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Exploring governance challenges of sustainable infrastructure development on the nexus between energy and mobility

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The development of infrastructure can create synergies across multiple sectors, yet the governance and decision-making processes that drive such transformations often receive insufficient attention. This study aims to highlight key challenges in decision-making associated with the 'infrastructural turn' at the intersection of energy and mobility. The case focuses on a public transport provider's initiative to leverage its metro power grid for the development of public charging infrastructure for electric vehicles. We trace how the collaborative decision-making process navigated through various configurations. The initiative challenged established organizational roles and pervasive silo mentalities and ultimately reached two significant milestones after nearly a decade. The findings suggest that harnessing potential synergies requires developing more integrative thinking and allowing sufficient space for joint goal-setting across sectors. We advocate for more research on informal organization and unintended consequences to better understand governance challenges of sustainable infrastructure development.

Society faces major sustainability challenges that are complex and persistent. The scientific literature presents a range of actions to influence the development and speed of sustainability transitions, to tackle these challenges[1–3]. The focus on sustainability transitions has led to a new outlook in the domain of infrastructure[4–8], which has been coined the fabric of society[9]. We refer to infrastructure as the immovable assets for transport processes[10]. Examples include roads, rails, power stations, cables and pipelines. There is a growing interest in the interdependencies between different infrastructural sectors[11–17]. For example, to explore opportunities for 'smart cities', as integrated infrastructures[14]. However, these interdependencies are not reflected in the historically developed siloed governance structures of these domains[13], which hinders sustainability transitions[9,18]. For example, the more electric vehicles (EVs) appear on the road, the more questions on not only how, but where to build charging points come to the forefront[19]. Our focal point is the development of infrastructural assets[12], rather than infrastructure operations. The governance and decision-making of infrastructure transformation, as a basis for change, is rarely given explicit attention[9,20].

Research has shown that infrastructure is highly synergistic with Sustainable Development Goals (abbr. to SDGs)[21], including 72% of all the targets[22]. Due to the widespread belief that infrastructural change is fundamental to achieving SDGs[23], the discourse on the purpose of infrastructure has shifted over the last couple of decades and is increasingly linked to shaping sustainability transitions[4,7,15,24,25]. The notion that infrastructure can move from being a limiting and conditioning factor to one which can be used to steer and shape sustainability transitions signals a turning point in how to consider infrastructure development. We refer to this shift as the infrastructural turn[20]. The perception of the purpose of infrastructure is changing and as a consequence, organizational boundaries are challenged. For example, is an EV charging point best understood as a component of energy infrastructure, the mobility and transportation system or of spatial planning? We refer to the energy-mobility nexus to address these organizational boundaries and further contextualize the infrastructural turn.

The infrastructural turn requires a different outlook on decision-making. It requires attention on strategic issues, as infrastructure and strategy are closely intertwined[4]. A long-term perspective on infrastructure development is important, given the high initial investments and long life cycle of assets[12,24]. In addition, a cross-sectoral perspective is needed as well, as the infrastructural turn creates a strong impulse to strategize across traditional boundaries[24,26]. For example, many sectors and organizations require infrastructure development in their plans for sustainability[4,22]. In addition, many plans require the development of different, interrelated perspectives[19]. Increasing the amount of EV charging points cannot be organized by any single government department or private actor for example, since how and where to build charging points depends on

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investment decisions as well as spatial plans. Harnessing the potential synergies of infrastructure requires joint decision-making across different sectors.

Joint cross-sectoral decision-making would require new forms of coordination. We refer to coordination to describe both a process and a goal[27–29]. This means coordination can be considered as an end-state, the result of some process, or as an ongoing process. New forms of coordination may be achieved by informal organization[30], in ways that generally go unnoticed[28]. Networks[31–33] provide a case in point and their role in the infrastructural turn is our focus of attention. Networks consists of multiple actors[34,35] who maintain informal relationships[28]. For example, to exchange resources[36]. Networks can be particularly useful for mobilizing actors and promoting change, although they may lack stability[37]. To better understand the coordination challenges of the infrastructural turn, we note two streams of literature: network governance and collaborative governance.

Network governance (NG) emerged as a specific branch of governance literature which challenges conventional thinking in markets and hierarchies by viewing networks as a distinct form of coordination[29,31,37]. Indeed, this strand of literature treats networks as a discrete form of governance and pays attention to its structural characteristics[29,38]. The field's distinctive themes include network properties and network management[38]. Studies often presuppose that networks in general, despite their problems[39,40], can produce positive outcomes that would not be possible in a market or a hierarchy[29]. Research has turned to network governance to better describe current societal challenges[30] or help develop new and comprehensive solutions[41,42].

A specific strand of literature known as collaborative governance (CG) has emerged and particularly focusses on promoting and sustaining collaboration among actors who do not always have the same goals or interests when governing a problem field in public arenas[37,38,43,44]. The distinctive elements of CG include sharing understanding, joint decision-making[38] and interaction patterns between actors over time[44–46]. Multiple studies combine the fields of NG and CG[38,43,47]. However, the overlap has resulted in an entangled relationship[30,38]. In this study, we combine structural and collaborative elements from NG and CG to provide a fuller understanding of coordination in networks and contribute to the scholarly discourse on the governance challenges of the infrastructural turn. We consider governance as a case of a goal-directed network as well as a serendipitous structure[32] to distinguish between coordination as a process and as a goal and navigate the "potential conceptual quagmire"[38], p. 1196) of the literature on NG and CG.

First, we focus on network formation. Network formation is one of the distinctive elements in the field of NG[38]. The key question here is how new forms of networked coordination 'get started in the first place'[29]. Our understanding of the establishment of networks is limited[48,49]. Second, we focus on the process of network development, using structural and collaborative elements from NG and CG[38]. We have a scarce understanding about network evolution[45], such as how, once the network is established, the collaborative efforts change, evolve, transform or decline[45]. There is a dire need for more empirical evidence that provides rich contextual insights and which touches on the rationale and dynamics of collaborative efforts at the grassroot level, as 'empirical realities' have not yet captured much scholarly attention in CG and NG[38].

The aim of this study is to better understand what makes the energy-mobility nexus of the infrastructural turn challenging, from a joint decision-making perspective. We focus on an empirical case to shed light on a newly emerging collaborative governance process and put an explicit focus on multiple actor perspectives including the local government, public transport provider and public transport authority. Our research question is: *"What challenges can be identified in the formation and development of a collaborative governance process on the energy-mobility nexus of the infrastructural turn?"*

This paper is based on an instrumental single case study in the area of Rotterdam in the Netherlands. The case follows a curious collaboration between public transport partners and the local government which is conceptualized as a collaborative governance process. Together, the actors proactively expand the scope of a public transport provider to include powering EV charging points, by utilizing the substations near subway stations. The data was collected using two primary sources of information: interviews with representatives of the organizations involved in the collaboration and a collection of key policy documents. A third source of data consisted of secondary information which reported on the collaboration such as websites and magazine and newspaper articles. We split the collaborative governance process up into multiple rounds to increase the focus on specific interactions between actors with different goals and interests[50]. The purpose of this focus is to illuminate themes, patterns and relationships in the decision-making process and contextualize key challenges. More information on our approach can be found in the Methods section.

Results

Case introduction

Around 2015, an engineer working at the asset management department of Rotterdam Electrical Tram (RET) came up with an idea. The RET, located in the area of Rotterdam-The Hague in the Netherlands, is a regional public transport provider and infrastructure operator. It is comprised of several entities including trams, busses, subways and infrastructure. The essence of the idea was to increase the societal benefits of RET's energy infrastructure. What if the power grid of the RET, the backbone of its public transport services, could be used by other organizations as well? For example, to charge electric vehicles? The 10 kV power grid[51], which stretches from the West to the East and from the North to the South of the city[52], is owned by the RET. The idea became known as the "E-PT-hub" (energy-public transport-hub) and over a period of several years, starting from the grassroots, the local public transport partners engaged in a collaborative governance process. The organizations explored opportunities and worked toward concrete deliverables. Through intended actions and emergent patterns, other actors became involved as well. The efforts generated new insights for practitioners interested in crossovers between energy, mobility, and spatial planning. What new possibilities might emerge when sectors move closer together, leveraging existing assets? Should we shift our way of thinking and focus on "bringing vehicles to charging points instead of the other way around"? Still, there were also many practitioners with reservations. What exactly does it mean when a public transport provider decides, based on a societal rationale, to take a step into a different domain?

A number of different actors were involved in the collaborative governance process. The core group consisted of the RET, Municipality of Rotterdam and the Metropolitan Region Rotterdam The Hague (MRDH). The RET is tasked with public transport in the area of Rotterdam-The Hague. The MRDH is the public transport authority of the RET while the Municipality of Rotterdam is the majority shareholder of the RET. We refer to the 'E-PT-hub partners' when we talk about this core group. Additionally, Holland Transport Advisors Rail (HTA-Rail) was approached early-on as the lead organisation of the core group. This is a private firm focused on collaborative relationships between rail operators (and local governments) and was a proactive partner from round 1 onwards. Another firm, Realise Opportunity & Create Change (ROCC), was brought on later to be in the lead for round 4. Stedin, the regional electricity grid operator, had no active role in the collaborative efforts but was regularly updated on the developments. This is because the grid operator could be affected by changes resulting from the initiative in terms of grid management. An overview of the interviews with actor representatives is provided in Table 1.

Key decision-making rounds

We identified six key rounds in the collaborative governance process of the E-PT-hub around which key challenges emerged. The formation of the process is presented in round 1. Rounds 2 to 6 describe the subsequent developments of the process. An overview of the key rounds is given in Fig. 1.

Round 1: Exploring opportunities

The first key round started when the idea was first discussed within RET, by an individual in the asset management department. Around 2015, this

Table 1 | List of quoted interviews

No.	Role interviewee(s)	Actor	Date	Format
I1	Coordinator EV charging infrastructure	Municipality of Rotterdam	08-09-2023	Online
I2	Lead for overall E-PT-hub process	HTA-Rail	03-10-2023	Online
I3	Fleet facility operators (1 and 2)	Municipality of Rotterdam	10-10-2023	Online
I4	Strategist (1) and asset manager (2)	RET	25-10-2023	In-person
I5	Manager public transport	MRDH	08-11-2023	In-person
I6	Program coordinator	Stedin	29-11-2023	In-person
I7	Lead for legal E-PT-hub process	ROCC	14-12-2023	Online
I8	Lead for Energy in Public Transport	Self-employed	30-07-2024	In-person

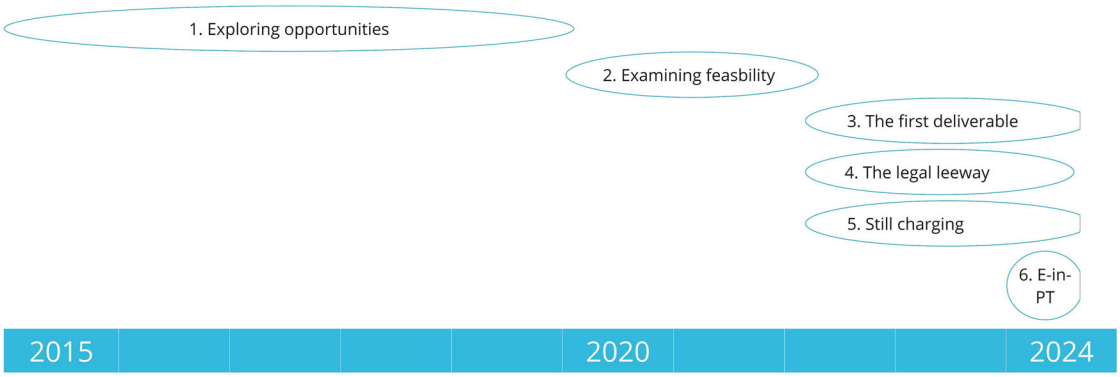

Fig. 1 | Overview key decision-making rounds. The six key rounds in the collaborative governance process of the energy-public transport-hub (E-PT-hub) around which key challenges emerged. Round 6, called 'Energy in public transport', is abbreviated to E-in-PT. The end points of three rounds (3, 5 and 6) are undefined, as they are still in development at the time of writing. Therefore, they are visualized with an altered oval shape.

Table 2 | Overview key round 1 (Exploring opportunities)

Timespan	Around 2015 to 2020
Boundaries	• Starting point: An idea originating within RET • Ending point: Joint readiness to explore new terrain
Key challenges	• Understanding the interests of multiple key actors • Willingness to engage in a joint decision-making process

engineer started thinking of ways to increase the societal benefits of RET's power grid[53]. Years later, the idea of integrating the power grid with the wider mobility systems was pitched in a collaboration between the RET, the Municipality of Rotterdam and Stedin[54,55]. The actors were exploring links between energy and mobility and how the existing power grids can best be put to use[54]. The engineer started coining the phrase "longest extension cord of Rotterdam" to emphasize the societal rationale and convey integral thinking. Together with a consultant, brainstorm sessions were organized and a tentative longlist of possible projects was made. However, these efforts were small-scale and scattered. The Municipality of The Hague and The Hague's Tram Company (HTM), another public transport provider in the region, were exploring options as well and discussed the topic in roundtables. This is when HTA-Rail first learned of the idea. However, the efforts of the public transport providers faded over time. According to multiple actors, there was simply a lack of urgency. For the RET, a window of opportunity was presented when a new concession was drawn up. The organization was on its way to introduce a new fleet of electric busses by the end of 2019[56] and to save costs, it was decided to install two charging points on the RET's power grid[52]. Even though this was a modest, internal affair, it demonstrated the potential of more integral thinking. When HTA-Rail later broached the topic of the E-PT-hub in a roundtable between public transport providers, it elicited a positive response from RET and rekindled the interest in a joint effort to explore new opportunities. RET told HTA-Rail: "It's not straightforward, since we are dependent on the MRDH and the Municipality of Rotterdam for success". An overview of key round 1 is provided in Table 2.

Round 2: Examining feasibility

The second key round started when the RET, Municipality of Rotterdam and the MRDH jointly wanted to examine the feasibility of the concept, including its organizational, technical and legal aspects. It was decided that the MRDH would finance the study and HTA-Rail would take the lead. At the outset, the potential societal impact of an E-PT-hub was believed to be significant. However, this all rested upon the specific configuration(s). On an abstract level, the benefits may include saving infrastructural costs and speeding up electrification[57]. To concretize the idea, the focus was put on subway station Kralingse Zoom[52,58]. This is one of a dozen RET subway stations with nearby parking facilities, known as 'Park and Ride' (P + R). P + R facilities can fulfil several purposes, such as managing traffic flows and stimulating public transport use. At the time, the P + R of Kralingse Zoom only had a limited number of charging points available for electric vehicles. This posed the question: what if the power grid of the RET could be used to power new, additional charging points at this location? Is it possible to make a significant difference, from a technical and legal perspective? The experts confirmed that there was substantial capacity left. According to the study, there was enough capacity for 1000 charging points. The results seemed to bode well for the E-PT-hub. For RET and its out-of-the-box thinking engineer, it showed how joint action is vital to tackle societal challenges[59]. According to the engineer, there is a need to "transcend the silo mentality"[59]. The results sparked further interest from the MRDH as well. The MRDH was convinced of the societal potential and the benefits for public transport, which helped to align the E-PT-hub with its organizational mandate. However, the Municipality of Rotterdam was more ambivalent, reasoning that the need for 1000 additional charging points at this location was not clearly justified. The Municipality, though, was also preoccupied with

Table 3 | Overview key round 2 (Examining feasibility)

Timespan	2020 - beginning of 2022
Boundaries	• Starting point: Jointly initiating feasibility study • Ending point: Jointly establishing whether there's grounds for a project
Key challenges	• Finding ways to address knowledge gaps • Aligning the societal rationale with organizational strategies and mandates • Framing the findings in helpful ways • Coping with silo mentalities

Table 4 | Overview key round 3 (The first deliverable)

Timespan	2022 – undefined
Boundaries	• Starting point: Willingness to start up a joint project • Ending point: Undefined
Key challenges	• Coping with competing, even conflicting, organizational goals • Developing a technically and financially sound project proposal • Translating a societal rationale into project ownership

realigning its various departments on the numerous initiatives to develop public charging infrastructure. The discussions on the E-PT-hub shifted back to its overall potential and its added value for the organizational strategy of the Municipality. The potential power capacity was shown to range between 1 and 9 MW[60]. Then, when the recently published municipal strategy on charging infrastructure[61] was added to the mix, the efforts became more collaborative. In addition, in September of 2021 the report on the legal feasibility of the E-PT-hub was published. The university of Tilburg had conducted the research using a broad scope, as it included Dutch and European law on energy, rail and market competition[51]. The outcome was a green light[62]. The publication recommended to request a 'Closed Distribution System' (CDS) qualification and an exemption from the Netherlands Authority for Consumers and Markets (ACM), the regulatory body of the Netherlands[51]. This would allow the RET to become the legally approved system operator of the E-PT-hub. The RET would also be exempt from a number of tasks and responsibilities related to public grids. Around January of 2022, the actor representatives met again to go over the organizational, technical and legal insights generated so far[63]. With resolute attitudes, they decided to continue the efforts[64]. An overview of key round 2 is provided in Table 3.

Round 3: The first deliverable

The feasibility study found no obstacles that would prevent the idea from moving forward. The next stepping stone, the RET, Municipality of Rotterdam and MRDH agreed, should be a concrete project. However, there were many hurdles still to overcome. "Everybody in the organizations told us that an E-PT-hub would not be feasible" said HTA-Rail. "But then we got back that it was technically and legally feasible". HTA-Rail also reached out to the Ministry of Economic Affairs and Climate for comment and, within a short period of time, received assurance that the project was indeed feasible. HTA-Rail continues: "We were now tasked with convincing the local government and rail operator". The focus on Kralingse Zoom continued. However, this location proved to be much more challenging than expected. For example, the E-PT-hub was not easily linked to existing concessions on charging infrastructure for surface parking. In addition, there was a private organization interested in building charging points as well. Switching the E-PT-hub to a nearby parking garage instead would raise the technical complexity and face other concerns, such as fire safety. Moreover, it turned out that the municipal department of urban development had other plans for this location. Instead of building charging points, they envisioned a new city square with car-free areas. With obstacles mounting up, the attention of HTA-Rail shifted to other locations and configurations. A meandering process of trial and error ensued, which included attention on logistical traffic[52]. Given the vast potential, what if the E-PT-hub could be used for electric trucks and other heavy electric vehicles[53]? In January 2023, HTA-Rail came into contact with another municipal department, the fleet facility operator, which was looking for additional capacity for its electric garbage trucks. Awaiting the results of key round 4 and circumventing considerable construction costs, a hybrid solution to start the first E-PT-hub project was proposed. For at least a year, a fleet of 6 garbage trucks would charge their batteries on a bus depot of the RET on the Kleiweg, using the RET's power grid. Setting up this unique collaboration between the RET and the fleet facility operator of the Municipality was not without its obstacles. The actors needed to formalize contractual agreements and, eventually, address a significant rise in projected costs. This was an unwelcome development, as minimizing financial risks was crucial. Following the coronavirus pandemic, declining numbers of travellers had placed considerable strain on the financial situation of the RET. According to multiple actors, it proved challenging to translate the societal rationale into organizational ownership. As one actor put it: "Once difficult choices need to be made, ownership dissipates". Still, the collaboration was formalized by top management and preparatory work was being done. The fleet facility operator was curious to learn about what this meant for garbage disposal in practise and emphasized that, contrary to intuition, strategic decision-making often unfolds "deep down in the operational sphere". In January of 2024, however, HTA-Rail proposed to halt the project in light of stalling progress within RET. The E-PT-hub partners jointly decided to pull the plug. As a result, while it had been in the works for some time, the Kleiweg project did not get off the starting blocks. An overview of key round 3 is provided in Table 4.

Round 4: The legal leeway

The feasibility study on the legal conditions of an E-PT-hub provided the actors with a clear recommendation. Submit a request to the ACM for a CDS qualification[51]. It was decided that the E-PT-hub partners would co-fund the efforts to prepare the necessary files and ROCC would take the lead. The ROCC faced difficulties, because it was not easy to follow the prescribed format step-by-step. This was to be expected as this legal route had never been used for this purpose before[53]. For example, there was ambiguity around the right applicant organization, which is generally supposed to be the infrastructure owner[51]. While the RET is considered the economic owner, the legal ownership of the network is divided between the Municipality and ProRail, the national rail operator[51]. The latter is due to the rail sector legacy, as part of the RET's network had once been part of the main railway network[65]. In addition, some information was dependent on specific configurations of the E-PT-hub, which were still uncertain at the time the request was drawn up. It was expected that the ACM would need some time to go over the submitted file. Therefore, errors would be costly. Moreover, should any additional submission via this route be required later on, than this would not speed up the efforts of the E-PT-hub partners either. As a consequence, there was scrupulous attention to detail. The file was ultimately submitted in July 2023[66]. The formal applicant of the submission was the RET. The file was substantiated by a number of documents, including two letters of the MRDH on the economic ownership of the infrastructure and a formal letter of approval by the executive board of the Municipality[65]. At the time, the ACM was already in the midst of reviewing its national energy capacity management. That same month, it had published a draft version of a new design code[67]. The purpose of the code was to move electricity grid operators away from handling new connection requests on a 'first come, first served' basis and instead focus on 'societal prioritizing'. This pathway was ushered in by recommendations set out in the 'national action agenda net congestion', published in December of 2022[68]. It was therefore likely that the ACM would navigate any lingering question about the E-PT-hub both from a local and national perspective. After reading about the submission, a member of Parliament posed questions to the Minister of Climate and Energy twice, seeking insights into his perspective on the subject[69,70]. The Minister responded by saying he welcomes the attempts at collaboration between energy and mobility, such as between rail operators

Table 5 | Overview key round 4 (The legal leeway)

Timespan	2022 - July 2024
Boundaries	• Starting point: Recommendation to submit proposal to ACM • Ending point: Legal approval by ACM
Key challenges	• Coping with the difficulties of an unconventional legal route • Coping with silo mentalities and risks of politicized discussions • Garnering broader support (e.g. different levels of government, rail operators and grid operators)

Table 6 | Overview key round 5 (Still charging)

Timespan	2022 - undefined
Boundaries	• Starting point: Willingness to scale up the joint efforts • Ending point: Undefined
Key challenges	• Coping with underlaying tensions between different organizational goals and strategies • Coping with meandering decision-making • Embedding the efforts in existing local decision-making structures • Developing collaborative cross-sectoral relationships

and wider mobility networks, as long as it meets the technical and legal conditions[71]. The Minister further stated that the legal procedure of the E-PT-hub can certainly be considered complex, but not infeasible[70,71]. The increasing political attention on net congestion seemed to bode well for the E-PT-hub, as it created favourable conditions to present the idea in the best possible light. Still, not everyone was lauding the developments. For example, according to ROCC, there was opposition from multiple rail operators. Indeed, several interviewees described how the E-PT-hub was dismissed as a viable option, without properly considering the broader complexity of the solution needed. This suggests a prevalence of silo mentalities, which could jeopardize the prospects of the E-PT-hub. Disagreements between actors such as rail operators might politicize discussions and potentially impact the project. Nevertheless, the legal procedures continued. The ACM requested additional information thrice, which was then provided by ROCC. The latest of these additions was sent over in February of 2024. Then in April, the ACM published a broad package of measures, including the earlier mentioned code on 'societal prioritizing', to reduce the issues related to net congestion[72]. The measures made flexible use of the electricity grids more attractive and created more space for experiments with capacity management. However, that space was still out of reach for the E-PT-hub partners. Two years prior, they had envisioned a final decision by ACM within months, followed by concrete results by now[52]. After the presentation of the broad package by ACM however, the status of the CDS request was still pending[73,74]. Then, in July of 2024, the legal approval of the E-PT-hub was official[65]. It was granted for two specific subway stations of the RET, with a maximum total energy capacity of 2000 MWh per year for nearby EV charging points. According to a spokesman of the RET, this paved the way for other public transport providers to open up their network for additional charging capacity in the cities[75]. An overview of key round 4 is provided in Table 5.

Round 5: Still charging

The efforts to demonstrate the potential of an E-PT-hub did not stop with the Kleiweg project (see round 3). The actor representatives firmly believed in the idea and were eager to scale it up. Moreover, the efforts acted as a catalyst to more integral thinking, as the E-PT-hub partners were now jointly looking at a map of the area searching for new opportunities to integrate the RET's power grid with the wider mobility system. Together with HTA-Rail, a map of the area was scanned for public spaces, close to RET assets, that required additional public charging infrastructure[53,63]. The RET set out to map all the challenges per location. In addition, together with the Municipality, they developed an assessment framework for deciding on partners for future E-PT-hub configurations. However, these efforts were mostly based on a technical perspective. Then, the societal rationale further began to crystallize. As one municipal representative wondered: "What if the P + R facilities, which are mostly empty during the evenings and weekends, are used for charging logistical traffic at night?". In contrast, a municipal fleet facility operator pondered: "What if a flow of heavy vehicles is rerouted to an E-PT-hub? Surely, that would change the dynamic in the public space?". Round 3 showed that starting from a broad societal rationale helped to overcome silo mentalities. However, it quickly became evident that the E-PT-hub partners still had to cope with underlaying tensions between competing organizational goals and strategies. These tensions surfaced during the development of specific E-PT-hub configurations. Besides personnel and (the sharing of) costs, the main bottleneck was usually the available public space. The absence of an established forum to explicate these tensions made it difficult for the E-PT-hub partners to entertain more synergistic outcomes in a collaborative setting. In addition, the absence of well-defined roles to address these tensions made the commitment of the individual representatives of E-PT-hub partners all the more crucial. Many times, the efforts to introduce more integral thinking on energy infrastructure would stall, as claims to the public space by other departments or organizations posed significant barriers. The lack of available space creates obstacles for other organizations as well. Eelco de Vink, program director at Stedin (regional electricity grid operator), has been involved in collaborative efforts to reduce net congestion for multiple years. He contends: "the interface between public space and energy is a discipline that doesn't really exist yet". Nevertheless, the E-PT-hub continued to garner attention. As the strategy department of RET remarked, there was a "world of difference" between the original technical concept and the potential configurations they were now working on. The lessons of this collaborative governance process were shared in bilateral meetings (including one with the Port of Rotterdam) and at conferences[58,76]. The presentations included topics such as collaboration, a new way of working, ownership and regulatory frameworks[57,60]. According to the engineer of RET, "everyone is following the progress with much anticipation", since it can have "major implications for the Netherlands"[53]. Indeed, more articles on links between energy, mobility and public transport emerged[74,77,78] which prompted further discussions. An overview of key round 5 is provided in Table 6.

Round 6: Energy in public transport

As 2024 came around the corner, there was a rapid and tumultuous string of developments (round 6 is called 'Energy in public transport'). It saw the launch of the website 'Energy in public transport' and under the same name, brought rail experts from across the Netherlands together to share insights. A small team of writers posted all the newest developments online, including news of the E-PT-hub. Then, on January 19th, the chairman of PT-Netherlands (association of all the Dutch public transport providers) wrote a strongly worded letter to the Ministry of Economic Affairs and Climate (EAC), urging both the EAC and the Ministry of Infrastructure and Water Management (I&W) to take combined action on net congestion by utilizing the energy infrastructure of public transport networks. Three recommendations were set out: (i) form an executive body for everyone to meet, (ii) create an overarching programme to manage and control the efforts and (iii) accelerate local projects. The letter included outspoken criticism of I&W in particular, attributing the lack of progress to the Ministry's stance on the energy infrastructure of rail networks, which it claims is 'not its responsibility'[79]. Meanwhile, earlier that week, a new action agenda on net congestion had been handed over to the Minster of Climate and Energy. The motivation behind this second agenda (first agenda mentioned in round 4) was that according to grid operators, the issues were not limited to high voltage networks. Lower voltage networks would be impacted as well. The agenda, soon published online, contained one single page on public transport networks and its potential for reducing net congestion. It was a short, abstract overview but, for the people behind 'Energy in public transport', reason to celebrate. The coordinator of the agenda, a self-employed individual who hadn't been aware of 'Energy in public transport', was suddenly

Table 7 | Overview key round 6 (Energy in public transport)

Timespan	January 2024 - undefined
Boundaries	• Starting point: The launch of 'Energy in Public Transport' • Ending point: Undefined
Key challenges	• Developing collaborative cross-sectoral relationships • Embedding the efforts in decision-making structures

engulfed by emails and social media requests. On April 3rd, a self-organized expert panel under the banner of 'Energy in public transport' ceremoniously handed over their investment agenda to the same person. On the final page of the investment agenda is a list of authors, including the originator of the idea behind the E-PT-hub, the engineer of RET. For the self-employed individual, now the coordinator of this investment agenda, it was about how to move forward. His continued involvement in net congestion deepened his understanding of coordination challenges in the wider energy domain. "The conditions for building new substations have escalated into a legal dispute between municipalities and grid operators" said the individual. "This is a course we can no longer afford to follow. We need to adopt a more integrative approach to the use of our limited public space". His sights turned to the recommendations set out in the letter of PT-Netherlands. Following the first recommendation, an existing body called the 'oval table on energy infrastructure rail' was revitalized and a meeting took place on May 31st 2024. It was to be the first such meeting since October of 2022 and was attended by people in the higher echelons of I&W. The individual, dreading a potential governance debacle, seized the initiative during the meeting and proposed to work on the overarching energy-public transport programme. The attendees voiced their support and commitment. This came as good news for the E-PT-hub partners. Only a few years prior, the added value of the E OV Hub was still up for debate. When the legal approval of the E-PT-hub (see round 4) was laid to rest a few months later, more good news came their way. This paved the way for E-PT-hubs to be realized in the months and years ahead. An overview of key round 6 is provided in Table 7.

Discussion

Case study research involves three levels of inference, namely the analysed case, the relation to the universe of cases (width) and the theoretical generality (breadth)[80,81]. The discussion is structured along these lines, in part to avoid misinterpretations, particularly regarding the case width[82,83]. Then, we discuss the limitations of this study and directions for future research.

It was a process that started at the grassroots, when an idea sprung up in the asset department of a public transport provider. When it was first entertained in round 1, however, the efforts to rethink the purpose behind these assets and augment their societal role came to no avail. This was in part because the idea inadvertently challenged the organizational boundaries of not just the RET but of its partners also, including the Municipality and the MRDH. Through repeated interactions, the actors came to the realization that a joint effort was required to gain momentum. The commitment of people at the individual level proved decisive, when in round 2 representatives of the RET, MRDH and Municipality led an effort to examine the feasibility of an E-PT-hub. The results provided the grounds for the next rounds. As they continued to move forward, the E-PT-hub partners altered the discourse on the purpose of infrastructure and, by spreading out-of-the-box ideas, stimulated more integral thinking. The meandering decision-making process of round 3 for example, in its attempt to commence the first E-PT-hub project, repeatedly switched in primary focus. Examples include cars, heavier vehicles and garbage trucks. Although there was bottom-up support and top-down commitment for an ongoing project on garbage trucks, the E-PT-hub partners still jointly decided to pull the plug due to stalling developments. Undeterred, the actor representatives continued to emphasize the societal rationale to challenge the pervasive silo mentalities. However, the absence of an established forum made it difficult for the E-PT-hub partners to discuss synergistic outcomes in a more collaborative setting. In addition, it was unclear what roles actors should take on in shaping the E-PT-hub and how those roles would be translated into project-specific ownership. The attempts at initiating projects were riddled with uncertainties, as proposals to scale up the idea went through many cycles of trial and error. Then, tensions between organizational goals and strategies came to the surface as specific configurations of the E-PT-hub materialized. The process continued to demand more time. However, nearly a decade after the start of the first round and without even a single project able to showcase demonstrable results, the process of the E-PT-hub reached two major milestones in a matter of months, namely the legal approval in round 4 and the establishment of new forms of coordination in round 6. Many times, prior rounds had not yielded the desired outputs. Still, these rounds arguably played an important role since they created the necessary space for joint goal-seeking. Even though the purpose behind specific configurations changed numerous times as options were explored and developed, the goal of the collaborative partners to create synergies between energy and mobility remained steadfast. The continued commitment of several key actors to show results stimulated integral thinking and ultimately cemented the prospect of an E-PT-hub in the months and years ahead.

We examined an initiative on the energy-mobility nexus of the infrastructural turn and identified a number of key decision-making challenges. The first challenge, illustrated by the E-PT-hub case, is the need for a more integrative perspective on infrastructural assets. Studies on charging infrastructure are in the process of integrating more perspectives, such as between the EV user and charging provider[19,84]. However, new possibilities that might emerge when existing assets are leveraged are easily overlooked. This study further explores new forms of integration by highlighting the broader group of assets and potential charging providers. The second challenge is being able to transcend organisational and sectoral boundaries. The E-PT-hub case indicates that harnessing potential synergies may require a different outlook on decision-making. New arrangements were necessary to discuss synergistic outcomes in a collaborative setting. The core group of actors transcended sectoral boundaries by mapping assets such as EV charging points, public transport substations, and parking spots onto a single geographical map. The findings indicate that the process of joint goal-setting is able to generate new insights, but demands novel forms of interaction and significant time. The E-PT-hub case is notable because the public transport provider was both the economic owner of the rail network and the energy infrastructure. This enabled the provider to proactively transform its role on the energy-mobility nexus, leveraging its status as an infrastructure operator. This raises a number of questions. For example, what are the benefits and challenges of involving more infrastructure operators, such as public transport providers, on the energy-mobility nexus? We noticed that contextual factors can play an important role in this regard. The legacy of the rail sector, siloed governance structures, and the regulations governing grid management were all relevant for understanding the challenges of the E-PT-hub. Our findings indicate that focusing more on the perspective of infrastructure operators can generate new insights into potential synergies that were otherwise overlooked.

We aimed to better understand the formation of collaborative governance processes. Research has tried to explain network formation at multiple levels: the actor level, the level of pre-existing relations between actors and the institutional level[39,85,86]. This includes an interest in the starting conditions of the process[44,47]. However, few studies address the fundamental question of how they get started in the first place[29,85]. A key starting point is to examine whether the process is self-initiated or externally initiated[40,45]. We showed that the E-PT-hub process was self-initiated at the grassroots level. Four key features proposed by[87] provide additional foci to explain the formation. The features are: domain (or field) complexity, program rationale, actor interdependence and management capacity. The complexity of the energy and mobility domain was affirmed by every interviewee. The program rationale, which refers to the purpose of the collaboration, induced continued commitment as mentioned earlier. In addition, the interdependence among these actors facilitated a shared sense of purpose. Lastly, the lead organization that was brought on provided

management capacity. The reliance on a lead organization[29] meant that the minimum level of required coordination could be attained and a public purpose, that could otherwise not be carried out[45], could be pursued. Indeed, the findings of[88] also indicate that management capacity is one of the most important factors in network formation. Still, the same group of key individuals (actor representatives) would stick together for years, even though they lacked any overarching formal structure to provide a common purpose. This raises questions on the nature of collaborative governance processes. Seminal definitions of CG have included[46] and excluded[44] informal organization and there is no distinct body of literature on informal networks[30]. As a consequence, structures and collaborative efforts induced by informal organization may be overlooked in research on network formation. Future studies could fill this void by utilizing a combined framework of structural and collaborative elements, found in NG and CG, respectively.

The many cycles of trial and error in the process of the E-PT-hub, plus the prolonged time without concrete results and the effects of contextual changes, enhance our understanding of network development as well. The common tendency in research is to focus on intentional, purposeful growth while overlooking unintended, emergent processes[89]. As mentioned earlier, the most consequential developments of the collaboration occurred in much later rounds. This supports the empirical findings of[45], namely, that early efforts to enhance process characteristics (e.g. aligning interests, joint problem solving or a focus on 'small wins'[44]) do not necessarily pay off until much later in the process. Furthermore, the effects of contextual changes in our case support the notion that context can both promote and undermine the establishment of a collaborative governance process[48]. To give an example, the urgent need of the RET to focus on its core operations due to the coronavirus pandemic made it more difficult to gain momentum. However, later on the process benefited from growing political support, due to the looming threat of net congestion coupled with the increasing scarcity of public space. Our findings on network development also tie directly into an ongoing scholarly debate around what constitutes network effectivity[40,90–93]. In NG and CG literature success is considered elusive, depending upon many endogenous and exogenous factors[38,91]. Some studies moved away from traditional measures of success, in favour of focusing on 'health' and 'usefulness'[45,94]. This begs an intriguing question: was the process of the E-PT-hub a success, or a failure? To better answer this question, we argue that, in addition to purposeful growth, more attention should be given to unintended and emergent consequences[89,95].

Our study has several limitations. First of all, our empirical data was limited and includes abstractions. For example, our approach did not include observations of meetings between the actors. In addition, we heavily relied on interviews with relatively few key individuals and their recollections and interpretations to learn about actor perspectives. Our other data sources (policy documents and reports in media) were less useful to reconstruct these. To validate our findings and correct for any factual inaccuracies, we requested and received input from one of the interviewees, who commented on the final version of this manuscript.

Second, specifying and empirically bounding the collaborative governance process was complicated by theoretical fragmentation. There are different views on the constitutive elements of collaborative governance processes[96] and hence, there is a debate about the unit of analysis[30] and boundary specification[97]. In our study, these questions surfaced when we specified the final round, since the core group of actors appeared to fall into the background. We decided to rely on the identified patterns and relationships, illuminated through process tracing, which connected all the rounds and provided a rationale for including round 6.

Finally, we underscore the importance of adopting a longitudinal view to coordination in networks, as processes are constantly in flux and can only be fully understood over extended periods of observation[89]. Prolonged efforts of formal and informal forms of interaction between actors to scour for synergistic outcomes deserve a key role in understanding the effectivity of collaborative governance processes. Following the analogy by[98] with film cinematography, it is worthwhile to develop frames that illuminate the ongoing flow of collaborative governance processes in new and insightful ways. We found that combining elements of NG and CG enabled us to coalesce structural and collaborative elements into a seemingly coherent storyline, which helped us to uncover purposeful and emergent patterns of network development.

Methods

Qualitative case study research

This work is designed as a qualitative case study[83]. The empirical case was identified and established through the course of the research process by systemically appraising the empirical material[83]. The case was selected on the basis of its curious collaborative nature on the intersection between public transport and energy. The empirical data was gathered via qualitative research methods. We conducted interviews with key representatives of the actors involved and analysed a number of policy documents. We conducted 8 (group) interviews and gathered the perspectives of 10 interviewees in total. The interviews took place between September 2023 and July 2024, both online and in-person (Rotterdam or Delft) and with informed consent. The interviews lasted about 1 hour. The protocol was semi-structured and included questions on the purpose of the collaboration and key decision-making challenges. The interviews were recorded, transcribed, coded and analysed. We also gathered around 40 documents (ranging from press releases and legal reports to strategic plans) that pertained to the developments of the E-PT-hub. Our secondary data consisted of around 20 documents which reported on the collaboration, such as websites and magazine and newspaper articles. Finally, we requested and received updates from one interviewee on key developments, such as the status of a project or formal procedure.

Process tracing

This study relied on process tracing to approach the case study research[82,99,100]. Process tracing provides an analytical tool to gain a greater understanding of the nature of causal relationships[100]. It can be used to examine whether and how collaborative governance yields different outputs[101]. Since coordination describes both a process and a goal[27–29], abstract findings can be open to interpretation. Therefore, to better understand collaborative governance challenges, the fuzzy and dynamic interaction between processes and goals needs to be untangled. Process tracing enables us to illuminate these mechanisms[102] by gathering empirical, diagnostic evidence[81,82,103] and focus on context[46,103,104]. A longitudinal focus is important, as capturing dynamic changes over time may be crucial for understanding the actors, interactions and evolving purpose of the collaborative governance process[43]. We first evaluated the interviews using thematic coding in Atlas.ti. Next, we triangulated the findings with the policy documents and media reports. The documents were collected via desk research. They were dated between 2018 and July of 2024 and chronologically ordered. They were scanned for relevance and, depending on the type of document and its relevance, coded in Atlas.ti similar to the interviews. The coding process followed a modified grounded theory approach, in which we use broad categories (e.g. processes, rationales and resources) to assess how the collaborative governance process was formed and developed[45].

Data Availability

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Competing interests

The authors declare no competing interests.

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