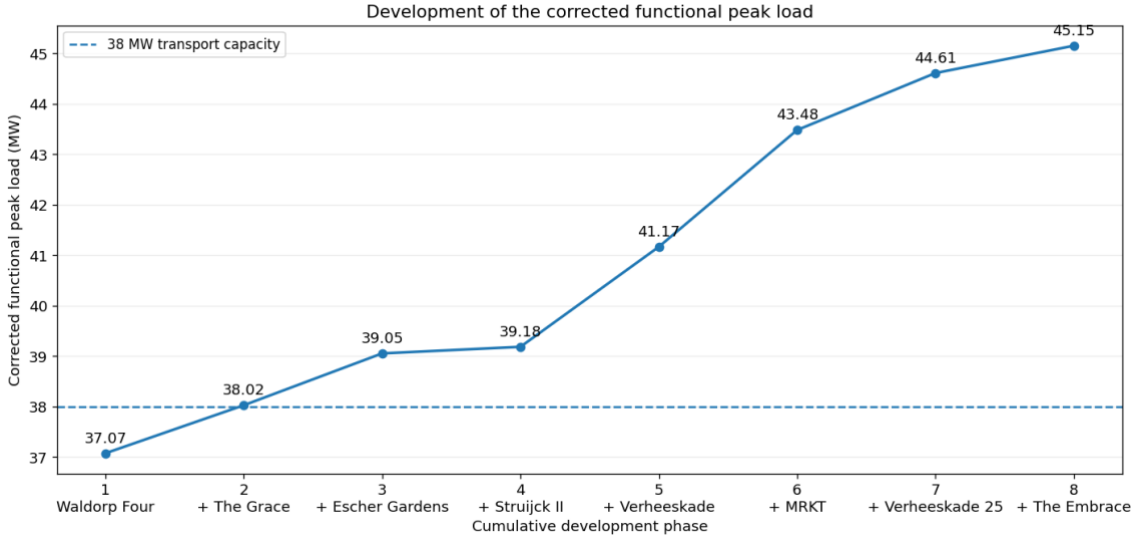


Figure 6.2. Unconstrained annual corrected functional peak at Jan Wapstraat across the eight cumulative phases.

Table 6.2. Annual corrected functional-load indicators.

Phase	Added development	Corrected peak (MW)	Hours above 38 MW	Energy above 38 MW (MWh)
1	Waldorp Four	37.1	0	0

2	The Grace	38.0*	1	0.020
3	Escher Gardens	39.1	4	2.98
4	Struijck II	39.2	5	3.54
5	Verheeskade 105-197 / 287-329	41.2	33	23.5
6	MRKT	43.5	230	202
7	Verheeskade 25	44.6	361	450
8	The Embrace	45.2	438	614

**The unrounded Phase 2 peak is 38.02 MW. Energy above the threshold is unconstrained demand, not Energy Not Served.*

6.2.2 Temporal composition of the final-phase peak

Figure 6.3 shows the 72 hours surrounding the Phase 8 peak within the predefined critical period. The maximum is not caused by one category in isolation, but by the coincidence of high existing-area demand with building and WKO/ATES electricity use. EV charging is relevant to demand and other high-load hours, but is zero at the exact peak at timestep 443. A technology can therefore have substantial flexible demand without being able to relieve the hour that defines the maximum. The timing of flexibility relative to the shared constraint matters more than consumption alone. Building demand is concentrated during daytime hours and is relatively low at night.

The corrected peak occurs at timestep 443 in every phase and lies within the predefined reporting window. The later operational analysis can therefore examine the same system-critical period across configurations without selecting a different window for each technology.

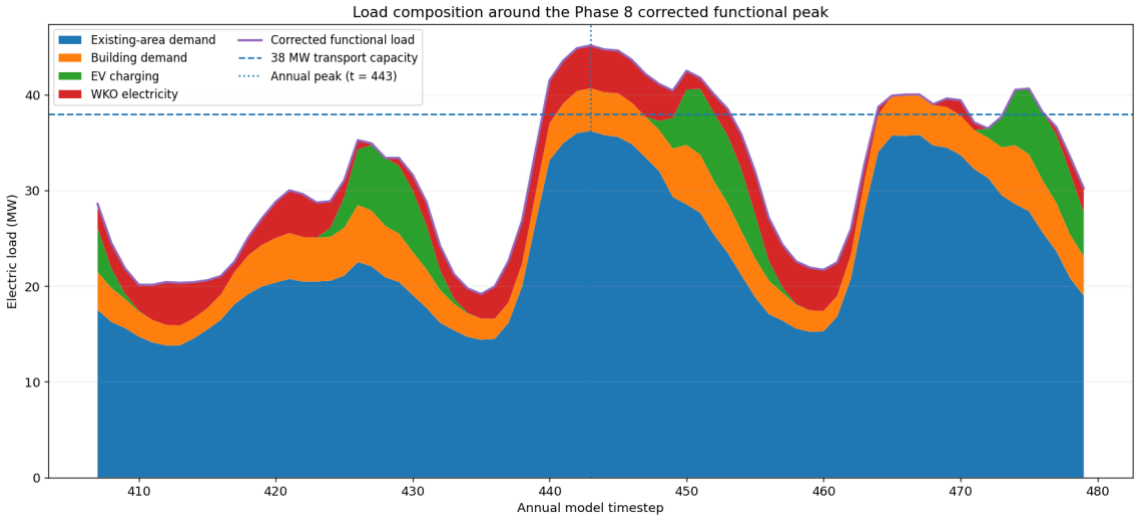


Figure 6.3. Composition of unconstrained Phase 8 functional load during the 72 hours surrounding the annual peak.

6.3 Contribution of WKO/ATES flexibility

6.3.1 WKO/ATES as the first operational layer

The first constrained experiments activate the 38 MW station limit and allow only WKO/ATES to respond. Battery storage, smart charging and HyER remain inactive. This WKO-only Reference is the relevant comparison for every additional flexibility measure.

Figure 6.4a and Table 6.3 show that WKO/ATES eliminates residual station congestion through Phase 4. This is technically meaningful because baseline congestion has already appeared in Phase 2 and is clearly present in Phase 3. Thermal flexibility therefore restores sufficient operational headroom for the first four phases, rather than merely improving a system that was already unconstrained.

The effect reaches its limit in Phase 5. Median residual peak requirement is then 0.60 MW and increases to 1.91 MW in Phase 6, 2.44 MW in Phase 7 and 3.09 MW in Phase 8. The narrow ranges across retained take-off settings show that, after runs caused solely by local connection limits are excluded, the result is governed primarily by the station constraint. WKO/ATES delays the capacity bottleneck, but it does not remove the cumulative effect of the later programme.

Table 6.3. Maximum residual station-congestion power after WKO/ATES flexibility.

Phase	Added development	Median residual peak (MW)	Range (MW)
1	Waldorp Four	0	0-0
2	The Grace	0	0-0
3	Escher Gardens	0	0-0
4	Struijck II	0	0-0
5	Verheeskade 105-197 / 287-329	0.60	0.60-0.60
6	MRKT	1.91	1.91-1.91
7	Verheeskade 25	2.44	2.44-2.44
8	The Embrace	3.09	3.06-3.10

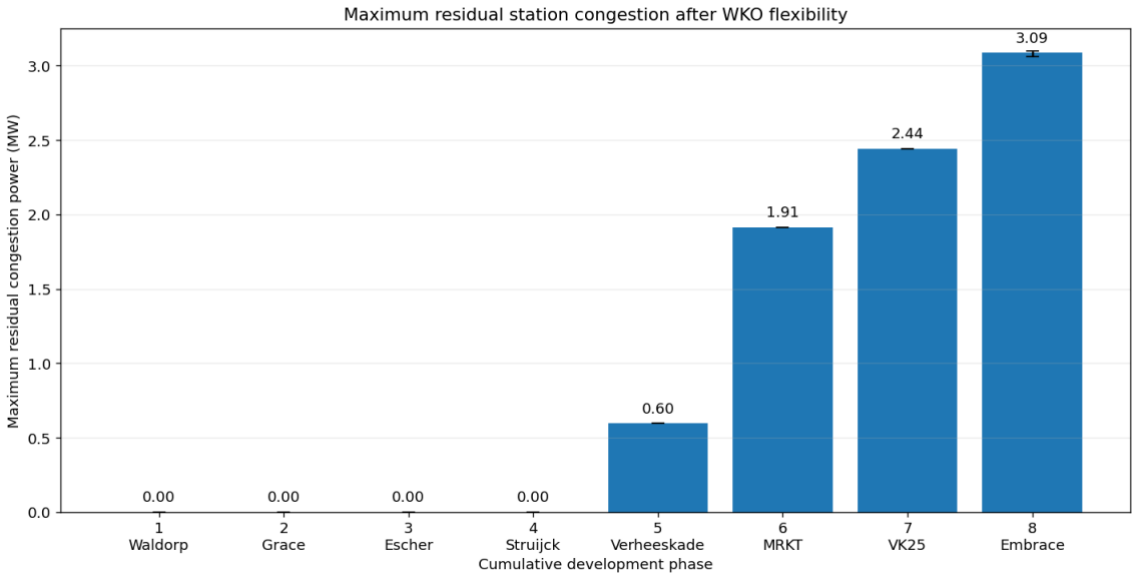


Figure 6.4a. Maximum residual station-congestion power under the WKO/ATES-only Reference pathway. Bars show the median across retained take-off settings.

6.3.2 Operational response during the Phase 3 peak

Figure 6.4b explains how WKO/ATES removes the Phase 3 exceedance. During the critical interval, WKO electricity demand is reduced compared with the unconstrained functional profile. At timestep 443, the difference is approximately 1.05 MW, sufficient to keep Jan Wapstraat within 38 MW. WKO demand is higher in several surrounding hours, which confirms that the thermal requirement is shifted rather than removed. Thermal storage and operating freedom separate the timing of heat and cold production from the timing of service demand.

This mechanism also defines the limitation of the result. The response depends on sufficient conversion capacity, thermal storage and recovery opportunities. It cannot be read as permanent demand reduction. WKO/ATES is best understood as a first flexibility layer that reduces the electrical measures required later. Once residual congestion reappears in Phase 5, the analysis must test whether flexibility accumulated in earlier projects or added to the current project can cover the remaining requirement.

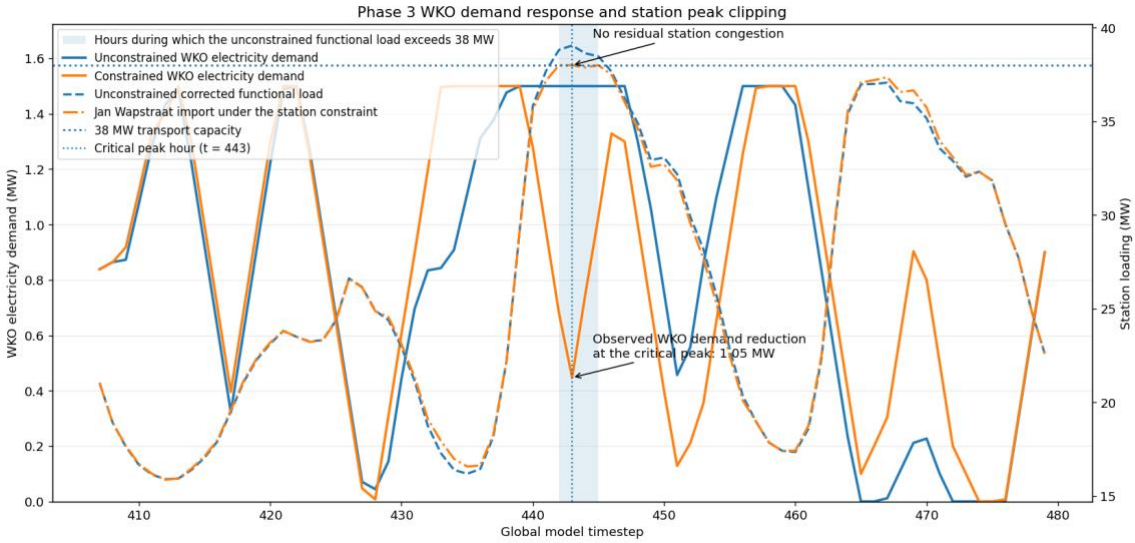


Figure 6.4b. Modelled Phase 3 WKO/ATES load shifting and Jan Wapstraat import around the corrected functional peak.

6.4 Effects of flexibility inherited from previous projects

The inherited pathways assess whether flexibility installed in preceding projects preserves capacity for the project added in the current phase. Battery storage, smart charging and HyER are disabled in the newly added project, while WKO/ATES remains flexible everywhere. Reference therefore means WKO-only; the other pathways add one electrical measure cumulatively across preceding projects.

6.4.1 Effects on peak, volume and duration

Figure 6.5a shows that peak, volume and duration can move differently. In Phase 5, inherited Battery and HyER eliminate the remaining congestion, while inherited Smart charging does not change the reported indicators because the movable EV demand does not coincide with the decisive hours. Earlier flexibility can therefore extend congestion-free development, but only if its operational capability matches the timing and duration of the station constraint.

In Phases 6 and 7, inherited Battery slightly increases the single maximum residual peak relative to Reference while substantially reducing congestion volume and duration. In Phase 7, the peak is about 0.32 MW higher, but congestion volume falls by 42.7 MWh and duration by 34 hours. The battery relieves the original overloaded period and creates a smaller number of more concentrated residual hours elsewhere. Smart charging similarly lowers volume by 4.4 MWh in Phase 6 and 27.1 MWh in Phase 7, and shortens congestion by 13 and 20 hours, without reducing the maximum in those phases.

By Phase 8, all inherited measures produce visible absolute benefits. Battery reduces residual peak by about 0.44 MW, volume by 62.5 MWh and duration by 31 hours. Smart charging reduces these indicators by about 0.40 MW, 40.5 MWh and 20 hours. HyER has the strongest effect, lowering the residual peak by about 2.11 MW, congestion volume by 111 MWh and duration by 61 hours. Its more consistent effect follows from dispatchable generation during constrained hours, whereas shifting technologies depend on available load, storage state and recovery time.

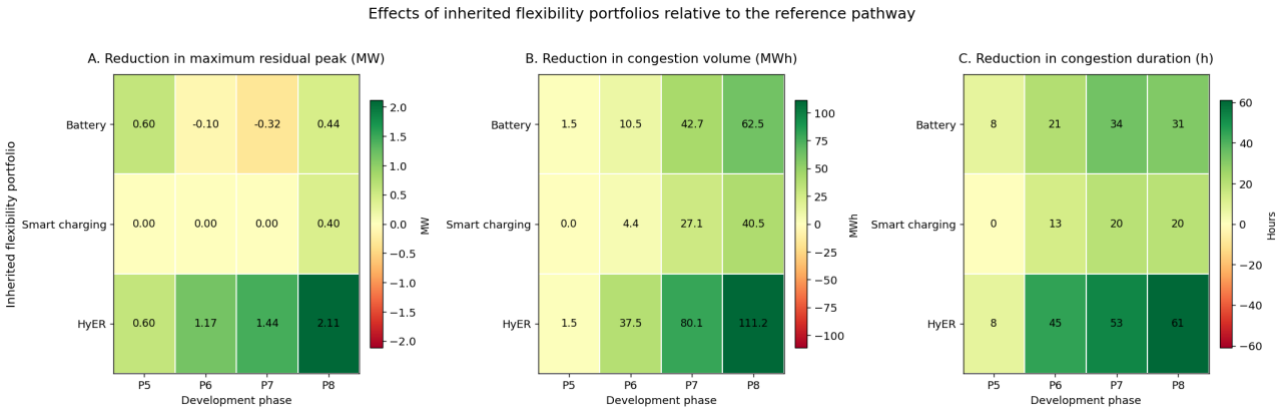


Figure 6.5a. Change in residual peak, congestion volume and duration under inherited flexibility portfolios relative to the WKO/ATES-only Reference pathway.

6.4.2 Development phases accommodated by inherited flexibility

Figure 6.5b translates these indicator changes into the development sequence. All inherited pathways accommodate Phases 2 to 4 because WKO/ATES alone is sufficient. In Phase 5, inherited Battery and HyER create enough headroom for the newly added development, whereas Reference and Smart charging leave 0.60 MW. From Phase 6 onward, none of the inherited pathways fully accommodates the new phase. HyER performs best, but still leaves 0.74 MW in Phase 6, 1.00 MW in Phase 7 and 0.97 MW in Phase 8.

This is the first direct indication of technical path dependence. Earlier projects do not only add demand; their flexibility choices alter the headroom inherited by later projects. However, the result also places a limit on that mechanism. Even the most favourable inherited pathway does not independently absorb Phases 6 to 8. The question is therefore whether measures in the newly added project can close the remaining gap.

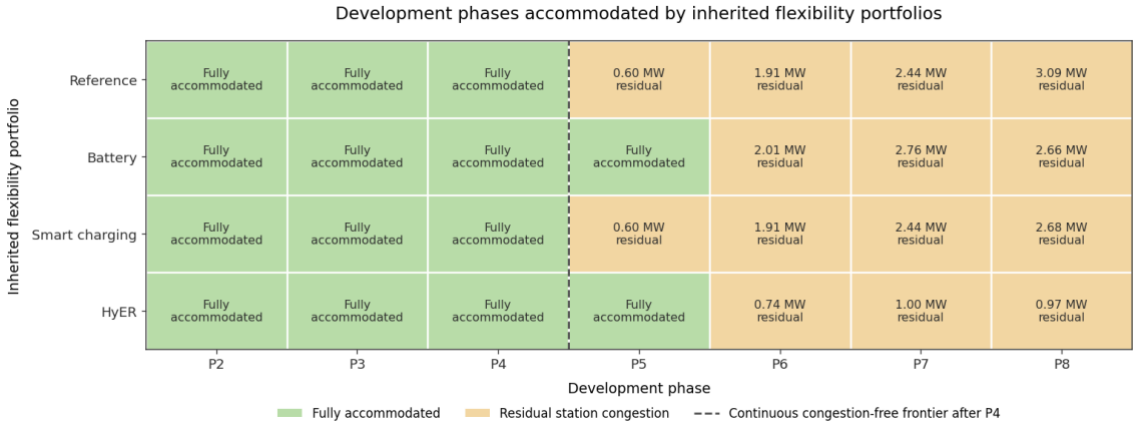


Figure 6.5b. Development phases accommodated by inherited flexibility. Full accommodation denotes zero residual congestion under all retained take-off settings.

6.5 New-project battery storage and smart charging

Battery capacities of 0, 500 and 1,000 kWh and smart-charging participation of 0%, 50% and 100% were tested in the newly added project, with HyER disabled there. WKO/ATES remained flexible and

the four inherited pathways were retained. The principal comparison uses the strongest evaluated package, a 1,000 kWh battery with 100% smart charging. If that package cannot eliminate congestion under an inherited pathway, weaker combinations within this experiment cannot do so either. Figure 6.6 shows that Phase 5 can be accommodated by this package only when preceding projects already follow the Battery or HyER pathway. Under inherited Reference and Smart charging, 0.30 MW remains, with 0.40 MWh over four hours in the critical period. The same equipment in the new project therefore produces a different station outcome depending on earlier investments. This is not a property of the new project in isolation, but of its position in the cumulative sequence.

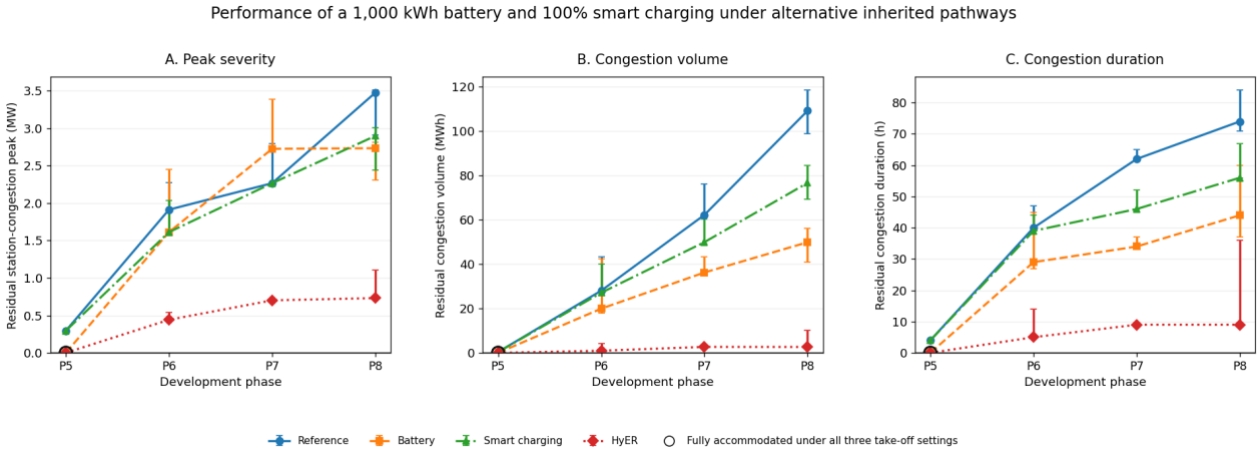


Figure 6.6. Residual congestion under the maximum new-project battery and smart-charging package across inherited pathways. Points show medians and error bars show ranges across retained take-off settings.

From Phase 6 onward, no battery and smart-charging combination in the new project eliminates station congestion. In Phase 6, the maximum package leaves 1.91 MW under inherited Reference, 1.61 MW under Battery, 1.91 MW under Smart charging and 0.44 MW under HyER. In Phase 8, inherited HyER again provides the most headroom, but still leaves 0.73 MW and 2.7 MWh over nine hours. Battery and smart charging materially reduce the burden in many hours, yet they cannot supply enough coincident relief to accommodate the later phases when concentrated in the newest project.

The results reinforce the need to interpret all three indicators. A shifted maximum does not mean that a battery has no value, and an unchanged maximum does not mean that smart charging has no effect. Nevertheless, reduction is not the same as accommodation. For Phases 6 to 8, the remaining peak is positive under every evaluated combination in this section.

6.6 Integrated flexibility in the newly added project

6.6.1 Contribution of new-project HyER

HyER was first isolated by disabling battery storage and smart charging in the newly added project and retaining the inherited Reference pathway. Table 6.4 shows a consistent reduction as HyER capacity increases. At 3X capacity, residual peak falls from 0.60 to 0.33 MW in Phase 5 and from 3.09 to 2.70 MW in Phase 8. Congestion volume also falls, but HyER alone does not eliminate congestion in any of the evaluated phases. The relative contribution declines as the cumulative

station requirement grows, because a project-specific generation module remains limited while demand from all established projects accumulates.

Table 6.4. Stand-alone contribution of new-project HyER under the inherited Reference pathway.

Phase	HyER	Residual peak (MW)	Congestion volume (MWh)	Duration (h)
P5	0	0.60	1.51	8
P5	1X	0.51	0.96	4
P5	3X	0.33	0.40	2
P6	0	1.91	38.5	51
P6	1X	1.82	33.5	46
P6	3X	1.64	24.7	36
P7	0	2.44	85.1	70
P7	1X	2.35	79.2	65
P7	3X	2.17	66.9	63
P8	0	3.09	114	72
P8	1X	2.97	106	72
P8	3X	2.70	95.9	71

6.6.2 Maximum new-project flexibility package

The complete new-project package combines a 1,000 kWh battery, 100% smart charging and 3X HyER. Figure 6.7 compares this package across inherited pathways. In Phase 5, inherited Battery and HyER eliminate congestion; inherited Reference and Smart charging leave only 0.030 MW during one hour. The package can therefore almost or fully accommodate Phase 5, but the result remains conditional on what preceding projects contribute.

The boundary becomes clear in Phase 6. No evaluated new-project-concentrated configuration eliminates congestion. The maximum package leaves 1.34 MW under inherited Reference and 0.17 MW under inherited HyER. The same hierarchy persists in Phases 7 and 8. In Phase 8, Reference leaves 2.59 MW, 88.2 MWh and 71 hours; inherited Battery leaves 2.35 MW, 33.9 MWh and 33 hours; inherited Smart charging leaves 2.44 MW, 60.3 MWh and 51 hours; and inherited HyER leaves 0.73 MW, 2.50 MWh and nine hours.

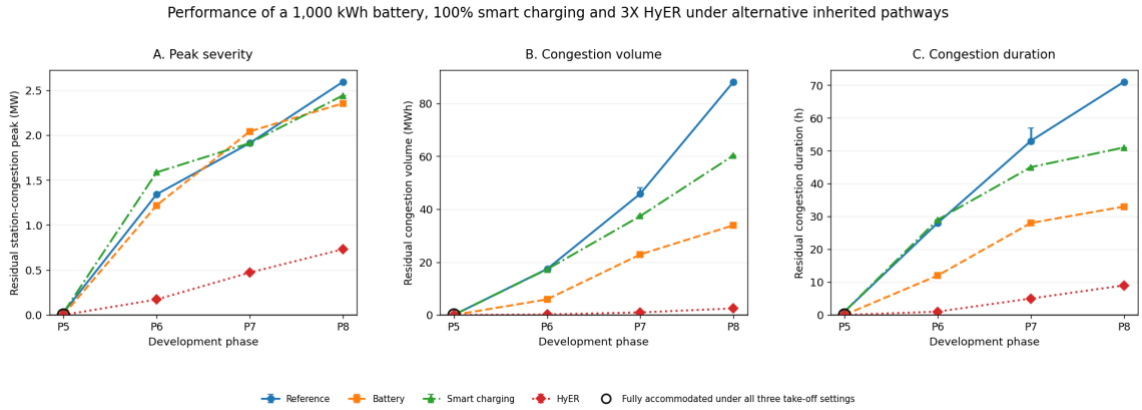


Figure 6.7. Residual congestion under the maximum integrated new-project flexibility package across inherited pathways. Points show medians and error bars show ranges across retained take-off settings.

6.6.3 Why residual congestion remains in Phase 6

Figures 6.8a and 6.8b explain the best Phase 6 new-project-concentrated result. Under inherited HyER, the remaining burden is 0.17 MW during one critical hour. Before activating the new-project package, the residual shortage at timestep 443 is 0.74 MW. The new-project battery supplies about 0.30 MW and HyER about 0.27 MW. Their combined contribution of 0.57 MW leaves 0.17 MW unmet. Smart charging cannot reduce the hour further because new-project EV charging has already been shifted away and is zero at that timestep.

The limiting factor is power rather than stored energy. The battery still contains usable energy but is operating at its discharge-power limit, while HyER is at its installed output limit. This distinction matters strategically: adding nominal energy capacity alone would not resolve this critical hour. The project lacks sufficient controllable power at the station peak.

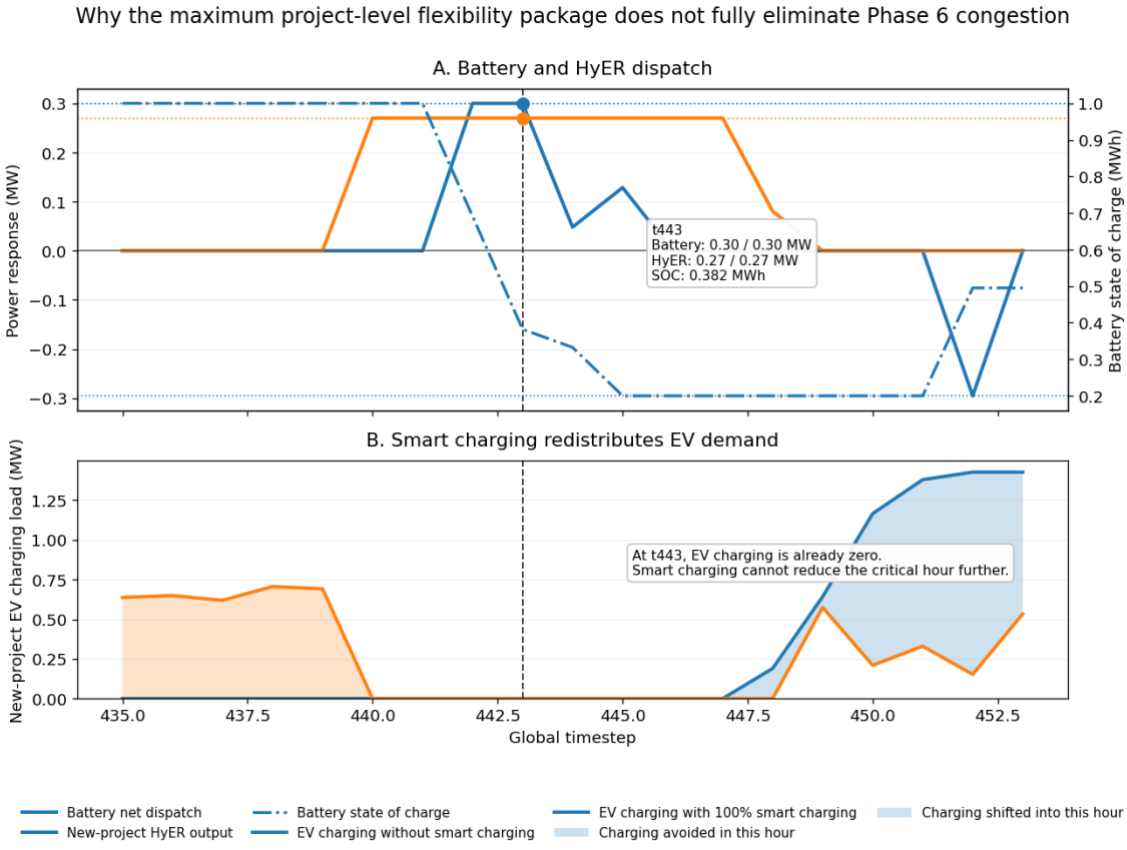


Figure 6.8a. Dispatch and limiting conditions of the maximum new-project flexibility package in Phase 6 under inherited HyER.

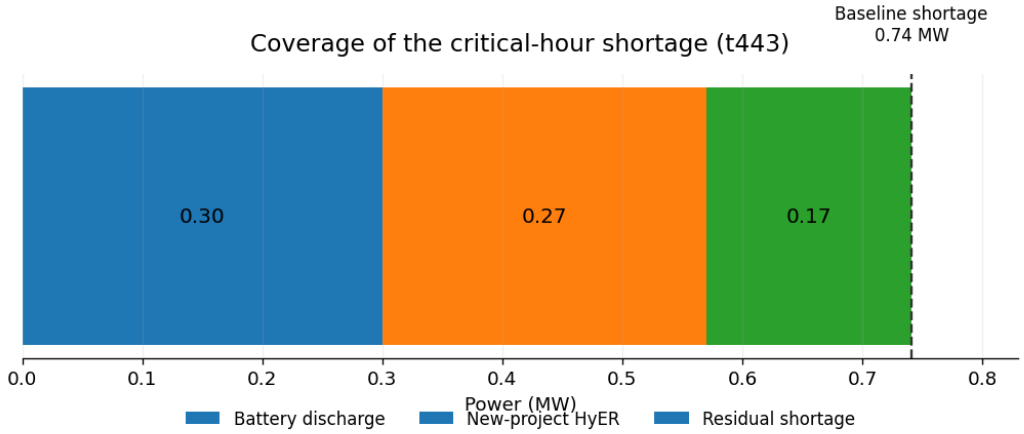


Figure 6.8b. Coverage of the Phase 6 shortage remaining before activation of the maximum new-project package under inherited HyER.

6.6.4 Declining contribution relative to the cumulative deficit

Table 6.5 compares the maximum new-project package with WKO/ATES-only under inherited Reference. Its absolute peak reduction remains approximately 0.50 to 0.57 MW, but its relative contribution falls from 95.0% in Phase 5 to 16.2% in Phase 8. The capacity of the newest project package remains broadly fixed while the station-level deficit reflects the full cumulative programme. Flexibility concentrated in the newly added project continues to mitigate congestion, but becomes progressively less capable of compensating for demand accumulated elsewhere.

Table 6.5. Reduction in residual peak relative to WKO/ATES-only under inherited Reference.

Phase	WKO-only peak (MW)	Maximum project package (MW)	Reduction (MW)	Reduction (%)
P5	0.60	0.030	0.57	95.0
P6	1.91	1.34	0.57	29.9
P7	2.44	1.91	0.53	21.7
P8	3.09	2.59	0.50	16.2

The later phases therefore expose a mismatch of scale. The station constraint is cumulative, but the additional response in these experiments is concentrated in one project. The analysis does not show that project-level flexibility is ineffective. It shows that, after Phase 5, it is no longer sufficient as the sole organising scale for the modelled development sequence.

6.7 Integrated area-wide flexibility scenario

The final experiment changes the scope of coordination. WKO/ATES, battery storage, smart charging and HyER are activated across the complete Phase 8 development portfolio and optimised around the shared 38 MW station constraint. Flexibility installed in early phases therefore remains available when later projects connect. This scenario tests the technical upper potential of accumulated resources, not the present feasibility of coordinating them across owners and connections.

6.7.1 Station-level performance

Figure 6.9a shows no Energy Not Served during the 336-hour critical period. Maximum station loading remains at 38.0 MW, so residual peak, volume and duration are zero. This is the only evaluated configuration that accommodates the full Phase 8 portfolio during that period.
The result should not be read as creation of ample spare capacity. Jan Wapstraat operates exactly at 38 MW during 90 of the 336 reported hours. The plateau in Figure 6.9a marks repeated binding of the station constraint. The portfolio succeeds by continuously reshaping demand and local supply around the limit, leaving little technical margin for demand error, asset unavailability, reduced participation or conditions outside the simulated period.

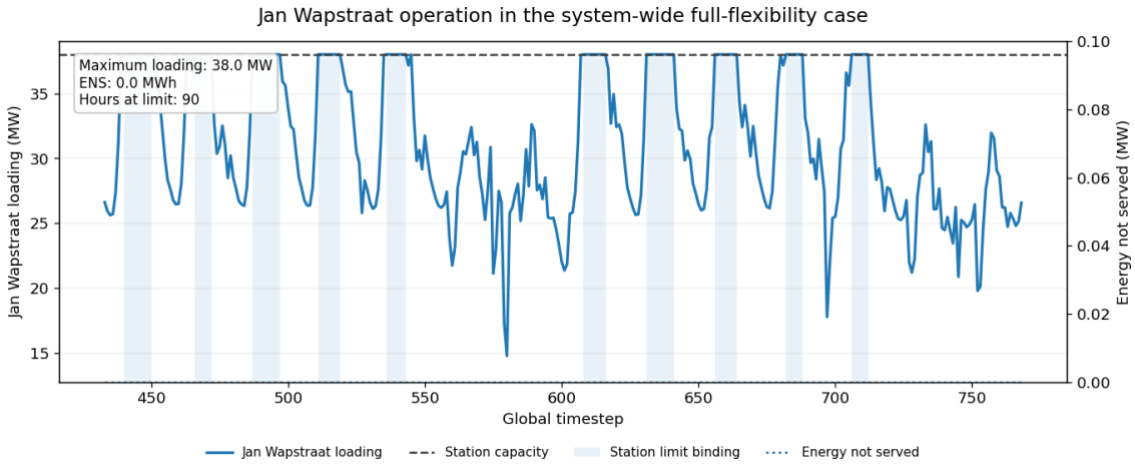


Figure 6.9a. Modelled Jan Wapstraat loading under the integrated area-wide flexibility scenario during the 336-hour critical period.

Figure 6.9b compares realised station import with the unconstrained Phase 8 functional profile. At timestep 443, unconstrained demand reaches about 45.2 MW, or 7.15 MW above the station limit. The difference from realised import is not the instantaneous output of one device. It results from decisions across multiple hours, including earlier charging, thermal preparation, shifted EV demand and local generation.

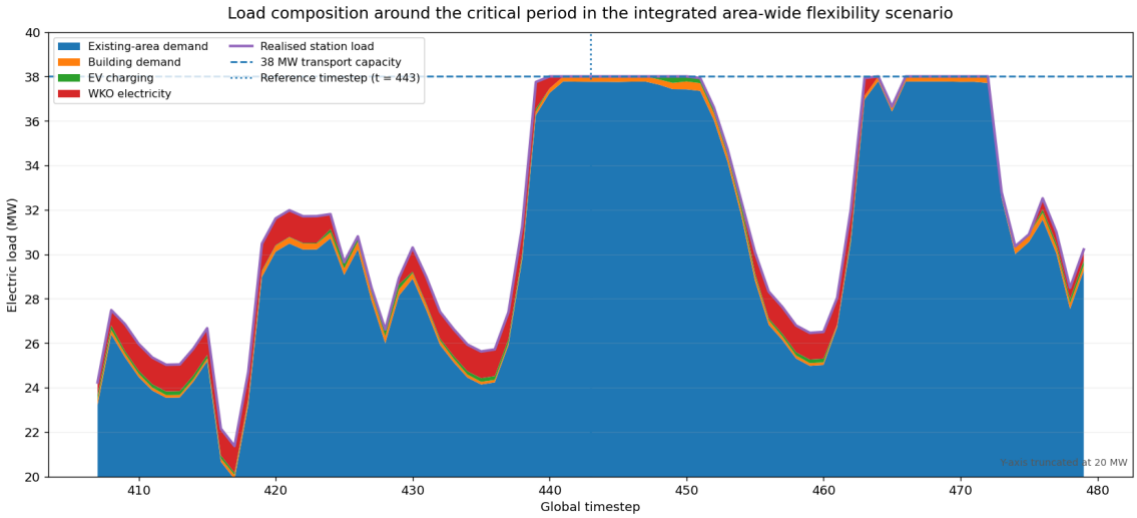


Figure 6.9b. Unconstrained Phase 8 functional demand and realised station loading under integrated area-wide flexibility around the corrected functional peak.

6.7.2 Coordinated portfolio response

Figure 6.9c shows the complementary response around the corrected functional peak at timestep 443. Batteries across the portfolio discharge about 1.09 MW and HyER supplies about 1.59 MW, for a combined instantaneous contribution of 2.68 MW. Smart EV charging is zero because charging demand has already been moved away from the critical hour. WKO/ATES contributes through reduced electrical input at constrained hours and recovery outside them.

The area-wide result is stronger because the portfolio combines different temporal functions and makes resources from multiple projects available to the same station objective. In this scenario, batteries deliver concentrated short-duration power, HyER supplies dispatchable generation across longer constrained periods, smart charging removes movable demand, and WKO/ATES uses thermal storage to shift electricity consumption. No single measure reproduces that complete response in the evaluated new-project-concentrated runs.

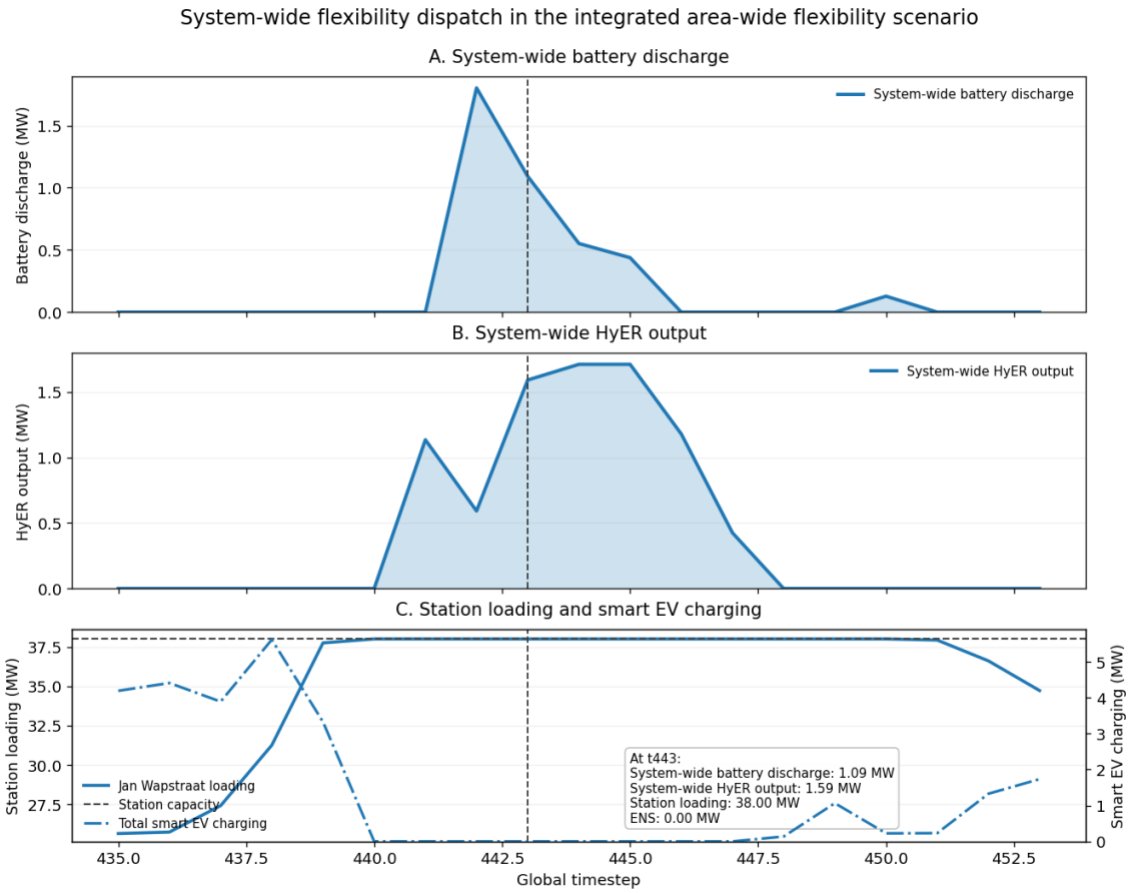


Figure 6.9c. Coordinated portfolio response around the Phase 8 corrected functional peak at timestep 443.

6.7.3 Comparison with new-project-concentrated flexibility

Table 6.6 summarises the change in scale. WKO/ATES alone leaves 3.09 MW in Phase 8. Adding the maximum package only to The Embrace reduces this to 2.59 MW. Coordinating all evaluated measures across the complete portfolio reduces residual congestion to zero during the critical period. The difference is not simply that the final scenario contains more assets. Earlier assets remain operationally available to serve a shared station-level objective instead of being bounded by the newest project.

Table 6.6. Comparison of Phase 8 station performance.

Scenario	Flexibility scope	Residual peak (MW)	Outcome
WKO-only	Flexible WKO/ATES operation	3.09	Residual congestion
Maximum new-project package	1,000 kWh battery, 100% smart charging and 3X HyER in The Embrace	2.59	Residual congestion
Integrated area-wide flexibility	Battery, smart charging, HyER and WKO/ATES across the full portfolio	0	Accommodated in critical period

This outcome establishes technical potential, not implementation readiness. It assumes access to information and control across projects and it is evaluated for one critical period. The 90 binding hours also show that success is fragile rather than abundant. These qualifications prevent the area-wide result from being interpreted as proof that reinforcement or additional flexibility is unnecessary.

6.8 Answer to Research Question 3

The phased redevelopment increases both the magnitude and persistence of modelled loading at Jan Wapstraat. Without congestion-oriented flexibility, the station margin is exhausted in Phase 2. That first exceedance is marginal, but Phase 3 already reaches 39.1 MW and confirms the direction of development. By Phase 8, corrected functional demand peaks at 45.2 MW, exceeds 38 MW during 438 hours and places 614 MWh above the threshold.

WKO/ATES provides the first effective flexibility layer and eliminates residual congestion through Phase 4. From Phase 5 onward it is insufficient on its own. Flexibility inherited from earlier projects can extend the congestion-free sequence through Phase 5 when battery storage or HyER is available, demonstrating that earlier decisions affect the headroom available to later projects. From Phase 6 onward, however, no inherited pathway and no evaluated package concentrated in the newly added project fully eliminates residual congestion

Battery storage and smart charging remain useful even when they do not reduce the single maximum hour, because they can reduce congestion volume and duration. HyER produces a more consistent peak effect in the tested conditions, but project-specific HyER is also overtaken by cumulative demand. The Phase 6 critical-hour analysis shows that the best new-project-concentrated case is power-limited: 0.17 MW remains although stored energy is still available. The later constraint is therefore not solved by adding nominal energy capacity without sufficient coincident controllable power.

The integrated area-wide scenario accommodates Phase 8 during the modelled critical period, but only through coordinated operation of complementary assets accumulated across the development portfolio. The station remains at its 38 MW limit for 90 hours, so this result represents an upper technical potential with little robustness margin. It does not establish that the required coordination exists, that performance holds throughout every condition or that individual projects acquire transport rights.

By Phase 2, the modelled development has already exhausted the available station margin; by Phase 6, no evaluated new-project configuration can recover sufficient headroom. The capacity problem must therefore be addressed before the later projects enter the development sequence, rather than once the final-phase deficit has materialised. Under the evaluated assumptions, the full development can be accommodated in the critical period only when flexibility distributed across projects is coordinated around the shared station limit. From Phase 6 onward, the required technical response must extend beyond the flexibility attached to the newly added project. Chapter 7 examines whether the institutional conditions identified in Chapter 5 can support that transition.

7 Strategic development pathways for flexibility governance

7.1 Strategic problem and analytical approach

Chapters 5 and 6 expose a mismatch between the scale at which flexibility is currently organised and the scale at which congestion occurs. Developers make decisions predominantly within individual projects and connections, whereas the binding constraint is the coincident load at station Jan Wapstraat. Without congestion-oriented flexibility, the first modelled exceedance already occurs in Phase 2. Phase 6 marks a different threshold: from that phase onward, none of the evaluated configurations in which additional flexibility is concentrated in the newly added project independently removes congestion. The strategic issue is therefore whether the institutionally observed project-bounded trajectory can evolve before technical responses concentrated at that scale become inadequate.

These results do not justify prescribing one technology. Batteries, smart charging, WKO/ATES flexibility and controllable generation are operational means whose station-level value depends on availability, control and interaction with the wider portfolio. Transition management distinguishes the strategic direction of preserving development continuity, the tactical organisation of roles and rules, and the operational deployment of assets (Loorbach, 2010). This chapter focuses on the tactical governance changes required to make technically effective options implementable.
The individual-collective flexibility framework developed in Section 5.6 provides the analytical starting point. Its four configurations are not repeated here as new concepts, but used to compare strategic directions. Dynamic Adaptive Policy Pathways (DAPP) provides the sequencing logic for moving between configurations under uncertainty (Haasnoot et al., 2013, 2024). Network and collaborative-governance theory clarify the institutional requirements of those movements, including leadership, rules, incentives and acknowledged interdependence (Provan & Kenis, 2008; Nielsen et al., 2024).

7.2 Strategic comparison of the four configurations

Section 5.6 defines the four configurations. The purpose here is to compare their strategic function in the future development of LHHS. Table 7.1 therefore focuses on what each configuration contributes to the pathway, which institutional condition limits it and whether it represents a starting point, parallel route, next step or conditional endpoint.

Table 7.1. Strategic role of the four configurations in LHHS.

Configuration	Strategic function	Principal institutional condition	Position in the recommended pathway
Fragmented project optimisation	Preserves project accountability and supports immediate project feasibility.	Does not create authority or incentives to protect station-level headroom for other projects.	Starting point, but not a sufficient end-state.

Shared asset with participant-oriented operation	Can create a durable operational platform and economies of scale.	Collective ownership or use does not ensure operation in response to Jan Wapstraat.	Parallel route that can support a later transition if its control mandate changes.
Coordinated project flexibility	Aligns distributed project assets with the shared constraint while retaining separate ownership.	Requires common information, availability, verification and allocation rules.	Preferred next configuration before reinforcement.
Integrated area flexibility	Provides the strongest alignment between portfolio operation and the station constraint.	Requires stable participation, operational authority, a viable contractual structure and formal capacity arrangements.	Conditional later configuration.

7.2.1 From fragmented optimisation to coordinated project flexibility

Fragmented project optimisation remains useful for accountability, financeability and transferability, but it should no longer determine the collective strategy. The technical analysis shows that measures concentrated in the newly added project become inadequate as cumulative demand grows, while transition-management theory locates the missing collective capacity at the tactical level. More technology within separate projects does not substitute for rules that connect those projects to the station constraint (Loorbach, 2010). Preserving fragmented optimisation as the only configuration would also reinforce the institutional lock-ins described by Kaya et al. (2026), because early contracts and routines would narrow the options available later.

Coordinated project flexibility is the preferred next configuration because it changes collective decision capacity without requiring immediate collective ownership. Network-governance theory suggests that this can be organised through a lead organisation or bounded coordinating function, while authority remains distributed across the municipality, Stedin and long-term operators (Provan & Kenis, 2008). The exact form should follow actual authority, legitimacy and implementation capacity rather than a mechanical governance template (Van den Oord et al., 2023). The strategic requirement is that information exchange develops into rules for availability, verification, compensation, service protection and transfer to future owners. An intermediary can support that process without owning every asset (Hofman et al., 2023), while the quantitative model can function as a boundary object for revising shared assumptions (Cuppen et al., 2021).

7.2.2 Shared assets as a parallel route

Shared participant-oriented assets should be treated as a parallel route rather than proof of area-level congestion management. Chapter 5 already establishes this distinction. Strategically, such assets are relevant because professional operation and long-term contracts may provide a platform for later coordination. A transition to collective grid control is nevertheless a governance change, not an automatic technical consequence. It requires a revised operating mandate, measurable performance, authority to alter operation and incentives that connect participant interests to the station objective. This follows collaborative-governance research showing that interdependence produces collective

outcomes only when supported by leadership, institutional design and incentives (Nielsen et al., 2024).

7.2.3 Integrated area flexibility as a conditional option

Integrated area flexibility should remain available as a later option, but should not be selected as the immediate organisational model. It aligns most directly with the integrated area-wide scenario, yet that scenario represents an upper technical potential and does not establish transport rights. Merwede demonstrates that an integrated arrangement can be developed in the Netherlands, but also that it depends on sustained cooperation, feasibility and business-case development, formal network arrangements and actor-specific land and ownership positions (Gemeente Utrecht, 2025; Merwede LAB, n.d.). For LHHS, deeper integration is justified only if recurring coordination needs outweigh its additional contractual and operational dependencies. In transition-management terms, a promising operational arrangement should not be treated as a settled tactical regime before its institutional conditions have been demonstrated (Loorbach, 2010).

7.3 Intertemporal distribution: a temporal upstream-downstream problem

The development sequence creates a distributional problem that the four configurations alone do not resolve. Early projects are “upstream” in time: they make connection, asset and contractual choices while more station headroom remains. Later projects are “downstream”: they inherit the reduced headroom and institutional choices created earlier. The analogy resembles river-basin governance, where upstream use can impose costs on downstream users, but here the ordering is temporal rather than geographical. Early projects do not necessarily act irresponsibly; they optimise within the rules and information available to them. Nevertheless, they may capture the benefits of separable project delivery while part of the cost of exhausted capacity emerges only for later projects and the wider area programme.

Common-pool-resource theory helps diagnose this asymmetry. Electricity networks are not open-access commons because Stedin governs access through regulated connections, contracts and capacity procedures. However, constrained infrastructure capacity has a subtractable quality: use of scarce simultaneous headroom limits what remains available to others. Infrastructure scholarship therefore identifies bottlenecks, access and the allocation of costs and benefits as common-pool governance questions (Künneke & Finger, 2009). The LHHS problem contains both an appropriation question about who may use the remaining headroom and a provision question about who pays for flexibility that preserves or creates usable space.

Ostrom's (1990) institutional principles do not prescribe a specific contract, but provide criteria for a robust arrangement. The relevant participants and system boundary must be identifiable; contributions should be proportionate to benefits and burdens; affected participants should have a role in modifying operational rules; performance should be monitored; and low-cost conflict-resolution procedures should exist. Applied to LHHS, this means that collective claims should be bounded to actors whose loading and flexibility materially affect the relevant Jan Wapstraat constraint. It also means that early flexibility providers should not be expected to preserve capacity for later projects without a credible benefit, while later beneficiaries should not pay for unverified or unavailable capacity effects.

Research combining common-pool and externality perspectives in water governance shows why beneficiary contributions can support measures implemented earlier or elsewhere when benefits are demonstrable (Sarker et al., 2008). By analogy, later LHHS projects could co-invest in, contract with or compensate earlier projects whose verified flexibility enables subsequent development. This is not a recommendation that later projects automatically finance earlier assets. The mechanism is defensible only if the station-level effect, availability period, counterfactual benefit and operational obligations can be established. Possible forms include staged participation fees, availability payments, shared investment or a municipal area fund, but legal and commercial design falls outside this thesis.

The theoretical implication is more important than the specific instrument: a first-come, project-by-project logic distributes scarce capacity and adaptation burdens implicitly. A coordinated pathway makes that distribution visible and negotiable. It can also reduce free-riding, in which projects benefit from portfolio flexibility without contributing to its provision. This strengthens the case for initiating governance before project-level pathways fail. Once early assets and contracts are no longer controllable or transferable, the cost of correcting the temporal asymmetry rises and the feasible pathway set narrows.

7.4 Recommended adaptive development pathway

Based on this comparison, LHHS should follow an adaptive path towards coordinated project flexibility, while allowing shared assets to develop in parallel and preserving deeper integration as a conditional option. Coordination should increase only when technical evidence and institutional readiness justify it.

7.4.1 Preserve options before the critical phases

The first action is to prevent avoidable lock-in. Phase 2 demonstrates that station congestion can occur early without congestion-oriented flexibility; Phase 6 demonstrates that the evaluated new-project-concentrated configurations no longer suffice. Neither phase is a fixed real-world deadline, because realised phasing, autonomous load, wider station demand and dependable flexibility may differ from the model. In DAPP terms, they are analytical signposts that motivate monitoring and option preservation (Haasnoot et al., 2013).

Before major remaining design, connection or transfer decisions, the municipality, Stedin, developers and prospective operators should therefore maintain one periodically updated capacity and development baseline. Projects need not pre-commit their assets to collective dispatch, but should avoid unnecessarily closing that option. Relevant tactical measures include compatible data definitions, identifiable control interfaces, clarity about future operational ownership and contractual provisions that allow later participation to be assessed. This implements Braams et al.'s (2024) institutional capacity for working under uncertainty: actors do not wait for complete knowledge, but organise the ability to revise routines and decisions as interdependence becomes clearer.

7.4.2 Move to coordinated project flexibility through explicit triggers

The second movement is from shared analysis to shared decision capacity. Technical triggers include forecasts showing persistent residual congestion after credible project measures, repeated dependence on flexibility from more than one project, a shrinking operational margin, or material changes in phasing or wider station loading. Institutional triggers include sufficient participant commitment, verified data, an implementable capacity or contractual arrangement, a viable cost-and-risk allocation and an operator capable of meeting service obligations. Phase 6 is one strong model-based trigger for preparing this movement, not an instruction to postpone coordination until Phase 6. When these conditions emerge, the network should establish rules for availability, activation, verification, compensation and non-performance. DAPP requires that actors specify who monitors signposts, who initiates reassessment and who may decide to change the pathway (Haasnoot et al., 2024). For LHHS, Stedin should validate the network relevance of indicators, the municipality should connect reassessment to area phasing, and participating asset operators should confirm deliverability. A lead organisation or bounded coordination function may administer the process, but decisions affecting transport rights remain within the regulated network domain.

7.4.3 Keep integrated area flexibility conditional

The third movement is optional. An integrated area arrangement becomes preferable if coordinated project contracts repeatedly prove too fragmented, if shared assets become central to the portfolio, or if one stable counterparty is required for a formal network arrangement. Its trigger is thus not congestion alone. There must also be institutional readiness: a defined group, legal and contractual feasibility, long-term operational capability, accepted distribution of costs and risks and protection of future owners and users.

This conditionality limits premature centralisation while preserving the technically strongest configuration. It also reflects network-governance theory: a separate administrative organisation is valuable when coordination needs are durable and complex, but creates unnecessary overhead when participation is small or temporary (Provan & Kenis, 2008; Van den Oord et al., 2023). The recommended endpoint is therefore not necessarily one area energy company. Success means that the governance form matches the technical interdependence and can adapt without sacrificing accountability, service delivery or legal capacity arrangements.

7.5 Actor-specific strategic roles

7.5.1 Municipality of The Hague: portfolio governance and meta-governance

The municipality cannot simply reopen issued permits or compel completed agreements to adopt a particular flexibility technology. Its strategic leverage lies in meta-governance: shaping the arena, rules and sequence through which interdependent actors coordinate. In transition-management terms, it should translate the strategic objective of development continuity into tactical routines for phasing, information, option preservation and allocation, while leaving technical dispatch to competent operators (Loorbach, 2010).

The municipality should differentiate its instruments. Existing commitments require convening, negotiation and incentives; open land, cooperation, procurement or planning moments may permit firmer requirements concerning information, controllability and transferability. It should connect energy capacity to portfolio decisions across projects, maintain the shared development baseline and

ensure that the temporal distribution problem is discussed explicitly. Braams et al. (2024) imply that this requires internal capacity as well: departments must share responsibility, work with uncertain thresholds and revise routines that treat grid capacity as a late technical check. If coordination becomes structurally complex, the municipality can initiate or procure an intermediary, but should not assume network-operation authority or promise transport capacity.

7.5.2 Developers: conditional participation and option preservation

Developers remain responsible for feasible, financeable and transferable projects. Their first task is still to limit avoidable connection demand and organise credible project-level flexibility. The strategic shift is that autonomy should not entail institutional isolation. Developers should contribute material load and phasing information, assess the station effect of design changes and preserve participation options where proportionate.

Commitments should be staged. Initial obligations can concern data, metering compatibility and assessment procedures. Dispatch or availability commitments should follow only when compensation, liability, service impacts and transfer to later owners are defined. This reflects both DAPP's preference for reversible near-term actions and Ostrom's principle that those affected by operational rules need a role in modifying them (Haasnoot et al., 2013; Ostrom, 1990). Developers providing verified flexibility should receive a proportionate benefit, while projects whose feasibility depends on that flexibility should contribute to its provision. The aim is not to socialise every project cost, but to prevent temporal free-riding and preserve options for the complete programme.

7.5.3 Stedin: system definition, validation and formal capacity interface

Stedin's role is to define the technical and regulated boundary within which collective action has meaning. It should clarify which constraint is relevant, what aggregated response can affect it, how performance can be validated and which contractual routes are available. The shared model should be updated against network information because Jan Wapstraat supplies a wider area than LHHS and local peak reduction does not automatically translate into usable transport capacity.

Stedin should not govern the development coalition or prescribe its technology portfolio. Its contribution is authoritative validation and the formal interface between an area arrangement and regulated capacity. This distinction directly addresses the institutional lock-ins observed by Kaya et al. (2026): if planning routines treat network development and urban development as separate domains, actors may coordinate around assumptions that cannot be implemented. Reduced modelled loading must therefore never be presented as an automatic capacity right. Any collective commitment must connect, where regulation permits, to a formal and dependable arrangement.

7.5.4 Energy and mobility operators, coordinator and future users

Energy, WKO/ATES and mobility operators determine whether flexibility remains operational after developers leave. They should translate strategic objectives into measurable availability, service limits, maintenance responsibilities and control protocols. Their early involvement is required to test whether congestion-oriented operation is compatible with thermal comfort, charging service, safety and commercial obligations. A proposed measure without a willing long-term operator is not institutionally implementable.

If coordination demand becomes durable, a bounded area coordinator can maintain the baseline, facilitate decisions, administer performance and resolve routine disputes without owning every asset. This intermediary function follows Hofman et al. (2023), while its governance form should be selected according to the actual scale, trust and authority requirements rather than assumed in advance (Van den Oord et al., 2023). Future owners and users must participate where rules affect tariffs, data, comfort or charging. In common-pool terms, monitoring and conflict resolution are not administrative additions; they are conditions for durable cooperation (Ostrom, 1990). Contracts must therefore remain understandable, transferable and adaptable when ownership or operators change.

7.6 Strategic synthesis

The strategic recommendation is to increase collective decision capacity without prematurely centralising asset ownership. Coordinated project flexibility offers the most credible intermediate configuration because it addresses the shared station constraint while preserving project accountability and keeping deeper integration available.

The corresponding development pathway is adaptive: preserve options early, establish station-level decision rules when technical and institutional triggers are met, and move to deeper integration only if recurring interdependence justifies it. This recommendation is grounded in the distinction between Phase 2 and Phase 6. Congestion is already possible from Phase 2 without flexibility; from Phase 6, the evaluated configurations that concentrate additional flexibility in the newly added project become insufficient. Governance development must consequently precede the point at which this technical response scale becomes inadequate. The central strategic finding is that flexibility is not only a portfolio of technologies, but also a problem of intertemporal allocation and institutional capacity. Early projects can shape the headroom and options available to later projects, while later projects may benefit from flexibility provided earlier. Making those externalities visible, verifiable and negotiable is the purpose of the recommended governance pathway. The quantitative analysis establishes the need for coordination; the interviews explain why that coordination must preserve project accountability, service obligations and transferability. The result is not a fixed blueprint, but a theoretically grounded route for increasing collective capacity before fragmented decisions become an irreversible constraint on area development.

8 Discussion

This chapter interprets the combined technical and institutional findings in relation to the literature, their broader relevance and the limitations of the research. The central issue is the mismatch between a cumulative station-level constraint and a development process in which investment, connection and operational decisions remain predominantly project-specific.

8.1 Interpreting the technical-institutional gap

The quantitative findings demonstrate that flexibility can materially alter the effective capacity boundary. Flexible WKO/ATES operation accommodates the modelled development through Phase 4. Flexibility inherited from earlier projects can extend this to Phase 5 when battery storage or HyER is available. From Phase 6 onward, however, none of the evaluated configurations in which additional flexibility is concentrated in the newly added project fully eliminates congestion. Only the integrated area-wide scenario accommodates the complete Phase 8 portfolio during the modelled critical period.

The decisive distinction is therefore not between flexibility and no flexibility. It is between flexibility organised around individual project resources and flexibility coordinated around the shared station constraint. Batteries, smart charging, WKO/ATES and local generation can all alter electricity exchange, but this capability only becomes congestion mitigation when the response occurs at the correct time, within the relevant electrical boundary and for the applicable network objective. This supports research distinguishing general demand flexibility from flexibility that is spatially and temporally aligned with a local constraint (Junker et al., 2018; Stawska et al., 2021).

The findings also confirm that technical controllability does not automatically create an available system service. Mlecnik et al. (2020) show that technically flexible buildings do not automatically become flexibility providers because service delivery also requires viable roles, market access, aggregation and participation by owners and users. The present case demonstrates the same mechanism at area level. Assets may be physically capable of responding while the authority, incentives and continuity required to activate them for Jan Wapstraat remain absent.

This distinction is particularly visible in the planned WKO/ATES system. WKO/ATES has the strongest physical implementation basis among the evaluated measures because thermal infrastructure is already embedded in the redevelopment. Its intended purpose, however, is the reliable provision of heating and cooling. A collective thermal system therefore remains participant-oriented unless its electrical operation is explicitly connected to the station constraint. This would require an operating mandate that protects thermal service while permitting congestion-oriented control. The existence of shared infrastructure alone does not provide that mandate.

The same principle applies in the opposite direction. Separately owned batteries or charging systems could, in principle, respond to a shared station objective without being transferred into collective ownership. Asset scope and control objective are therefore separate dimensions. This supports Mancarella's (2014) distinction between commercial aggregation and technically constrained coordination, as well as Charbonnier et al.'s (2022) finding that apparently decentralised coordination structures can differ substantially in information exchange, decision authority and alignment with a

system objective. A portfolio is not operationally coordinated merely because its assets are located in the same development area.

The integrated area-wide scenario should consequently be interpreted as an upper technical potential, not as an immediately available development strategy. It assumes that assets across projects are observable and controllable for a shared objective. It also operates exactly at the 38 MW limit during 90 of the 336 reported hours. The elimination of residual congestion therefore does not represent abundant spare capacity. It represents a tightly coordinated outcome with little margin for forecast errors, non-participation, maintenance or asset outages.

The institutional evidence does not demonstrate that this level of coordination currently exists. No arrangement was identified through which assets across projects would respond dependably to Jan Wapstraat. This does not mean that area-wide coordination is institutionally impossible. It means that the technically strongest scenario requires a delivery arrangement that has not yet been established. The central gap is thus not a lack of potentially useful technologies, but a lack of demonstrated capacity to organise those technologies around the collective constraint.

Physical mitigation must also be distinguished from formal access to transport capacity. Reducing loading at Jan Wapstraat does not automatically assign the resulting headroom to the projects providing flexibility. Connection categories, existing contracts, waiting-list positions and regulated allocation procedures continue to determine whether a project obtains transport capacity. A technically effective portfolio can therefore remain practically ineffective when its performance is not recognised through a dependable capacity or connection arrangement. Flexibility complements reinforcement and capacity-allocation procedures, but does not replace them.

Taken together, the findings indicate that flexibility can substantially mitigate the pre-reinforcement capacity gap, but its effective contribution becomes conditional on increasing coordination as cumulative demand grows. Project-level arrangements remain relevant in the earlier phases, whereas full technical accommodation in the later phases requires a station-oriented portfolio arrangement whose institutional conditions are not yet established.

8.2 Scientific contribution

The first scientific contribution of this thesis is the integration of technical relevance and institutional feasibility at the level of a flexibility arrangement. Existing technical research frequently estimates the potential of batteries, smart charging or flexible building systems while assuming access to the required assets and control capabilities. Governance-oriented research, in contrast, explains why ownership, authority, incentives and coordination matter, but less often quantifies the consequences at a specific constrained network boundary. By combining both perspectives, this thesis demonstrates that neither is sufficient on its own.

The quantitative model does not establish institutional feasibility. It shows what selected configurations could achieve under explicit assumptions. Conversely, the interviews do not determine how many megawatts of congestion can be removed. They explain why technically plausible configurations are more or less compatible with the responsibilities, interests and dependencies observed in the case. The analytical value lies in the interaction between these forms of evidence.

Technical effectiveness identifies the scale of coordination that becomes necessary, while the institutional analysis reveals why that coordination cannot be assumed.

The second contribution is the identification of a scale mismatch between project-bounded decision-making and station-level congestion. Urban development projects are financed, contracted and delivered individually, but their electricity demand is constrained collectively. This resembles broader findings in urban-infrastructure research, which show that physical networks and institutional arrangements evolve across different spatial and organisational boundaries (Monstadt, 2009; Coenen et al., 2021). The present study makes this mismatch measurable within a phased development sequence. It shows when additional flexibility concentrated in one project ceases to compensate for demand accumulated across the wider portfolio.

The third contribution is the temporal dimension of this mismatch. Earlier projects do not only add demand. Their decisions concerning connections, charging systems, thermal infrastructure, storage and controllability influence the headroom and options inherited by later projects. Early projects are upstream in time, while later projects are downstream. Earlier actors can make project-rational decisions while sufficient headroom remains, whereas the cumulative consequences become most restrictive for projects arriving later.

This does not imply that early developers act irresponsibly. They act within the responsibilities, information and incentives available to them. The problem is that a project-by-project process allocates scarce capacity and adaptation burdens implicitly. Benefits can be captured within an early project, while part of the cost of exhausted station capacity emerges only later. This temporal asymmetry extends the literature on flexibility governance by showing that coordination concerns not only simultaneous dispatch, but also the intertemporal distribution of options, benefits and responsibilities.

The fourth contribution concerns institutional path dependence. The interviews show that developers prefer to limit dependencies that could affect delivery, financing and future property transfer. This preference is rational within the existing project structure. However, continued project-specific contracting can make later coordination more difficult if data rights, control interfaces and operational obligations have already become embedded in completed assets. The institutional trajectory can therefore become self-reinforcing before collective operation is technically indispensable.

This finding connects urban energy flexibility to transition literature emphasising that infrastructures, routines and institutional arrangements constrain future options (Köhler et al., 2019; Coenen et al., 2021). Flexibility is often presented as a means of preserving technical adaptability. The present study shows that this adaptability can be lost institutionally even when the assets remain technically controllable. A flexible technology embedded in an inflexible contract may no longer be available for the collective objective.

The analytical framework was therefore useful, but the findings also refine it. Technical relevance and institutional feasibility are not independent filters applied once to a technology. They interact over time. A technically relevant asset can become less institutionally accessible as ownership and contractual arrangements solidify. Conversely, increasing congestion can alter the value of coordination and make an arrangement institutionally more attractive than it was during earlier

phases. Institutional feasibility should therefore be understood as dynamic and pathway-dependent rather than as a fixed characteristic of a technology or governance model.

8.3 Broader relevance for phased urban redevelopment

The numerical results are specific to Laakhavens Hollands Spoor, the assumed development sequence, the reconstructed Jan Wapstraat profile and the evaluated flexibility parameters. The precise thresholds at Phase 2 and Phase 6 should not be transferred directly to other locations. The underlying mechanism, however, is not unique to this case.

Analytical generalisation is possible to urban developments with four characteristics. First, development is delivered through multiple projects and actors. Second, the relevant network boundary extends beyond the planning or project boundary. Third, electricity demand grows before reinforcement becomes available. Fourth, flexibility decisions are made locally while congestion is determined by coincident demand at an upstream network component. Comparable developments can experience the same mismatch even when their technologies, actors and numerical capacity deficits differ.

This is particularly relevant in the Netherlands, where housing delivery and electrification increasingly coincide with long network-development lead times. The results suggest that congestion should not be treated only as a connection problem encountered by the next project in line. By that point, much of the relevant technical and institutional design may already have been fixed in preceding projects. The first visible exceedance may be small, but it marks the disappearance of the buffer on which independent project delivery implicitly relies.

The message is therefore more urgent than a conventional recommendation to “improve coordination”. In the evaluated sequence, almost all station margin has been consumed by Phase 2, while most of the development programme is still to follow. Project-level measures provide meaningful relief, but cannot accommodate the later phases on their own. If the area continues along the present trajectory, coordination will become necessary after contracts, ownership structures and technical systems have already been established separately. At that point, creating collective controllability is likely to be more difficult than preserving the option during earlier development decisions.

This does not mean that every area requires an energy company or centrally owned asset portfolio. The results instead support a proportional approach in which collective decision capacity develops before collective ownership is considered. Coordinated project flexibility can retain identifiable project responsibilities while connecting distributed assets to a shared objective. Deeper integration becomes relevant only when repeated interdependence justifies the additional organisational and contractual burden. The strategic pathways developed in Chapter 7 translate this interpretation into actor-specific roles and adaptive decision points.

The broader societal relevance lies in the relationship between grid congestion and urban-development continuity. Network reinforcement remains necessary, but developments scheduled before reinforcement cannot rely solely on future capacity. Flexibility can bridge part of that period, provided its technical effect and institutional availability are addressed together. Treating flexibility only as an equipment choice risks installing assets that are unavailable for the constraint that

ultimately matters. Treating congestion only as a network-operator problem overlooks the development and contractual decisions that shape whether demand can later be coordinated.

8.4 Methodological reflection and limitations

The conclusions must be interpreted within the boundaries of the research design. The institutional analysis is based on four purposively selected interviews with two developers, the Municipality of The Hague and Stedin. These actors represent central perspectives in the case, but they do not cover all parties required for implementation. The future WKO/ATES operator, charging operators, aggregators, investors, future property owners and users were not interviewed. The findings therefore identify institutional conditions and tensions, but do not constitute a negotiated governance or contractual design.

All interview material was coded by one researcher. The retained fragments and coding workbooks provide an audit trail between source material, codes and higher-order themes, but no inter-coder reliability assessment was conducted. Theme development and interpretation therefore remain partly dependent on the researcher's judgement. The convergence between respondents and documents strengthens several findings, particularly the preference for project-bounded responsibility and the absence of demonstrated station-oriented coordination, but it does not remove this interpretive limitation.

The sequence of the mixed-methods design also shaped the evidence. Interviews and documentary analysis preceded the quantitative results. This was valuable because scenario selection was informed by case-specific resources and actor perspectives rather than imposed solely from technical literature. However, respondents were not confronted with the Phase 2 and Phase 6 thresholds or with the technical performance of the integrated area-wide scenario.

In retrospect, I would have used an early version of the model as an interview stimulus. The model did not need to provide a validated forecast to support that purpose. Even an indicative visualisation of cumulative station loading could have enabled more specific questions about risk perception, willingness to coordinate, acceptable dependencies and the timing of institutional action. A second interview round after modelling could also have tested whether the results changed the actors' interpretation of the problem. The selected sequence produced a grounded technical assessment, but a more iterative design might have achieved deeper integration between the qualitative and quantitative components.

The case-study design does not support statistical generalisation. Laakhavens Hollands Spoor is an information-rich case shaped by a particular network boundary, development programme, set of actors and regulatory context. Its wider relevance lies in analytical generalisation to comparable mechanisms, especially the mismatch between project-level decisions and cumulative network constraints (Yin, 2018). Comparative research is needed to determine how strongly the identified temporal and institutional dynamics depend on local ownership, network topology and planning instruments.

The quantitative results are scenarios rather than forecasts. Future programmes, delivery dates and functional demand were derived from available planning information. These may change before the projects become operational. Where gross floor area was converted to usable floor area, a uniform

factor of 0.85 was applied. Standard electricity-demand intensities and temporal profiles were used because project-specific measured consumption does not yet exist. These assumptions are appropriate for comparative analysis but do not support exact predictions of future peaks.

No measured hourly time series was available for the complete Jan Wapstraat supply area. The station reference was reconstructed and scaled to the reported 36.2 MW capacity requirement for 2026. Existing LHHS demand and demand in the wider supply area were held constant across the development phases to isolate the effect of the selected projects. This excludes uncertain demolition, vacancy, replacement and autonomous demand growth. Depending on how those developments evolve, the model may either overstate or understate future station loading.

The model evaluates the 38 MW station constraint but does not represent complete power-flow behaviour, voltage conditions, reactive power, protection coordination or every local cable and transformer constraint. Remaining within 38 MW therefore does not demonstrate that every project can be connected without further local infrastructure. It also does not create a contractual right to transport capacity.

Operational flexibility was assessed during one selected 336-hour critical period. Preparation and recovery horizons reduce end effects, and the annual corrected peak occurs within the selected period in all phases. Nevertheless, the analysis does not capture every possible combination of weather, mobility, occupation and thermal-storage conditions. The optimisation also assumes perfect information and coordinated control of the activated resources. Forecast errors, communication failures, maintenance, user non-participation and asset outages are not represented.

These limitations are most consequential for the integrated area-wide scenario. That scenario reaches zero residual congestion but remains exactly at 38 MW during 90 hours. It should therefore be interpreted as an upper technical potential with little robustness margin, not as a dependable operational guarantee. The selected battery, smart-charging and HyER capacities are scenario parameters rather than detailed engineering designs. HyER is particularly exploratory because fuel supply, emissions, safety, costs and productive use of heat were not assessed in detail.

Finally, the thesis does not demonstrate a viable business case or legally enforceable delivery model. Investment costs, asset degradation, operating costs, compensation, liability and the distribution of benefits were not quantified. The institutional analysis identifies what remains unresolved, but does not prove that the technically effective arrangements can be financed or contracted under current conditions.

8.5 Directions for future research

Future research should first use more iterative mixed-methods designs. Preliminary model outcomes can be used as boundary objects through which developers, municipalities, network operators and future asset operators examine shared assumptions and consequences (Cuppen et al., 2021). Interviews can then test not only general attitudes towards flexibility, but responses to concrete development thresholds, distributional effects and governance alternatives. Revised stakeholder input can subsequently improve the model, creating a genuine feedback loop between technical and institutional analysis.

Second, future technical research should evaluate robustness. Multiple weather years, EV-availability profiles, occupation levels, development sequences and background-demand trajectories should be tested. Stochastic or rolling-horizon optimisation could represent forecast uncertainty and determine how much reserve is required for dependable operation. Asset location and capacity could also be optimised rather than tested only through predefined packages.

Third, institutional research should develop and compare concrete governance arrangements for coordinated project flexibility. This requires participation from long-term WKO/ATES and charging operators, developers, Stedin, the municipality, future owners and users. Research should examine dispatch authority, data access, performance verification, liability, transferability and the distribution of costs and benefits. Particular attention is needed for the temporal asymmetry between early projects that can preserve flexibility and later projects that may depend on it.

Fourth, financial and legal analysis is required to determine whether the evaluated pathways can become implementable propositions. This should compare investment and operating costs, degradation, avoided connection costs, congestion value and potential revenues. It should also investigate how verified station-level reductions could be connected to formal and dependable transport-capacity arrangements without assuming that physical headroom automatically produces a capacity right.

Finally, comparative case research should test the analytical generalisability of the scale and timing mismatch identified here. Cases should differ in development phasing, land ownership, municipal instruments, network topology and the organisation of collective infrastructure. Such comparison can establish when coordinated project flexibility is sufficient and when a more integrated area arrangement becomes necessary.

9 Conclusion

This thesis examined to what extent technically relevant and institutionally feasible flexibility arrangements can reduce station-level electricity-grid congestion during the phased redevelopment of Laakhavens Hollands Spoor prior to planned grid reinforcement.

The results show that flexibility can materially reduce both the magnitude and persistence of congestion, but that its contribution depends strongly on the scale and organisation of implementation. Without additional congestion-oriented flexibility, the modelled station load increases progressively across the development phases and reaches 45.2 MW in Phase 8, exceeding the 38 MW capacity by 7.2 MW. Flexible WKO/ATES operation accommodates the modelled development through Phase 4, while favourable inherited flexibility and additional project-level measures can extend this to Phase 5. From Phase 6 onward, project-level configurations reduce congestion but do not fully eliminate it.

The complete modelled Phase 8 programme can only be accommodated in the integrated area-wide flexibility scenario, in which WKO/ATES flexibility, batteries, smart charging and local generation are coordinated across the full development portfolio around the Jan Wapstraat constraint. This demonstrates that the technical challenge is not only the availability of individual flexible technologies, but also the cumulative and coordinated use of resources installed during earlier development phases.

The institutional analysis shows, however, that this area-wide configuration is not currently established. Development responsibilities, investment decisions and operational control remain largely project-specific, while no coordinating actor, shared dispatch arrangement or durable cost-allocation mechanism was identified. Project-level smart charging and battery storage are therefore conditionally feasible, and WKO/ATES is established as thermal infrastructure, but its use for station-level congestion management is not currently demonstrated. The technically strongest scenario thus exceeds the level of institutional feasibility presently observed in the case.

The answer to the main research question is therefore conditional. Flexibility can substantially mitigate station-level congestion and can postpone the effective capacity boundary during the pre-reinforcement period, but project-level flexibility alone is insufficient for the later phases. Full technical accommodation requires coordinated operation across projects, while the governance conditions for such coordination still need to be created.

For the redevelopment actors, the practical implication is to combine immediate project-level measures with preparations for future coordination. Existing transport positions should be retained where possible, new assets should be designed with controllability and data access, and responsibilities for dispatch, compensation and transferability should be addressed before later projects are completed. Flexibility should be treated as a phased risk-management strategy rather than as a substitute for grid reinforcement.

Finally, modelled reductions in station loading do not automatically create contractual transport rights for individual projects. The contribution of flexibility will only become practically effective when technical performance is connected to formal capacity-allocation and operational arrangements. Network reinforcement therefore remains necessary, while flexibility can help bridge part of the temporary capacity gap before it becomes available.

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Appendix A: Interview Protocols

A1: Developer interview topic guide

The interviews with COD and Redevco followed the same semi-structured topic guide to support comparison between the two developer perspectives. Questions were adapted during the interviews to the specific project context and the respondent's expertise.

The following topics were addressed:

- The energy concept of the development, including whether the project was expected to use an all-electric or collective energy system.
- The role of electricity-grid congestion in project planning and decision-making.
- Potential flexibility options, including individual or collective battery storage.
- The controllability of collective or project-level energy systems and their potential contribution to peak reduction.
- Previous experiences with electricity-capacity constraints and solutions considered by the project organisation.
- Opportunities for cooperation with surrounding development projects.
- The main technical, organisational and financial barriers to implementing flexibility.
- Relevant legal or contractual restrictions.
- The potential use or retention of existing electricity connections.
- The implications of the revised ACM prioritisation framework.

Project-specific prompts

For COD, additional attention was given to the existing electricity connections and contracted capacity at the MegaStores site.

For Redevco, additional attention was given to the limited availability of existing connections at the Escher Gardens site and the project's dependence on obtaining new transport capacity.

A2: Stedin interview topic guide

The interview with Stedin focused on the electricity-system boundary, the location of network constraints and the interpretation of the Jan Wapstraat congestion assessment. The following questions were used:

- Where are the current bottlenecks in the electricity network around Jan Wapstraat located? Do these constraints occur only at higher network levels, or also within the medium- and low-voltage networks?
- Several interview respondents referred to a new medium-voltage ring in Laakhavens. When is this infrastructure expected to be realised, and what effect is it expected to have on electricity supply and network loading in the area?

- The congestion assessment projects a total required capacity of approximately 54 MW and a shortage of around 16 MW for the complete Jan Wapstraat supply area in 2036. Is it possible to indicate which share of this demand and shortage is associated with the redevelopment of Laakhavens Hollands Spoor?
- Is information available on the capacity of the individual medium-voltage substations in the area, and are additional substations expected to be constructed before 2036?
- The congestion assessment identifies limited flexibility potential among existing connected users. Did this assessment also consider the future WKO/ATES systems planned by Eteck and their possible controllability?

A3: Municipality of The Hague interview topic guide

The interview with the Municipality of The Hague focused on the relationship between area development, energy infrastructure and public-private coordination. The following topics were addressed:

- Current developments in Laakhavens that affect the area's energy requirements, including existing bottlenecks and emerging implementation challenges.
- The future transformation of Laakhavens, particularly the shift towards a more residential programme and its implications for the space available for businesses and other functions.
- Planned developments, policy processes and decisions expected to influence the area, including their indicative timing and sequencing.
- The organisations with an important role in the local energy system and the way cooperation between the municipality, developers, infrastructure operators and other actors is organised.
- The municipality's role in coordinating energy infrastructure, grid-capacity issues and possible collective solutions within the phased redevelopment.

Appendix B: Coding framework excerpts

B1: COD

Code	Definition	Theme	Example fragment IDs
connection retention	Strategy to retain existing connections and contracted capacity.	Connection capacity and rights	COD_021
connection vs transport capacity	Distinction between a physical connection and the right to transport capacity.	Connection capacity and rights	COD_024
large-user/small-user mismatch	Barrier in converting large commercial connections to many residential connections.	Connection capacity and rights	COD_040
WKO flexibility uncertainty	Unclear potential to shift or reduce WKO load.	WKO and collective energy systems	COD_079
smart charging	Load balancing or managed EV charging.	Flexibility options	COD_085
battery business case uncertainty	Uncertainty about who pays for, owns or manages battery assets.	Governance and development risk	COD_020
project autonomy	Preference to solve energy issues within the project boundary and limit dependency on other developments.	Governance and development risk	COD_017

B2: Redevco

Code	Definition	Theme	Example fragment IDs
no legacy capacity	Location has no substantial existing building, load or connection to reuse.	Existing site and connection position	HS_011; HS_013
prioritisation uncertainty	Unclear how the project will be placed	Connection procedure and capacity rights	HS_017; HS_020; HS_021

	in the queue or prioritised under Stedin or ACM rules.		
grid capacity delay	Risk that lack of grid capacity delays development.	Development risk and uncertainty	HS_022; HS_056
collective system dependency	A collective system creates dependency between buildings, owners or third parties.	Governance and saleability risk	HS_034; HS_035; HS_063
collective vs individual storage	Distinction between batteries per building or unit and one large shared battery.	Flexibility options	HS_076; HS_077
end-user affordability	Residents ultimately pay energy costs and may or may not benefit from flexibility assets.	End-user and ownership structure	HS_078; HS_079; HS_083; HS_084
owner-tenant split	Building owners, tenants or residents and battery owners may have different incentives and rights.	End-user and ownership structure	HS_080; HS_082

B3: Stedin

Code	Definition	Theme	Example fragment IDs
Jan Wapstraat bottleneck	Identification of Jan Wapstraat as the relevant congestion point or station-level constraint.	Grid structure and congestion level	ST_002; ST_004; ST_027; ST_080
local vs upstream constraint	Distinction between local medium-voltage infrastructure and upstream transport capacity.	Grid structure and congestion level	ST_024; ST_029; ST_030
MS ring not transport capacity	The medium-voltage ring does not add station or transport capacity.	MS ring and local connectability	ST_024; ST_029
future assets excluded from current flex potential	Future WKO, battery or other assets are not included in the current flexibility-potential assessment.	Flexibility potential and options	ST_045; ST_048; ST_049

smart charging / grid-aware charging	Grid-aware or controlled EV charging as a flexibility option.	Flexibility potential and options	ST_050; ST_051
large-user connection retention	Retention or relocation of a large-user connection during redevelopment.	Connection rights and capacity retention	ST_055; ST_056; ST_057
large-to-small conversion impossible	Large-user capacity cannot be exchanged for many small-user connections.	Connection rights and capacity retention	ST_061; ST_062
cancelled capacity redistribution	Cancelled capacity is returned to the waiting-list allocation process rather than being reserved locally.	Connection rights and capacity retention	ST_063; ST_064

B4: Municipality of The Hague

Code	Definition	Theme	Example fragment IDs
energy planning gap	Energy was not integrated as explicitly as mobility in programme decisions.	Governance and development risk	RON_029
collective infrastructure risk	Large collective infrastructure requires upfront investment and creates risks.	Governance and development risk	RON_035
cooperation agreement	SOK or other formal agreement between the municipality and developers.	Actor coordination and governance	RON_037
developer connection responsibility	Developers coordinate with the grid operator to obtain electricity.	Connection capacity and rights	RON_066
connection retention advice	Advice not to shut down existing connections unnecessarily.	Connection capacity and rights	RON_074
large-user to small-user mismatch	Difficulty using a large connection for many small dwelling connections.	Connection capacity and rights	RON_084

Appendix C: Quantitative model inputs and scenario settings

C1: Electricity demand assumptions

Annual electricity-demand assumptions were derived from CBS StatLine datasets. Residential demand was based on the average electricity delivery per dwelling in the municipality of The Hague in 2024. Non-residential demand intensities were selected and rounded from the CBS energy-performance indicators for utility buildings, using the building type and floor-area category considered most representative of each modelled function.

Table C.1. Annual electricity-demand assumptions by modelled function.

Function	Applied source or category	Demand intensity	Unit	Explanation
Housing	CBS StatLine – Energy consumption of private dwellings; dwelling type and regions (81528NED), total dwellings, municipality of The Hague, 2024	2,150	kWh/dwelling/year	Average annual electricity delivery per dwelling in the municipality of The Hague. Fully electric space heating is excluded from this underlying residential-demand assumption.
Offices	CBS StatLine – Energy performance indicators for utility buildings in the service sector; floor-area class (83374NED), office category	75	kWh/m²/year	Selected and rounded modelling value based on the electricity-intensity values for office buildings.
Education	CBS StatLine – Energy performance indicators for utility buildings in the service sector;	50	kWh/m²/year	Selected modelling value for large secondary, vocational and higher-education buildings.

	floor-area class (83374NED), education category			
Business premises	CBS StatLine – Energy performance indicators for utility buildings in the service sector; floor-area class (83374NED), relevant commercial-building category	60	kWh/m²/year	Applied to commercial premises without energy-intensive industrial production.
Retail (home furnishing)	CBS StatLine – Energy performance indicators for utility buildings in the service sector; floor-area class (83374NED), retail category	70	kWh/m²/year	Applied to home-furnishing stores and large-scale retail functions.
Retail (other)	CBS StatLine – Energy performance indicators for utility buildings in the service sector; floor-area class (83374NED), retail category	75	kWh/m²/year	Applied to other retail functions.
Services, leisure and hospitality	CBS StatLine – Energy performance indicators for utility buildings in the service sector; floor-area class (83374NED), hospitality, leisure and service categories	100	kWh/m²/year	Selected higher-intensity value reflecting kitchen equipment, refrigeration, ventilation and longer operating hours.
Care and welfare	CBS StatLine – Energy performance indicators for utility buildings in the service sector; floor-area class (83374NED), healthcare category	60	kWh/m²/year	Applied to light healthcare and welfare functions.

Indoor sport	CBS StatLine – Energy performance indicators for utility buildings in the service sector; floor-area class (83374NED), indoor-sport category	50	kWh/m²/year	Applied to small indoor sports facilities.

C2: Hourly load-profile assignment

Annual electricity demand was converted into hourly demand profiles using Dutch reference load profiles. Residential demand was represented using the MFFBAS 2026 profile 1.00_E1A_AZI_A. Non-residential profiles were selected from Liander's MOOI Eigen dataset using the accompanying workbook that recommends either an aggregated SBI profile or a standard commercial and office profile for each economic activity. The selected profiles were normalised and scaled so that their annual sum equalled the calculated annual electricity demand of the corresponding function.

Table C.2. Assignment of hourly reference load profiles by modelled function.

Function in model	Annual demand assumption	Assigned standard profile	Dataset / selection basis	Selection rationale
Housing	2,150 kWh/dwelling/year	1.00_E1A_AZI_A	MFFBAS 2026	Residential small-consumer withdrawal profile without electricity feed-in, using the 2026 calendar.
Offices	75 kWh/m²/year	KO_KANTOOR_ONDERWIJS	Liander MOOI Eigen – standard K&O profile selected using the recommended-profile overview	No separate generic office profile was available. The combined office and education profile represents predominantly daytime and weekday electricity use.
Education	50 kWh/m²/year	SBI 85 – mean	Liander MOOI Eigen – aggregated SBI profile for education, selected using the recommended-profile overview	A sector-specific education profile was available and was considered more representative of the large existing educational institutions in LHHS than the general KO_KANTOOR_ONDERWIJS profile.

Business premises	60 kWh/m²/year	KO_OVERIG	Liander MOOI Eigen – standard K&O profile selected using the recommended-profile overview	Applied to light commercial and business premises without energy-intensive industrial processes.
Retail (home furnishing)	70 kWh/m²/year	KO_OVERIG	Liander MOOI Eigen – standard K&O profile selected using the recommended-profile overview	No sufficiently representative general retail profile was available. KO_OVERIG was selected as the closest available commercial-use profile.
Retail (other)	75 kWh/m²/year	KO_OVERIG	Liander MOOI Eigen – standard K&O profile selected using the recommended-profile overview	No sufficiently representative general retail profile was available. KO_OVERIG was used as a general commercial-use profile.
Services, leisure and hospitality	100 kWh/m²/year	KO_OVERIG	Liander MOOI Eigen – standard K&O profile selected using the recommended-profile overview	KO_OVERIG was used for the temporal demand pattern. The comparatively high electricity intensity of these functions was represented through the annual demand assumption.
Care and welfare	60 kWh/m²/year	KO_KANTOOR_ONDERWIJS	Liander MOOI Eigen – standard K&O profile selected using the recommended-profile overview	Small care and welfare functions were assumed to have an occupancy pattern dominated by daytime and weekday use.
Indoor sport	50 kWh/m²/year	KO_OVERIG	Liander MOOI Eigen – standard K&O profile selected using the recommended-profile overview	No specific indoor-sport profile was available. KO_OVERIG was selected because this function represents a relatively small share of the total programme.

Additional system-level inputs

Station reference. The reconstructed existing LHHS demand was combined with residual demand from the wider Jan Wapstraat supply area. In the absence of a measured hourly profile for this residual demand, it was assigned the same normalised temporal pattern as the reconstructed existing LHHS profile. The residual component was scaled so that the combined reference profile reached an annual maximum of 36.2 MW, corresponding to Stedin's projected required transport capacity for 2026. A station transport limit of 38 MW was applied in the constrained experiments (Stedin, 2025). Both background-demand components were held constant across all development phases.

Electricity-price input. The hourly electricity-price signal was based on historical 2025 market prices from Jeroen.nl. Only the market-price component was used; procurement fees, energy taxes and VAT were excluded. The resulting price series was used as the exogenous electricity-cost signal in the least-cost optimisation.

C3: Common flexibility and operational parameters

Table C.3 summarises the flexibility, conversion, storage and operational parameters applied consistently across the project models. Values are reported as external inputs, derived parameters or explicit modelling assumptions; project-specific capacities are reported separately in Section C4.

Table C.3. Common flexibility, conversion and operational parameters.

Technology	Parameter	Applied value	Unit	Basis and modelling interpretation
Battery storage	Energy-capacity scenarios	0; 0.5; 1.0	MWh	Scenario parameter; three levels used to compare no battery, moderate storage and maximum new-project storage.
Battery storage	Default new-project charging and discharging power	0.30	MW	Modelling assumption; charging and discharging power was limited to 0.30 MW in the new-project configuration.
Battery storage	Minimum state of charge	20	% of energy capacity	Modelling assumption; battery energy could not fall below 20% of installed capacity.

Battery storage	Initial state of charge	50	% of energy capacity	Initial-condition assumption; the battery started each model horizon at 50% of installed energy capacity.
Battery storage	Charging electricity factor	1.03	MWh input per MWh stored	Modelling parameter corresponding to an assumed charging efficiency of approximately 97.1%.
Battery storage	Discharging storage factor	1.03	MWh withdrawn per MWh supplied	Modelling parameter corresponding to an assumed discharging efficiency of approximately 97.1%.
Battery storage	Implied round-trip efficiency	94.3	%	Derived from the charging and discharging factors.
EV charging	Average EV battery capacity	60	kWh per EV	Modelling assumption; a uniform 60 kWh battery capacity was applied to all represented EVs.
EV charging	Arrival state of charge	30	%	Modelling assumption; mobile EVs were assumed to return with 30% state of charge.
EV charging	Required departure state of charge	80	%	Service constraint; EVs were required to reach 80% state of charge before departure.
EV charging	Initial state of charge	80	%	Initial-condition assumption; EVs present at the start of the model horizon were initialised at 80% state of charge.
EV charging	Minimum state of charge	20	%	Modelling assumption; aggregate EV-fleet storage could not fall below 20% state of charge.
EV charging	Daily mobile share	71.4	% of EV fleet	Modelling assumption; 71.4% of the represented EV fleet participated in the daily arrival and departure cycle.
EV charging	Charging power	4.76	kW per EV	Modelling assumption; charging power was limited to 4.76 kW per connected EV.
EV charging	Electricity-input factor	1.087	MWh input per MWh charged	Modelling parameter corresponding to an assumed charging efficiency of approximately 92.0%.
Smart charging	Participation levels	0; 50; 100	%	Scenario parameter; the three levels represent increasing availability of charging demand for temporal shifting within the represented vehicle-availability and departure constraints.

HyER	Capacity levels in principal experiments	0X; 1X; 3X	—	Scenario parameter; three configurations were evaluated to compare increasing levels of controllable local generation.
HyER	1X fuel-cell process capacity	0.17	MW	Derived from the stated PHIAB 9080 outputs of 0.09 MWe and 0.08 MWth (Hyer Power, n.d.; YES!Delft, 2025).
HyER	3X fuel-cell process capacity	0.51	MW	Derived as three times the 1X configuration, producing 0.27 MWe and 0.24 MWth.
HyER	Electrical output share	90/170	—	Derived from the stated 90 kW electrical and 80 kW thermal outputs of the PHIAB 9080: approximately 52.9% (Hyer Power, n.d.; YES!Delft, 2025).
HyER	Thermal output share	80/170	—	Derived from the stated 90 kW electrical and 80 kW thermal outputs of the PHIAB 9080: approximately 47.1% (Hyer Power, n.d.; YES!Delft, 2025).
HyER	Hydrogen-input factor	30.3	kg/MWh	Modelling conversion based on an assumed hydrogen energy content of 33 kWh/kg.
HyER	Hydrogen price	8	EUR/kg	Operating-cost assumption; a hydrogen price of EUR 8/kg was applied in the least-cost optimisation.
WKO/ATES	Electricity use for heat supply	0.25	MWe per MWth	Modelling conversion assumption; equivalent to a modelled COP of 4.
WKO/ATES	Electricity use for cooling supply	0.05	MWe per MWth	Modelling conversion assumption; equivalent to an electricity-to-cooling ratio of 1:20.
WKO/ATES	Electricity use for heat or cold regeneration	0.05	MWe per MWth	Modelling conversion assumption; regeneration was available subject to the represented outside-temperature conditions.
WKO/ATES	Initial warm-storage level	50	% of WKO capacity	Initial-condition assumption; warm storage started each model horizon at 50% of installed WKO/ATES storage capacity.
WKO/ATES	Initial cold-storage level	50	% of WKO capacity	Initial-condition assumption; cold storage started each model horizon at 50% of installed WKO/ATES storage capacity.
Building thermal model	Residential temperature bounds	20–23	°C	Comfort constraint; residential indoor temperature was restricted to 20–23°C and initialised at 21°C.

Building thermal model	Amenities temperature bounds during use	20–24	°C	Comfort constraint; indoor temperature was restricted to 20–24°C during scheduled occupied periods.
Building thermal model	Amenities temperature bounds outside use	16–28	°C	Modelling assumption; a wider temperature range was permitted outside scheduled occupied periods.
Building thermal model	Effective thermal capacity	260	kJ/m²K	Modelling assumption; applied uniformly to residential and amenities floor area.
Building thermal model	Residential heat-loss coefficient	0.6	W/m²K	Modelling assumption; applied to residential floor area.
Building thermal model	Amenities heat-loss coefficient	1.0	W/m²K	Modelling assumption; applied to amenities floor area.
Building thermal model	Amenities internal heat gain	12	W/m²	Modelling assumption; applied during scheduled operating periods.

C4: **Project-specific flexibility and take-off parameters**

Table C.4 reports the project-specific capacity settings applied in the model. The represented EV fleet was derived from the expected parking capacity of each project. Where project-specific parking numbers were available from municipal project information, these values were used directly. Where no parking capacity was reported, it was estimated by scaling from a comparable project with known parking provision according to project size. The resulting parking capacity was used as the basis for the modelled EV fleet. WKO/ATES storage, heating, cooling and free-cooling capacities were specified as project-specific modelling assumptions and scaled according to the relative size of each development. These parameters support comparative scenario analysis and should not be interpreted as detailed engineering designs or confirmed installed capacities.

Table C.4. Project-specific flexibility capacities and local take-off limits.

Project	Total EVs	Initial EVs at home	WKO storage capacity (MWhth)	Maximum WKO heating/cooling power (MWth)	Amenities free-cooling capacity (MWth)	Project-template default take-off limit (MW)
Waldorp Four	90	80	2,500	2.00	0.10	1.00
The Grace	250	225	2,900	2.00	0.70	1.60
Escher Gardens	240	220	2,500	2.00	2.40	1.60
Struijck II	36	33	350	0.28	0.014	0.20
Verheeskade 105–197 and 287–329	490	440	5,000	4.00	4	2.75
MRKT	420	380	5,000	4.00	4	2.61
Verheeskade 25	270	245	3,000	2.40	0.12	1.52
The Embrace	125	110	1,500	1.20	0.35	0.70

C5: Inherited flexibility pathways

Table C.5 presents the scenario settings used in the final model configuration, which includes all eight development projects. The battery and fuel-cell capacities reported for the inherited pathways represent the combined capacities of the seven projects included before The Embrace was added in Phase 8.

Table C.5. Inherited flexibility pathways and selector settings for the Phase 8 model configuration.

Pathway	Linny-R selector	Inherited battery	Smart-charging participation	Inherited HyER capacity
S_REF	S_REF	0 MWh; 0 MW	0%	0
S_DEMAND	S_DEMAND	0 MWh; 0 MW	100%	0
S_BAT	S_STORAGE	4.5 MWh; 2.3 MW	0%	0
S_FC	S_BACKUP	0 MWh; 0 MW	0%	3.23 MW fuel-cell process capacity

C6: Integrated area-wide flexibility scenario

The integrated area-wide scenario represents the maximum evaluated level of technical coordination in Phase 8. WKO/ATES, battery storage, smart charging and HyER are made available across the complete eight-project portfolio and operated around the shared 38 MW Jan Wapstraat constraint. The scenario is intended as an upper technical potential rather than as a representation of an existing governance or contractual arrangement. Table C.6 summarises the applied aggregate capacities, control setting and simulation horizon.

Table C.6. Aggregate settings for the integrated area-wide Phase 8 flexibility scenario.

Component	Area-wide setting	Interpretation
Development scope	All eight projects	Complete Phase 8 development portfolio
Station constraint	38 MW	Combined electricity import through Jan Wapstraat
Battery storage	5.5 MWh energy capacity; 2.6 MW charge/discharge power	Combined maximum battery configuration across the seven inherited projects and The Embrace

Smart charging	100% participation across all projects	Charging could be shifted within the represented vehicle-availability and departure constraints
HyER fuel-cell capacity	3.74 MW process capacity	Combined 3X HyER configuration across the complete portfolio
HyER electrical capacity	Approximately 1.98 MWe	Based on an electrical-output share of 90/170
HyER thermal capacity	Approximately 1.76 MWth	Based on a thermal-output share of 80/170
WKO/ATES storage	22,750 MWhth	Combined thermal-storage capacity across all eight projects
WKO/ATES heating and cooling capacity	17.88 MWth	Combined maximum heating/cooling conversion capacity
Control objective	Coordinated operation around the station constraint	Resources were no longer operated only for individual project limits
Simulation horizon	672 operating hours plus initial state	Four-week experiment including preparation, critical and recovery periods
Principal assessment interval	336 hours	Two-week critical period used for congestion volume and duration

Appendix D: verification and validation

D1: Electricity balance

Figure D.1 compares total electricity supply with the stacked electricity-demand components for a representative Waldorp Four configuration. The supply line follows the upper boundary of the demand stack throughout the illustrated period. Any remaining difference is below the reported numerical precision of the exported results, supporting the internal consistency of the hourly electricity balance.

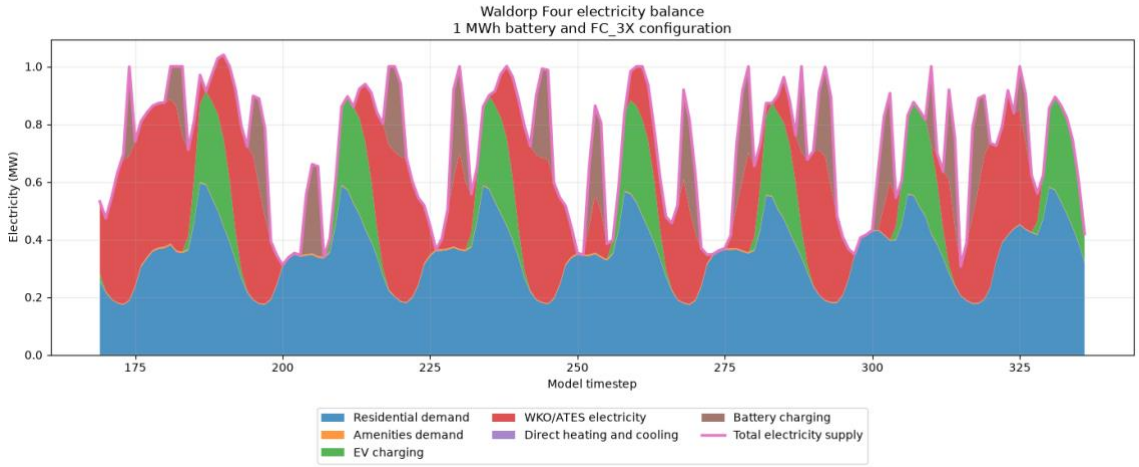


Figure D.1. Electricity-balance verification for a representative Waldorp Four configuration.

D2: Heat balance

Figure D.2 compares total heat supply with residential heating, amenities heating and unused fuel-cell heat. The total heat-supply line corresponds with the combined output destinations throughout the illustrated period. Because the HyER unit produces heat whenever it generates electricity, heat that is not

required by the represented thermal demand is routed to the unused-heat output. This ensures that all produced heat remains accounted for in the model balance.

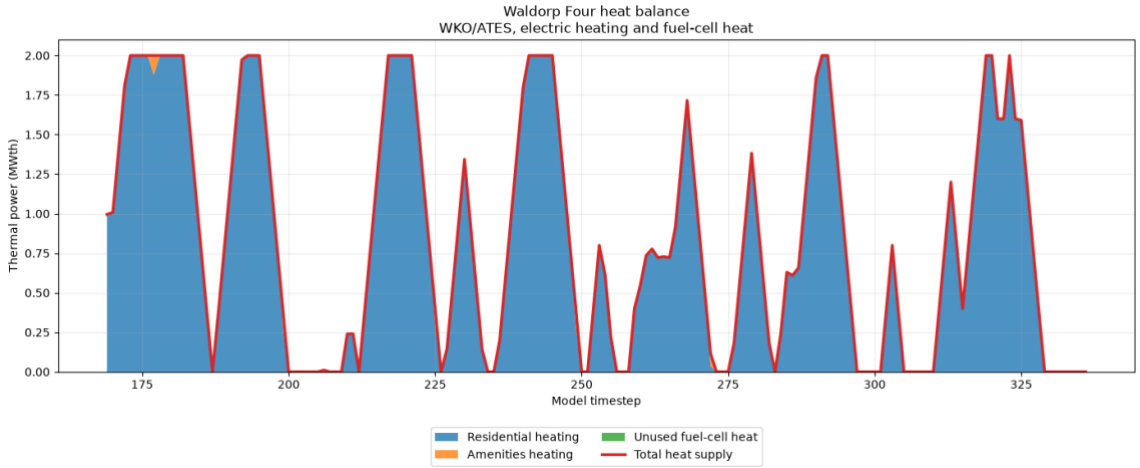


Figure D.2. Heat-balance verification for a representative Waldorp Four configuration.

D3: Annual WKO/ATES behaviour

Figure D.3 shows the seasonal transfer of thermal energy between the warm and cold WKO/ATES storage volumes over the annual simulation. The combined storage level remains practically constant, while the individual warm and cold volumes do not return exactly to their initial distribution and finish within approximately 5% of their initial levels. The result supports internal storage consistency but should not be interpreted as demonstration of a fully cyclic annual operating state.

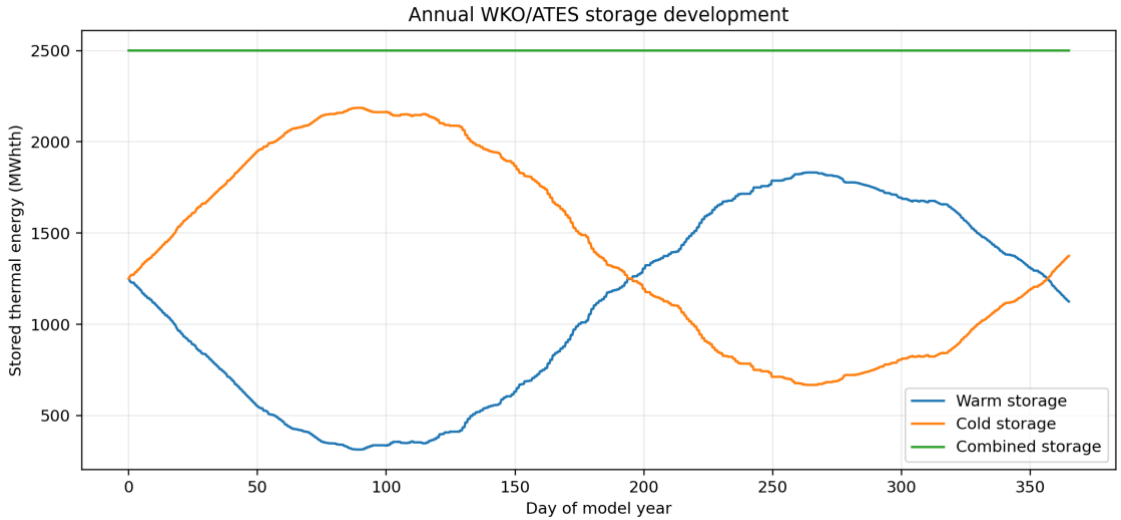


Figure D.3. Annual development of warm, cold and combined WKO/ATES storage.

D4: Project demand example

Figure D.4 illustrates a representative week of the generated project-level electricity-demand profiles used as model inputs. Residential demand follows a recurring daily pattern, while non-residential functions are concentrated more strongly during daytime operating hours. The lower non-residential demand during the weekend reflects the temporal profiles assigned to these functions in Appendix C.

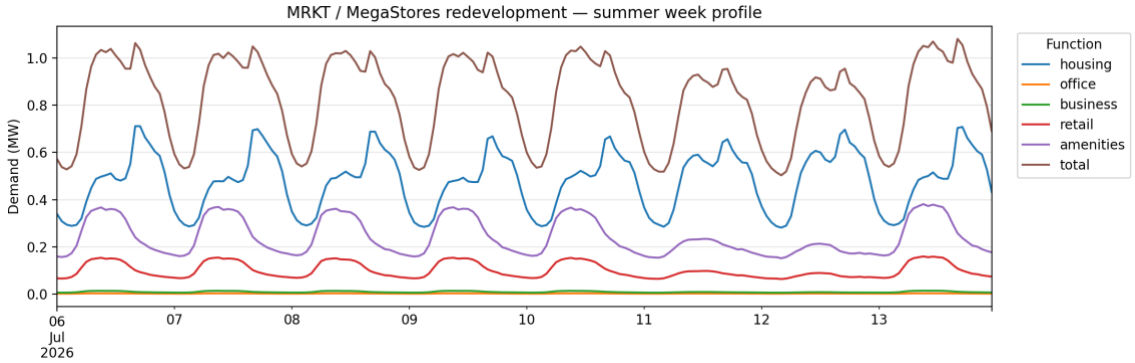


Figure D.4. Example of generated project-level electricity-demand profiles for MRKT / MegaStores redevelopment.

D5: Verification summary

Table D.1 summarises the principal model and post-processing verification checks. Numerical balance checks were evaluated using representative verification runs, while dataset and processing checks were performed before the congestion indicators were calculated.

Table D.1. Summary of model and post-processing verification checks

Verification check	Reported indicator	Outcome
Electricity balance	Maximum absolute hourly residual	0.000 MW
Heat balance	Maximum absolute hourly residual	0.000 MWth
Battery state-of-charge balance	Maximum absolute hourly residual	0.000 MWh
EV-fleet energy balance	Maximum absolute hourly residual	0.000 MWh
Battery operating bounds	Minimum and maximum state of charge	Within modelled bounds
Simultaneous battery charging and discharging	Number of affected timesteps	0
Building comfort	Number of temperature-bound violations	0
Load shedding	Maximum value in verification runs	0 MW
Energy Not Served	Maximum value in verification runs	0 MWh
Annual WKO/ATES combined-storage balance	Initial versus final combined storage	Practically unchanged

EV service requirements	Arrival, departure and minimum state-of-charge constraints	Verified in representative model runs
Selector activation	Activation of battery, smart-charging and HyER scenario settings	Verified across scenario configurations
Solver feasibility	Solver status of retained model runs	Checked before results were included in the analysis
Time-series length	Consistency with the specified simulation horizons	Checked before indicator calculation
Duplicate runs	Duplicate scenario identifiers in exported results	Checked before indicator calculation
Missing variables	Availability of variables required for indicator calculation	Checked before indicator calculation
Numerical conversion	Conversion and parsing of exported Linny-R values	Checked before indicator calculation
Energy Not Served sign convention	Direction of ENS values used in residual-congestion calculations	Checked before indicator calculation

Appendix E: Documentary corpus

The documentary corpus was assembled purposively to reconstruct the urban-development context, electricity-system boundary, formal grid-access procedures and case-specific conditions relevant to Laakhavens Hollands Spoor and station Jan Wapstraat. The corpus contains the municipal, regulatory and network-operator sources that were actively used in the case reconstruction and institutional analysis.

Scientific literature used for theoretical framing, interview transcripts and quantitative datasets or model-parameter sources were not counted as part of the documentary corpus.

Reference	Title	Issuing organisation	Date/version	Document type	Selection rationale	Analytical use
Gemeente Den Haag (n.d.)	Central Innovation District	Municipality of The Hague	n.d.	Municipal project webpage	Official municipal source describing the wider spatial context in which LHHS is located.	Used to establish the position of LHHS within the CID and the spatial organisation of the development area.
Gemeente Den Haag (2025a)	Geamendeerd voorstel van het college inzake Vaststelling Ontwikkelstrategie Laakhavens Hollands Spoor	Municipality of The Hague	2025	Municipal decision document	Formal municipal source containing the existing programme and decision context for LHHS.	Used to reconstruct the existing functional programme and establish the baseline urban-development context.

Gemeente Den Haag (2025b)	Ontwikkelstrategie Laakhavens Hollands Spoor	Municipality of The Hague	2025	Municipal development strategy	Principal adopted strategy for the redevelopment and the most comprehensive official source on programme, spatial organisation and infrastructure direction.	Used to reconstruct the future development programme, multi-actor development structure, mobility strategy and planned collective heat and cold infrastructure.
Gemeente Den Haag (2026)	Projectenoverzicht CID	Municipality of The Hague	2026	Municipal project overview	Most recent consolidated municipal overview of individual projects, programmes and indicative development status.	Used to identify the principal LHHS projects and construct the indicative development sequence used in the case and quantitative assessment.
Stedin (2025)	Congestiemanagement-onderzoek: Onderzoek naar de toepasbaarheid van congestiemanagement voor afname in Den Haag Zuid en Oud-Rijswijk (Jan Wapstraat)	Stedin	2025	Congestion-management study	Direct network-operator assessment of the constrained station and therefore the authoritative case-specific source on	Used to establish the 38 MW station limit, projected capacity requirement, waiting-list demand, reinforcement timing and the network context for the

					reported network capacity and congestion.	quantitative assessment.
Stedin (n.d.-a)	Afnamecongestie in Den Haag Zuid en Oud-Rijswijk	Stedin	n.d.	Network-operator webpage	Case-specific public information on congestion and congestion management in the relevant supply area.	Used to interpret the status of congestion and the relationship between identified flexibility, network reliability and additional transport requests.
Stedin (n.d.-b)	Eerder aanvragen in het bouwproces	Stedin	n.d.	Procedural guidance	Directly relevant procedural guidance for developments whose detailed address information is not yet final.	Used to assess how municipalities and authorised developers can apply earlier for connections and how application procedures interact with phased urban development.
Stedin (n.d.-c)	Maatschappelijk prioriteren voor transportcapaciteit	Stedin	n.d.	Procedural guidance	Network-operator explanation of the applicable prioritisation and waiting-list procedures.	Used to interpret the treatment of small-user requests, societal-priority categories and the implications of prioritisation for mixed-use development.

ACM (2025)	Codebesluit prioriteringsruimte transportverzoeken 2025	Authority for Consumers and Markets	2025	Regulatory decision	Formal regulatory basis for prioritising transport requests in congestion areas.	Used to establish the regulatory framework governing priority categories and to distinguish priority in allocation from the physical availability of network capacity.